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Mechanical Engineering

Maintenance Engineering & Operations

BUILDING A KNOWING MAINTENANCE ORGANIZATION

by introducing a Knowledge Improvement Process for predictive maintenance at the Royal Netherlands Navy

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Abstract

Possibilities of predictive maintenance (PdM) are investigated in several industries to optimize the lifetime of assets and it's maintenance processes. The Royal Netherlands Navy (RNLN) envisions to introduce PdM within its maintenance organization (Ministerie van Defensie 2020). A preliminary analysis at the RNLN revealed that currently there is no designated space or context to develop predictive insights in the maintenance processes (corrective, preventive and condition-based). This manifests itself in insufficient information and knowledge availability for maintenance engineers to develop accurate maintenance plans and tasks. Using multiple iterations of the Design Science Research Methodology of Peffers et al. (2007) a Predictive Maintenance Knowledge Improvement Process Predictive Maintenance Knowledge Improvement Process (PdM KIP) was proposed to improve and stimulate knowledge creation in the predictive maintenance process of the RNLN. Using this four step process (collect information, information validity check, information analysis and process information) members can share and improve knowledge by using its output to improve data analysis, giving feedback on maintenance decisions and communicate the effect of these decisions on the maintenance execution and performance of assets. The applicability of the PdM KIP was demonstrated using the Navy's Combat Support Ship case, resulting in an increase in knowledge sharing and creation when used and implemented correctly. This study recommends the design of a (virtual) space to crystallize and improve knowledge within the (to be designed) maintenance organization's knowledge system, which can be facilitated by the PdM KIP.

Contents

List of abbreviations

CBM	Condition based maintenance
CPA	Condition & Performance Assessment - department within the RNLN
CSS	Combat Support Ship
DfM	Data for Maintenance - department within the RNLN
DMI	Maintenance department of the RNLN
DMO	Defense Material Organization
DSRC	Design Science Research Cycles
DSRM	Design Science Research Methodology
IMP	Information Management Practices
PdM	Predictive maintenance
PdM KIP	Predictive Maintenance Knowledge Improvement Process
RNLN	Royal Netherlands Navy
SAP	ERP system/ maintenance registration system used by the RNLN

Chapter 1

Introduction

This chapter provides information on the research topic and the motivation for this research. Section 1.1 gives general insights in the maintenance strategies of the RNLN as well as knowledge creation, section 1.2 provides a general introduction in the case organization (RNLN). The problem description, in section 1.3, gives insights in the challenges of the Royal Netherlands Navy faces on (predictive) maintenance. In section 1.4 the current state of research on PdM and CBM is described. The fifth section is the research design (section 1.5), where the research questions are motivated as well as the research methodology. In section 1.6 the research outline explains the structure of this thesis.

1.1 Knowledge creation in PdM

This thesis will be addressing 4 types of maintenance: preventive (planned) maintenance, corrective maintenance, condition based maintenance and predictive maintenance. These maintenance types are shown in figure 1.1 on a timeline.

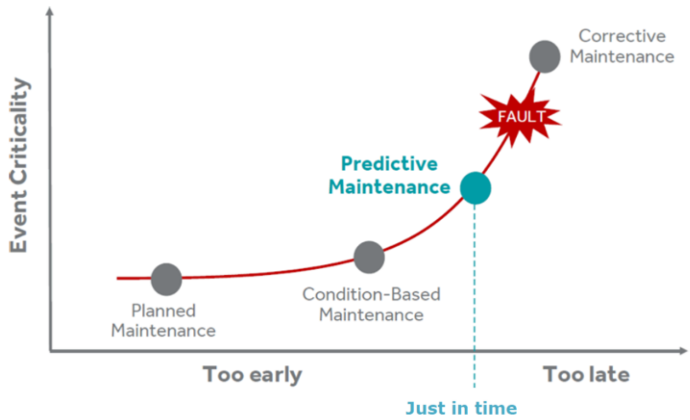

Figure 1.1: Maintenance timeline (Primavera Project 2022)

Preventive maintenance is a strategy where maintenance is performed regularly by scheduled maintenance activities with the aim to prevent failures in the future. Corrective maintenance is performed after a failure has occurred, as shown in figure 1.1. Predictive maintenance (PdM) is the concept of being able to predict a failure before it happens (just-in-time) and then adapting the

maintenance of an asset accordingly. Where in predictive maintenance a failure is predicted before it will occur, in condition based maintenance (CBM) the condition of an asset is monitored to assist decision making on maintenance. Predictive maintenance can be used as an objective for smart maintenance and to evolve a maintenance organization to industry 4.0, which entails connecting assets and real-time monitoring their conditions.
This thesis is conducted as a part of the PrimaVera project where predictive maintenance is researched in 8 work packages, of which 6 technical and two concerning dissemination and management (Primavera Project 2022). All work packages focus on a different element of predictive maintenance, however all of them are connected, as shown in figure 1.2. The work in this thesis will focus on the organizational aspects of predictive maintenance and knowledge creation within the maintenance organization. Therefore, the scope of this thesis lies within work package five (organizational behavior and human decision making). Knowledge creation and knowledge

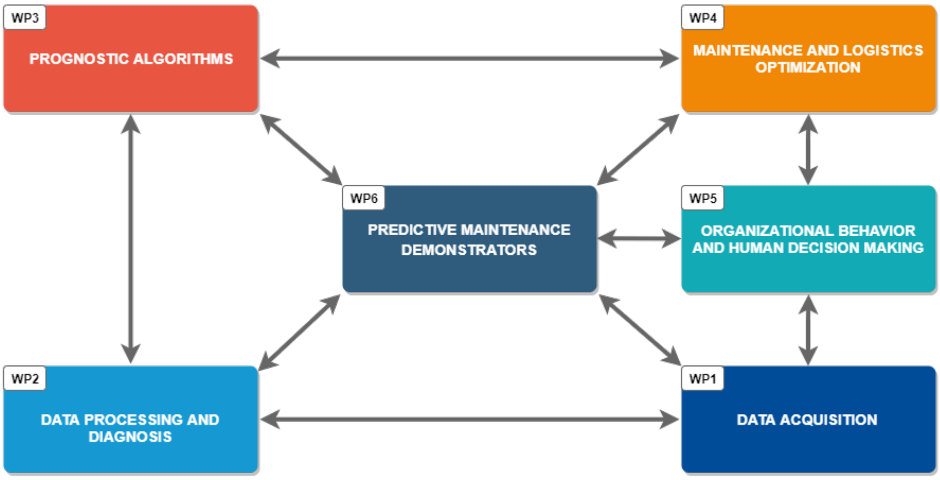

Figure 1.2: Work package overview PrimaVera (Primavera Project 2022)

improvement in predictive maintenance can be of added value in maintenance decision making. By increasing knowledge in the whole predictive maintenance process a maintenance decision maker has more information about the assets and can therefore make more adequate decisions on maintenance. The outcome of this thesis will create added value to literature and industry with the designed artefact which will facilitate knowledge creation and knowledge improvement in the predictive maintenance process.

1.2 Introduction of the case organization

Everyone has to deal with maintenance, whether this is on a large or small scale, it is inevitable. The Royal Netherlands Navy (RNLN) aims to modernise and expand on the aspects of information gathering and processing, as well as maintenance (Ministerie van Defensie 2020). Predictive maintenance could facilitate those aims resulting in an increase in availability, reliability and safety of the assets. Data for Maintenance (DfM), a department within the RNLN is working to achieve this goal guided by the technical roadmap in figure 1.3. When a mechanic or engineer has insights in condition data, the usage or maintenance of an asset can be adapted. When this data for maintenance system is correctly implemented it can be a very useful tool to increase the reliability of a vessel. The knowledge creation within predictive maintenance and the correct use of this process is a big challenge, not only the technical aspect but also the social and organizational aspects. The engineers and mechanics need to understand the added value of this new approach and be able to use it. The current condition based maintenance process is preliminary executed by manual condition monitoring and analysis on vibrations and fluids. The condition monitoring department (CPA) of the RNLN analyzes manually retrieved data and gives advice on the basis of thresholds and trends. The thresholds can not always be verified, because parts are mostly preventively replaced and not ran until breakdown. When there is no or not enough information available about a breakdown it can be difficult to update or verify the threshold of a breakdown. The motivation for the RNLN to move towards predictive maintenance is mainly due to changes in the following three aspects:

1. **People:** The number of people aboard of a ship is decreasing, which also means that tasks should be done more efficiently and there is no time for additional tasks. Ashore there are not enough people to analyze all data effectively and thoroughly.
2. **Complexity:** The maintenance of a ship is getting increasingly difficult, this is because of technical push and pull. This development is mainly on complex systems, electronics, radars, weapons systems, etc. For example, assets which contain more sensors (push) and a demand from engineers who would like more information about installations (pull).
3. **Maintenance:** Maintenance on the ships of the RNLN is mainly time-based, which means that a ship will have small maintenance every few months and large overhaul every approximate five years. The downside to this is that a lot of parts will be replaced which don't need replacing yet, which costs money and time.

1.3 Problem statement

The RNLN aims to implement predictive maintenance on its fleet, starting with the introduction of a new vessel (the Combat Support ship) in 2024. A complete image of the problem statement is formed by conducting 14 interviews, an overview of which is given in section 1.5.3. The most prominent topics in the interviews can be summed up in 5 main challenges:

1. **Data entry and data quality:** Information and data are often not or incorrectly registered in the ERP system/ maintenance registration system used by the RNLN (SAP) system, which causes that maintenance engineers have little information about an installation. Often there is limited feedback on the functionality of a system after maintenance, which also causes a lack of information and knowledge for maintenance engineers.
2. **Policy and standards:** In the current work procedures of the maintenance organization at the RNLN there is no clear work procedure for predictive maintenance. This leads to limited use of (administrative) condition information in the formation of maintenance plans.
3. **Resource capacity:** Small periodic maintenance is sometimes not executed due to resource capacity issues, but the task is checked off as "executed" in the administration system (SAP). This leads to an incorrect and incomplete overview of performed tasks in maintenance.

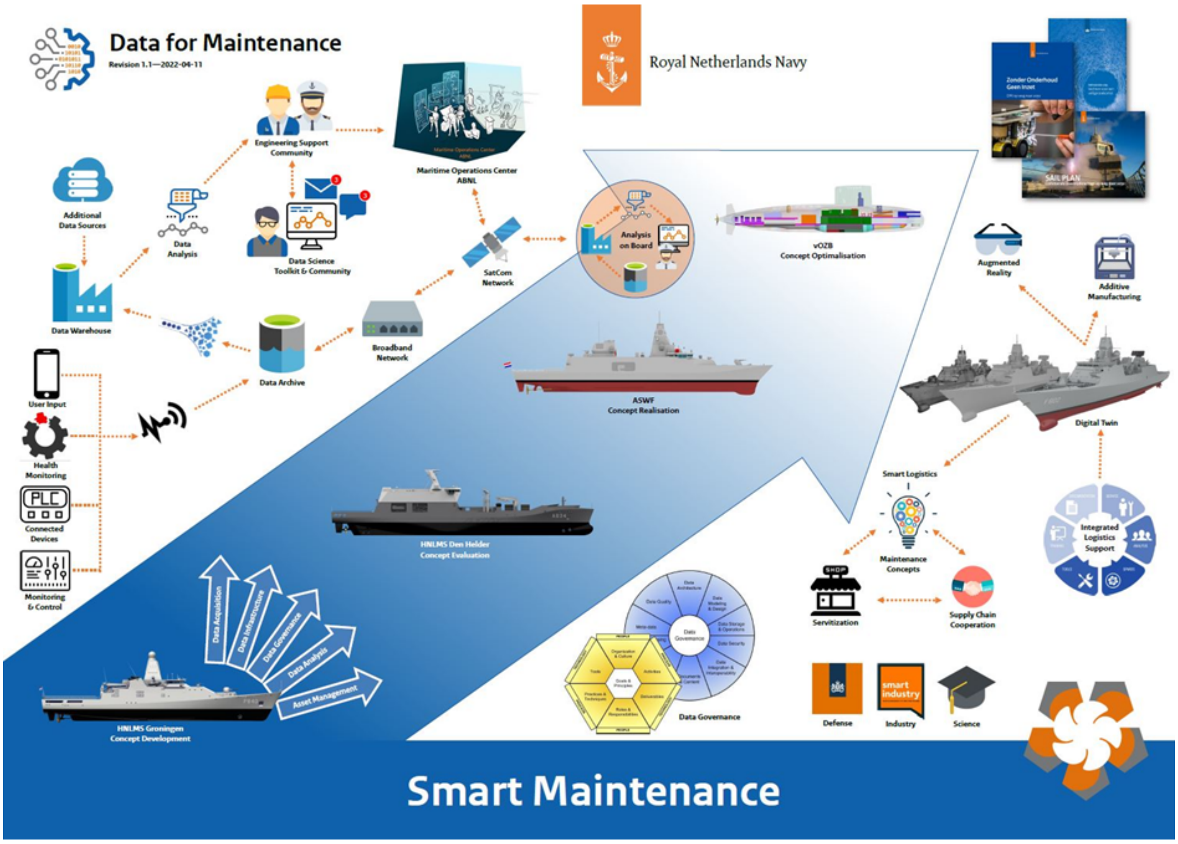

Figure 1.3: Smart maintenance roadmap (Data for Maintenance 2022) showing the technical road towards the Defense visions

4. **Data literacy:** Not all maintenance engineers know how to work with condition-data, these people don't know how to access the condition-data and are often not willing to work with it. Next to this, it is not mandatory for them to work with this data, when it is it could change the approach to maintenance planning.
5. **Autonomy:** The staff aboard of a ship is responsible for the overall operational readiness of the ship, but maintenance engineers are responsible for the operational readiness of installations aboard of those ships. In the current situation, the ship's staff decides if the advice on CBM should be executed or not, maintenance engineering is mostly not involved. This is causing engineers to miss out on the opportunity to include condition information and data in maintenance plans.

These challenges can be linked to the work packages of the PrimaVera project (figure 1.2). The data quality challenge as well as the resource capacity have effect on the data acquisition, therefore these challenges can be linked to work package one. The data entry, policy and standards as well as the data literacy can be linked to work package five in the PrimaVera project, and lie within the scope of this thesis. The last challenge, autonomy, can be related to work package four in the PrimaVera project: maintenance and logistics optimization.
The challenges listed above were described by employees of the maintenance organization at the RNLN (DMI), and their problem statements were quite similar. The main challenge discussed is the

information availability, quality and management at the RNLN, which could be improved by knowledge creation. Currently data entry and quality are scarcely available, and therefor the biggest challenge for the RNLN is to improve the knowledge, information availability and information management. By improving these factors we expect an improvement in decision making for maintenance at the RNLN. An environment for knowledge creation and improvement could facilitate the improvement of data entry and quality and therefor improve the main challenges on PdM for the RNLN.

1.4 Current state of research

This section describes the current state of literature on predictive maintenance and knowledge creation within this process. This short overview of current literature gives insights in the use of predictive maintenance and it's application (levels), as well as the (relevant) previous researches performed at the DfM department of the RNLN.

According to Ellis (2008) condition based maintenance is a management strategy, and the objective is to minimize the total cost of inspections and repairs with the use of data. Monitoring should be applied on parts where it is cost-effective, then you can generate adequate notice on pending failure and plan repairs based on asset degradation (Ellis 2008)(Ellis 2009). Not only the data from the asset should be monitored but also financial maintenance data, these two combined can make a cost-effective CBM program. According to Shohet (2003) CBM requires the development of performance indicators: (1) the physical performance of the (building) system, (2) the frequency of failure of (building) systems, and (3) actual preventive maintenance carried out on the systems. As an addition to this, Ellis (2008) says that you should also include performance measurement systems as a tool for the strategic objectives. And the application of CBM will require analytical tools, such as failure mode, effect, criticality analysis (FMECA) and Reliability Centered Maintenance (RCM) to determine the likelihood of failure (Ellis 2008). According to Tsang (1995) condition monitoring can be classified in five types of symptoms: dynamic effects, particle release, chemical release, physical effects, temperature change, and electrical effects. These classes of symptoms can be monitored using several techniques, such as vibration monitoring, process-parameter monitoring, thermography, tribology, and visual inspection. The paper of (Tsang 1995) describes that the use of CBM requires three decisions, before and during it's use. Before the use of CBM a company should decide on: (1) selecting the parameters to be monitored, (2) determining the inspection frequency, (3) establishing the warning limit. During the use of CBM decisions are made very often, these decisions are: what maintenance action to take, and when the next inspection will be.

"The adoption of these new predictive technologies is not an easy task" McKone & Weiss (2002), and the use of predictive maintenance can be an addition to a maintenance strategy to help detect equipment problems and reduce the opportunity for premature periodic replacements and equipment failure. McKone & Weiss (2002) describe the use of PdM in combination with traditional maintenance strategies, and how a company can benefit from that. The main difficulties for PdM, described by Tiddens (2018), are (1) selecting the most suitable techniques for PdM, (2) identifying the most suitable candidates for PdM, and (3) evaluating the added value of PdM. In Tiddens et al. (2020) the applications of predictive maintenance in industry are explored with numerous case studies. Which results in a framework being proposed for predictive maintenance with four elements: Initiation, monitoring and data gathering, maintenance techniques and decision making. Also, Tiddens (2018) describes the application of PdM on suitable candidates based on failure data as an addition to the, commonly applied, experience based methods. The level of maturity in maintenance can be assessed in different ways and can be of added value for companies who desire to think in maturity, in this case CBM maturity. Smith (2018) describes maturity stages as: (1) react, (2) prepare, (3) prevent, (4) predict, (5) systematize. This maturity model describes asset management in a company. Maintenance maturity is a part of asset management maturity as described in Chemweno et al. (2015), where there are five levels of maturity. A model for describing the maturity of condition based maintenance is described by van de Kerkhof (2020) van de Kerkhof et al. (2019). In which a condition based maintenance maturity model is developed, which can be used to determine the CBM maturity. In this model the organization can be classified five levels: (1) no CBM, for example when assets are not maintained; (2) Reactive CBM, when none of the assets are monitored structurally but it can be used to investigate anomalies; (3) Planned CBM to improve the efficiency of maintenance (easy-to-learn/ easy-to-use CM technologies); (4) Proactive CBM to increase reliability and productivity of (mainly important) assets; (5) World class CBM to increase the value realised from the asset base. This maturity model gives a good overview of the condition based maintenance maturity of a company, and can establish maturity thinking. The maturity model of van de Kerkhof (2020) will be used in this thesis to gain insights in the CBM maturity of the RNLN and four selected companies in the industry.

This thesis builds on knowledge gathered during previous student research conducted at the department DfM at the RNLN, which is the starting point of this work. The first research was conducted by D.P. Brus (2022) on the social impact of implementing predictive maintenance at the RNLN. This work gives an overview of the social barriers of implementation of PdM, and also how they could be improved. The second student research was conducted by W.H. Redel (2022), the topic of which is: The impact of data-driven maintenance on the Royal Netherlands Navy's maintenance planning and execution. This research identified methods which can be used to analyze and improve maintenance plannings, also a decision table was proposed to adopt to data-driven maintenance.

1.5 Research design

In this section the research design is proposed. Section 1.5.1 gives an overview of the research question and it's sub-research questions. The research question will describe the goal of this research, and be supported by the sub-research questions. In section 1.5.2 the research method for this thesis is described. Section 1.5.3 provides an overview of all the input in this research from people at the RNLN and from external companies.

1.5.1 Research Questions

The main focus of the RNLN, and project Data for Maintenance (DfM), is on the technical aspects of implementing predictive maintenance. The goal of this research is to develop a predictive maintenance process for the Royal Netherlands Navy where knowledge creation is secured. This is done to improve the information entry and quality (challenge 1 in section 1.3) in the registration systems such that knowledge about maintenance in the predictive process is secured. The main research question is:
How can knowledge be enhanced in the predictive maintenance process of the RNLN's maintenance department with the aim to improve maintenance decision making?

To reach the answer of this research question some sub-research questions are formulated:

1. How are the current maintenance processes of preventive maintenance, corrective maintenance and condition based maintenance structured within the RNLN?
2. What lessons can be learned from literature and industry on the knowledge creation in a predictive maintenance process?
3. How should the future predictive maintenance process within the RNLN be structured?
4. How can knowledge be created to improve decision making within the predictive maintenance process?
5. How can knowledge creation within the newly developed PdM KIP process be demonstrated using a use case, based on the introduction of the Combat Support Ship?
6. How can knowledge creation within the newly developed PdM KIP process be evaluated?

1.5.2 Research method

In this section research methods are elaborated. These methods can be used to support the research towards answering the defined research questions. The goal of this research is to design an artifact to increase knowledge creation within the predictive maintenance process. There are different types of design research frameworks which can be used to structure this thesis, such as the Design Science Research Methodology (DSRM) of Peffers et al. (2007) and the Design Science Research Cycles (DSRC) of Hevner (2007). In this research it is chosen to use the DSRM of Peffers et al. (2007) based on the nature of the design and the design steps. The DSRM describes a six step method to approach design science:

1. Identify problem and motivate
2. Define objectives of a solution
3. Design and development
4. Demonstration
5. Evaluation

6. Communication

The research can start at either of the first four steps, depending on the research. In the case of this research the initiation will start at step 1 (identify problem and motivate), which is done in chapter 1. The design science research methodology is shown in figure 1.4.

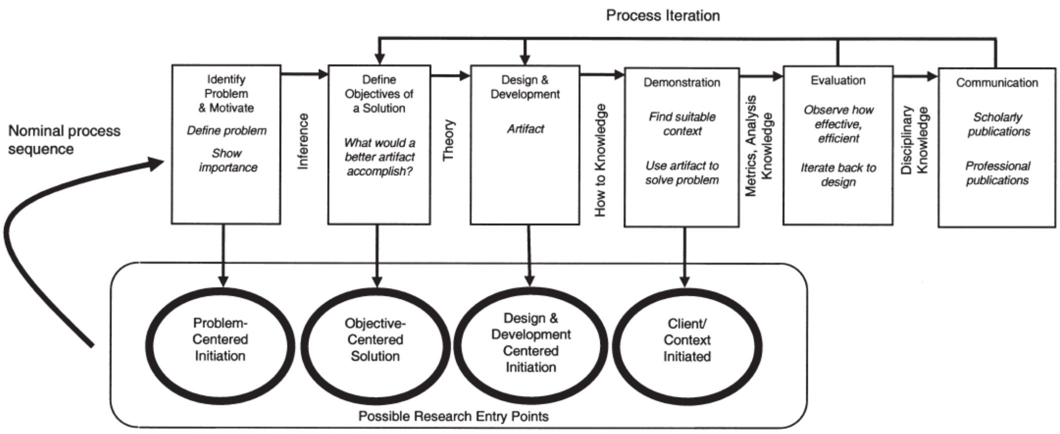

Figure 1.4: Design science research methodology Peffers et al. (2007)

The DSRC of Hevner (2007) structures design science in a three cycle process, shown in figure 1.5. The three cycles in this framework are the relevance cycle, design cycle and the rigor cycle. The relevance cycle inputs requirements from the context and environment into the research. The design cycle builds and evaluates the design. The rigor cycle provides grounding theories and methods, as well as experience and expertise from the design environment. These design research cycles are very generally defined, but can guide any design research to a successful completion.

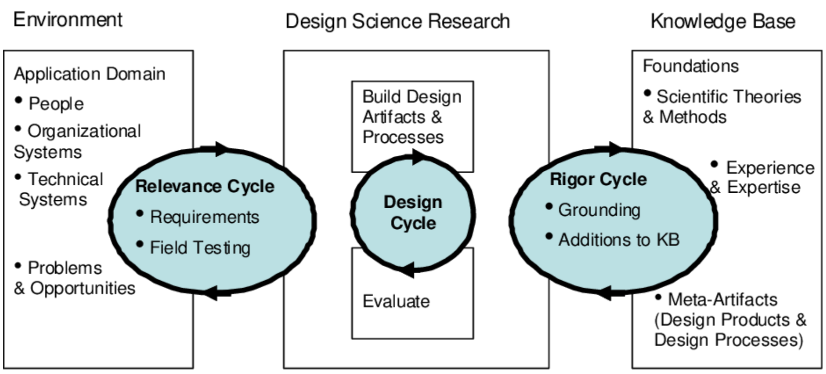

Figure 1.5: Design science Research Cycles Hevner (2007)

In this research the design science research methodology of Peffers et al. (2007) is used because of the problem centered initiation of this project, and the clarity of the design research steps. The six steps in the design science methodology will guide the design of a knowing maintenance organization at the RNLN. The research questions in section 1.5.1 can be related to the steps of the

DSRM. Next to this, the rigor cycle of Hevner (2007) is used to shape the evaluation of the proposed knowledge improvement process, and asses it's applicability in other maintenance processes.
The first step in the research is to identify the problem and motivate it, by gaining general knowledge about the organization and literature. This is done to identify the starting-point of the research, and to identify background information. The background information of the RNLN is mainly obtained by conducting interviews, shown in section 1.5.3. The second step in the framework of Peffers et al. (2007) is to define objectives of a solution. This is done by the first two sub-research questions. The first sub-research question focuses on the current maintenance processes at the RNLN. We can identify three different processes in the current working procedures: preventive, corrective and condition-based maintenance. These processes will be split up and analyzed separately by using lean process flow diagrams (Coutinho 2021). This is be done to get a standardized and good overview of all processes at the maintenance department of the RNLN. The second research question focuses on the current state of PdM in literature and industry. To identify this, a literature research is conducted and multiple interviews with the industry are performed.
The next step in the DSRM is the design and development phase. To facilitate the design of a knowledge improvement process a predictive maintenance process is designed, answering sub-research question three. All the gained information from interviews will be gathered in the design. The design of a knowledge improvement process will answer sub-research question 4, which should be applicable to the predictive maintenance process.
The fourth step in Peffers et al. (2007) is to demonstrate the design of the knowledge improvement process for PdM, this will be done by the use case of the Combat Support Ship at the RNLN. This ship will be an introduced in 2024 and can facilitate PdM due to the added capacity such as sensors. In this design step of the DSRM the fifth sub-research question is treated.
In the fifth step the evaluation of the designs is done, corresponding to research question 6. This is executed by letting experts evaluate the design according to the design objectives and applicability.
Steps three, four and five will be repeated until the desired and optimal design is created. The last step in the framework of Peffers et al. (2007) is to communicate my findings. This will be done by presenting and by publishing this thesis.

1.5.3 Interviews and input

This section shows an overview of all the people who were involved in this research in table 1.1. A total of 39 people provided input for the outcome of this research, some of these people are referenced in this work. The referencing to these people is done by title, when multiple people with the same title are referred an additional letter in column ”reference in paper” is assigned.
All interviews were documented in Atlas.ti to identify patterns between the interviews, next to this the maturity model was filled in using a survey which were stored. Most of this information is qualitative research, which means that the accuracy of information has limitations. All perspectives on the information are taken into account by interviewing engineers and managers from several technical departments within Maintenance department of the RNLN (DMI), Defense Material Organization (DMO) and Condition and Performance analysis (CPA). All interviews showed different perspectives on the problem description and the designed solution. The interviews

contributed to the formation of the process flow diagram for the current maintenance situation and the final design. The maturity model (of van de Kerkhof (2020)) was used to assess the current maturity of the RNLN and industry, which was executed by several participants using a survey. To demonstrate, verify and evaluate the design three input sessions were organized. The first input session was used to verify the predictive maintenance process and it's applicability for the RNLN. The second input session was used to demonstrate the use of a predictive maintenance process with knowledge creation by frameworks in literature ((Choo 1999)(Kettinger & Marchand 2011)). The last input session was used to demonstrate the Predictive Maintenance Knowledge Improvement Process (PdM KIP) by a use case of the Combat Support Ship, and an evaluation was executed. During these input sessions 13 people participated, however not everyone was present during every session. The whole spectrum of the predictive maintenance process was covered by inviting people from DMI, DMO, CPA, and technical services. After every input sessions all the invited people were updated on the conclusions of the input session and they had the opportunity to provide feedback or additional information.

1.6 Research Outline

In this section the outline of the thesis is described using the design research framework of Peffers et al. (2007). The chapters are structured in a way to cohere with the design research concepts of Peffers et al. (2007). Figure 1.6 shows an overview of the chapters and sub-research questions. The first chapter (1) is the introduction, where the background information is identified as well as the problems. In chapter 2 all the objectives for the design are researched, such as the current maintenance structure, literature and industry. Chapter 3 shows the design of a knowledge improvement process for the predictive maintenance process at the RNLN. Chapter 4 describes the demonstration of the design, which will verify its applicability. The evaluation step in the Peffers et al. (2007) framework is described in chapter 5, where the design is evaluated.

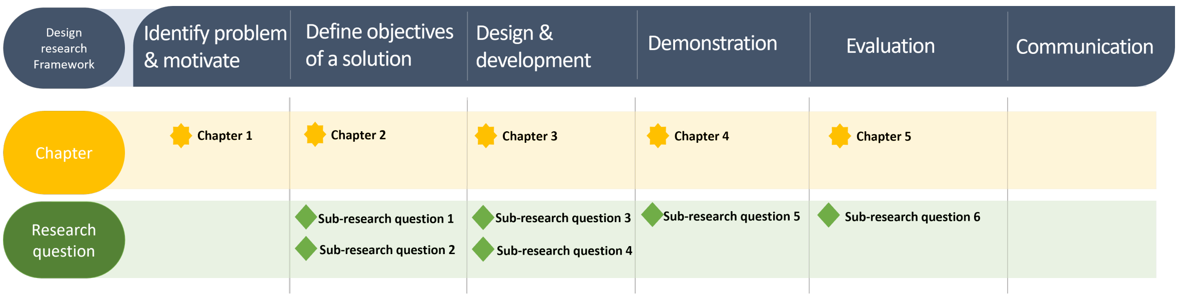

Figure 1.6: Research methodology and outline

Number of people	**Company**	**Department**	**Function**	**Reference in paper**	**Participation**				
					Interview	**Maturity model**	**Input session 1 (02-11-2022)**	**Input session 2 (16-11-2022)**	**Input session 3 (30-11-2022)**
1	RNLN	DMI	Head technical services		x	x			
2	RNLN	DMI	Senior maintenance engineer	A	x	x			
3	RNLN	DMI	Senior engineer		x	x			
4	RNLN	DMI	Installation manager			x			
5	RNLN	DMI	Manager			x			
6	RNLN	DMI	Assistant engineer			x			
7	RNLN	DMI	Senior engineer			x			
8	RNLN	DMI	Maintenance engineer			x			
9	RNLN	DMI	Senior engineer			x			
10	RNLN	DMI	Engineer			x			
11	RNLN	DMI	Senior engineer			x			
12	RNLN	DMI	Engineer			x			
13	RNLN	DMI	Engineer			x			
14	RNLN	DMI	Senior engineer			x			
15	RNLN	DMI	Senior engineer			x			
16	RNLN	DMI	Senior engineer			x			
17	RNLN	DMI	Senior maintenance engineer	B, C, D	x	x		x	
18	RNLN	DMI	Maintainer		x				
19	RNLN	DMI	Maratime support		x		x		x
20	RNLN	DMI	Maratime support		x		x	x	
21	RNLN	DMI	Head innovations management					x	
22	RNLN	DMI	Weapon system manager				x	x	
23	RNLN	DMI	Head engineering				x	x	x
24	RNLN	DMI	Head technical services					x	
25	RNLN	DfM	Senior engineer			x			
26	RNLN	DfM	Manager	A		x	x	x	
27	RNLN	DfM	Manager	B			x	x	x
28	RNLN	DMO	Senior support manager		x				
29	RNLN	DMO	Manager					x	x
30	RNLN	CPA	Manager		x	x	x	x	
31	RNLN	CPA	Engineer			x	x	x	x
32	RNLN	CPA	Technical services			x			
33	RNLN	CPA	Technical services			x			
34	RNLN	CPA	Technical services			x			
35	Dutch Railways		Senior project manager		x				
36	Dutch Railways		Maintenance engineer		x	x			
37	Port of Rotterdam		Asset manager		x	x			
38	Alstom Transportation		Manager		x	x			
39	Equans refrigeration		Technical lead		x	x			

Table 1.1: Overview of the interviews and input of this research

Chapter 2

Research objectives

In this chapter the foundation is set for the design of a knowing maintenance organization at the Royal Netherlands Navy according to step 2 in the DSRM of Peffers et al. (2007). In section 2.1 the current maintenance processes of the RNLN are explained, divided in three parts (preventive maintenance, corrective maintenance and condition based maintenance), this will answer sub-research question 1. Section 2.2 describes the condition based work processes of different companies in the industry, this is done to get insights in how other companies work with CBM, and how knowledge is created by using CBM or PdM. In section 2.3 the used literature on knowledge creation and decision making are elaborated. The research in literature and industry will answer sub-research question 2. This is all done to get a good understanding about how the current processes work at the RNLN and how they can improve, based on literature and practice. This chapter will be concluded with section 2.4, the design criteria in that chapter will show all the important aspects needed in the design.
The research questions answered in this chapter are:

- Sub-research question 1: **How are the current maintenance processes of preventive maintenance, corrective maintenance and condition based maintenance structured within the RNLN?**
- Sub-research question 2: **What lessons can be learned from literature and industry on the knowledge creation in a predictive maintenance process?**

2.1 Current maintenance processes of the RNLN

In this section the three maintenance structures of the Dutch Navy will be described, lean flow charts are added to give a good overview. The overview of information flow between departments was sketched by doing interviews and having conversations with people involved in the maintenance process. These lean flow diagrams were verified with engineering personnel of the maintenance department at the RNLN. The flow diagrams are made for preventive maintenance (section 2.1.1), corrective maintenance (section 2.1.2), and condition based maintenance (section 2.1.3). Next to the flow diagrams the current maintenance situation is quantified by using a maturity model by van de Kerkhof (2020) in section 2.1.3. In the process charts the standard lean flow chart symbols are used Coutinho (2021). The flow diagram always begins at the oval-shaped start symbol and ends at the oval-shaped end symbol, different steps can be taken between them. For example a square is a process or action, a diamond shape is a decision etc. The flow in the diagram is shown by the arrows, and describe the taken path in maintenance. A blue square in the flow diagrams represent an action in the SAP system.

2.1.1 Preventive maintenance

Currently the main focus of maintenance at the RNLN is preventive. Preventive maintenance has worked for the RNLN for decades and it keeps the vessels in operational state most of the time. The current organizational process for preventive maintenance is shown in figure 2.1. There are three time-based maintenance cycles, one large overhaul every five year, smaller maintenance every approximate three months and continuous periodic maintenance. For these maintenance cycles preventive maintenance plans are made by maintenance engineers, in these plans the standard (preventive) maintenance is described. Figure 2.1 shows the preventive maintenance process at the RNLN. In this figure the short term represents the maintenance tasks performed aboard of the ship. The long term preventive maintenance is described for every five years, this cycle it is also applicable for the three-monthly maintenance process but there is no test before maintenance. The largest preventive maintenance cycle is every five years, where more than a thousand parts are replaced or repaired (Senior maintenance engineer, RNLN 06/2022*b*). For this large overhaul there is a standard maintenance list, which is the basis of the maintenance plan, next to this the crew of a ship can provide input for the maintenance period. Also, about 12 months before the large overhaul maintenance a test for maintenance is done where engineers go aboard to do tests on the vessel (Senior enineer, RNLN 08/2022). The maintenance is often based on the experience of the engineer and what maintenance has been performed in the past. ”If a maintenance engineer doesn't go aboard, he doesn't know what is going on and which installations should be improved. This is all due to lack of information registration, if the ship doesn't register (small) failures the maintenance engineer can not improve the system.” (Senior maintenance engineer, RNLN 09/2022*c*). During maintenance, it can happen that when a part is taken off-board for maintenance it turns out that the installation has had an overhaul or was replaced just a short while ago, and engineering did not know about it. This is due to the incorrect, incomplete or absence of registration in SAP. Another challenge is the information transfer from outsourced maintenance, often the performed tasks are not registered or checked and this information is lost (Senior maintenance engineer, RNLN 09/2022*c*).

The current preventive maintenance strategy of the RNLN might have worked for the past decades, but it is not working perfectly. The main issues are lack of information about malfunctions of an installation due to poor registration and that maintenance engineers are often not involved. The installation managers are responsible for the functionality of their systems, however they are often not included in decision making or information sharing about an installation (Senior maintenance engineer, RNLN 09/2022*c*).

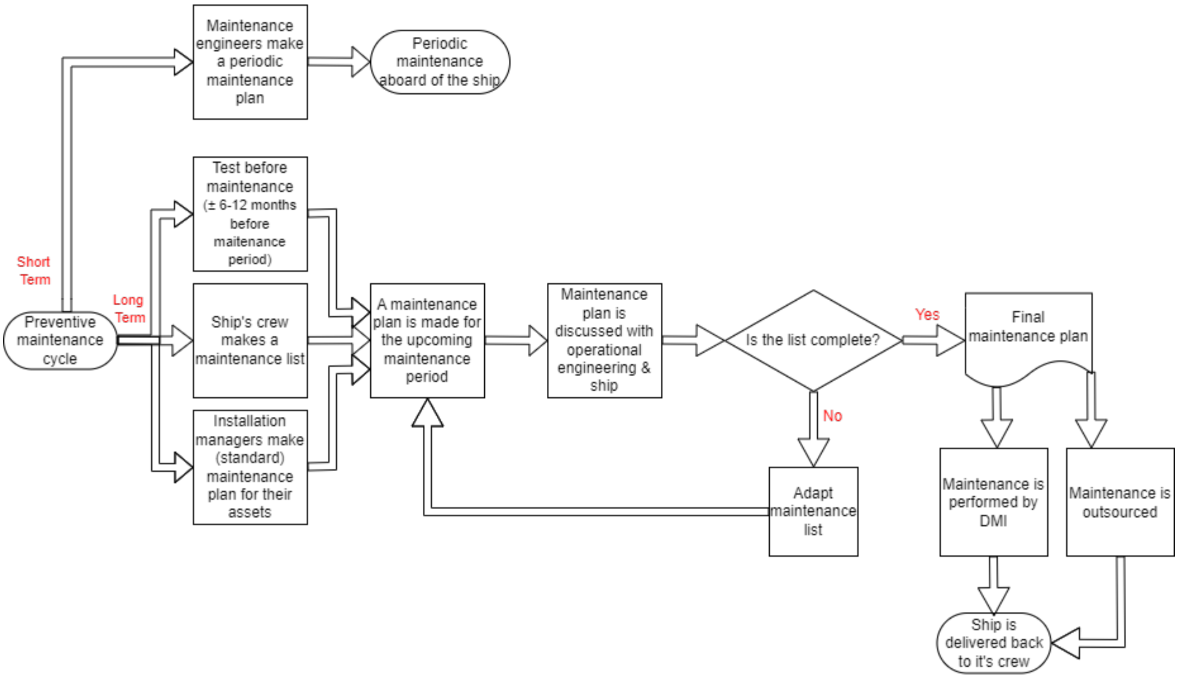

Figure 2.1: Preventive maintenance cycle RNLN

2.1.2 Corrective maintenance

Corrective maintenance happens when a part breaks down before preventive maintenance was conducted. This maintenance is performed by the mechanics aboard of the ship in most cases, if this is not possible it's done by the RNLN maintenance department or it's outsourced. The corrective maintenance process is shown in figure 2.2. If a breakdown is noticed by someone aboard, this person will need to report this to the major or head of technical services. When the breakdown is reported it should be registered in SAP and given priority 1 to 5. However it often happens that breakdowns are not reported, incorrectly reported or incompletely reported. In the first case, when a breakdown is not reported, it is often small or not labour intensive. Aboard of the ship there is a booklet where people can write small breakdowns to request a repair. These are not processed in the maintenance administration. The consequence is that when something small breaks down often it is not detectable in the system, and a maintenance engineer will not know about it or can not analyze it's behaviour (Senior maintenance engineer, RNLN 09/2022*c*). In some cases the breakdowns are registered incompletely or incorrectly, an example of this is not registering the right equipment, or registering the right installation but not the part (it is then not specified enough). Another example is that a breakdown is reported, however there is no explanation on why it has failed or what happened. When the maintenance service aboard is not able to fix the problem themselves they can ask assistance from external companies, maintenance engineering, or CPA (Condition and Performance Assessment). The information exchange between the ship and engineers will always happen through department operational engineering, which is a group of military engineers who will then connect the ship's crew with the right engineer. A big problem with this structure is that information is not (directly) shared. This causes maintenance engineering to have little information about what is being done with the installations, which makes it unpredictable when looking in the repair history of an installation or when an installation is scheduled for preventive maintenance (Senior maintenance engineer, RNLN 09/2022*c*). Also, when Condition & Performance Assessment - department within the RNLN (CPA)/maintenance engineering/external parties are included in the problem solving this is also not registered in any system and the three parties do not know of each other what they are working on. Another issue is that there is hardly any feedback processed when a repair is done. Work orders are often closed without any added information on what has been done or what was wrong with the installation. This is caused by the difficulty and effort that it takes to register this information, but also because a senior mechanic often registers and closes the work orders. Not all mechanics can access the work order system, this is done by one person. If this person does not exactly know what was done he will not register it in the system, or it could also be that it is incorrectly registered.

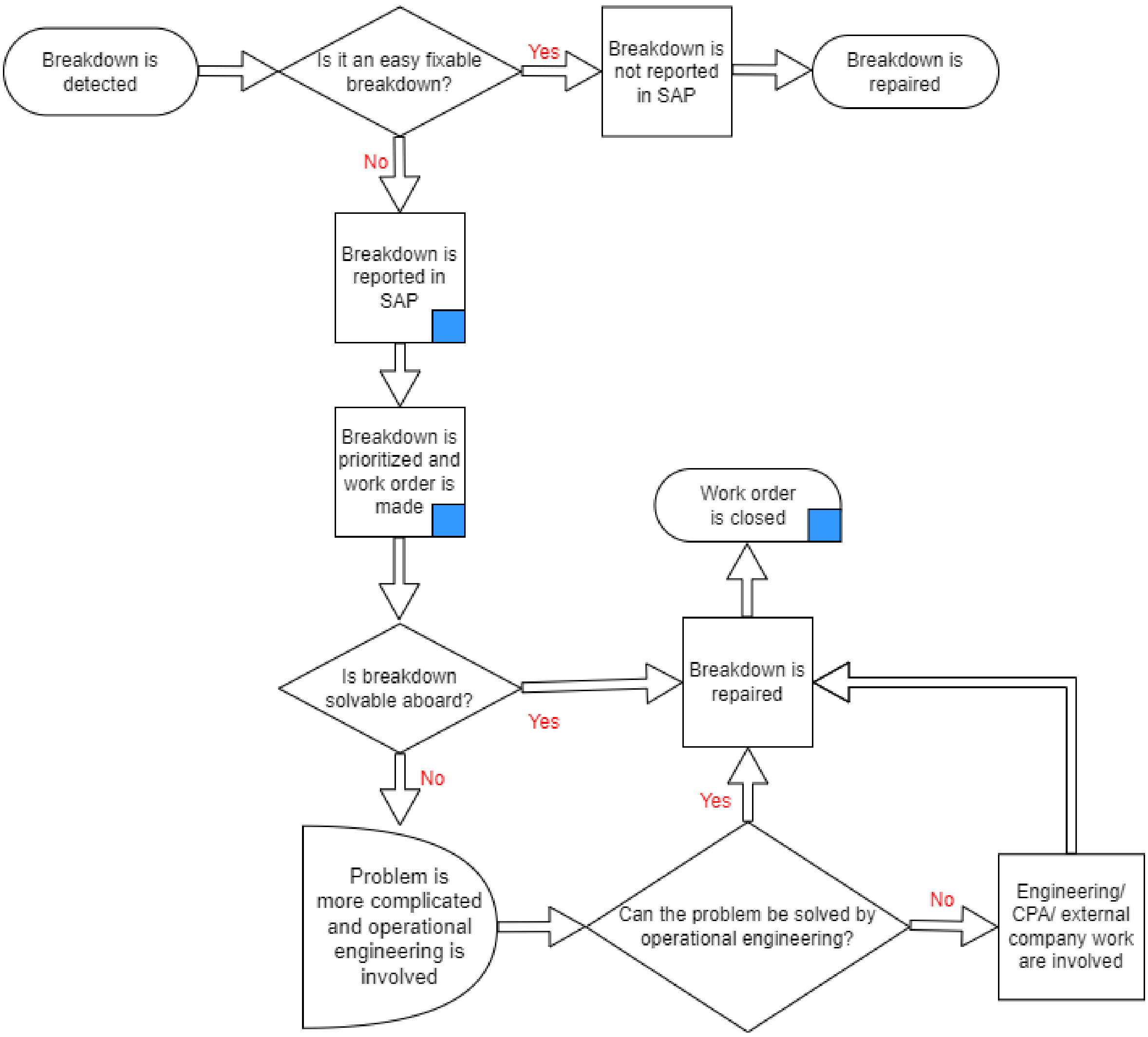

Figure 2.2: Corrective maintenance cycle RNLN

2.1.3 Condition based maintenance

Condition based maintenance is scarcely used in the organizational structure of the RNLN, but some people do try to use it and some information is available. The available condition data is measured by CPA (Condition and Performance Analysis), this department does vibration and liquid analysis. These measurements are performed once every approximate four months. However, due to personnel shortages these measurements are no longer done on the whole fleet (CPA, RNLN 08/2022). The data is analyzed by CPA who also write a report and give maintenance advice where needed. The main client of CPA is the ship, who decides what to do with the maintenance advice. The knowledge created by CPA can also be used by engineering to get a better insight in the current state of installations. However, his information is not often used by engineers (Senior maintenance engineer, RNLN 06/2022*b*). Some engineers don't know they can use it or don't know how to use it. But there is also a small group of engineers who do use the information of vibration/liquid analyses, these engineers do that from their own initiative (Senior maintenance engineer, RNLN 08/2022*a*)(Senior enineer, RNLN 08/2022). The overview of the condition based maintenance process at the RNLN is shown in figure 2.3. In the condition based maintenance cycle the use of condition information is not mandatory for maintenance engineers to use. Maintenance engineers can decide if they want to use the information, and if they do, how they use it. Next to this, there is little information sharing and feedback on maintenance tasks available for maintenance engineers. Another challenge is the business operations maintenance, currently the ship's crew is responsible for the maintenance but the maintenance engineers are responsible for the functionality of the installations aboard. In the current condition-based situation the ship's crew can decide to take action or not when the condition report is received. This is often a problem because it is not discussed with the responsible maintenance/installation engineer. Also, on some of the RNLN's ships the crew rotate every three months. Which causes knowledge to get lost and there is a general attitude that "the next crew will fix it". Where some of the maintenance is postponed until the crew is rotated, however when there is no correct registration of maintenance tasks the next crew will not know that a certain task needs to be done.

CBM maturity of the RNLN

For this research it is important to quantify the perspectives of interviewees, this is done by using a condition based maintenance maturity model by van de Kerkhof et al. (2019). All the interviewees were asked to fill in the maturity model and rate the following aspects from level 1 (no CBM) till 5 (world class CBM): worth, condition monitoring technologies, assets, data, IT-infrastructure, strategy & goals, decisions, structure, budgeting & capacity, processes & documentation, governance, knowledge & skills, culture (van de Kerkhof 2020). Most of the aspects in the model are focused on the organisation and the people involved.

The maturity model is assessed in by 23 participants, mainly maintenance and installation engineers. The maintenance organization of the Royal Netherlands Navy is very large consisting out of different technical groups. Each technical groups has a different advancement in the usage of condition based maintenance. It is also possible that not every group is able to implement condition

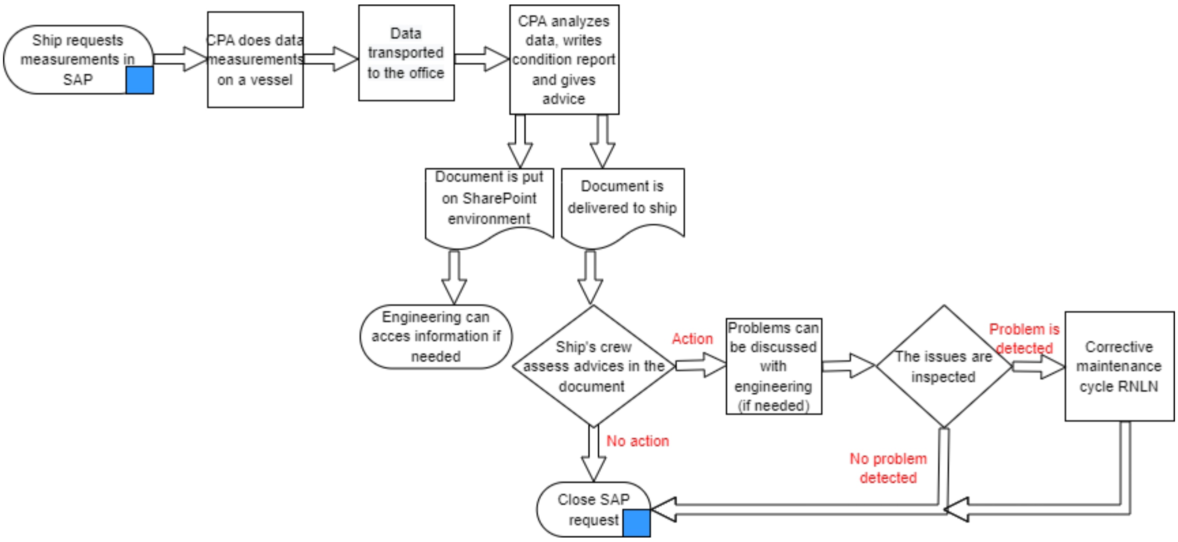

Figure 2.3: Condition based maintenance cycle RNLN

based maintenance due to the type of equipment or information available. The distribution of participants from different departments of the RNLN is shown in table 2.1.

Department	Number of participants
Technical services (aboard)	1
Platform	1
Sensor weapon systems	2
Command control	4
Defence special products	6
CPA	5
Data for maintenance (DfM)	2
Submarines	2

Table 2.1: Number of participants between departments at the RNLN

Figure 2.4 shows the CBM maturity on all aspects described by van de Kerkhof et al. (2019), the average maturity is 2.4 which means that the overall current maturity of the RNLN is scaled between reactive and planned CBM. Because the maturity model was filled in by a lot of engineers within the maintenance organization this means that the input varies a lot. Therefore the outcome of the maturity in figure 2.4 is represented by boxplot, where the deviation from the average can be seen. The worth of condition based maintenance was averagely scaled at 2, which is reactive maintenance. There were people who said that it should be level 4, proactive CBM. Both could be justified. The condition of an asset such as diesel engines is currently measured, when a deviation is detected it can proactively be solved (Senior maintenance engineer, RNLN 08/2022*a*). The lowest that the worth was scaled was 1.5, this person's opinion was that the worth lied between no CBM and corrective CBM because currently they do not work with the concept but they are willing to adopt the concept.
Condition monitoring technologies differ a lot between the different departments, some departments

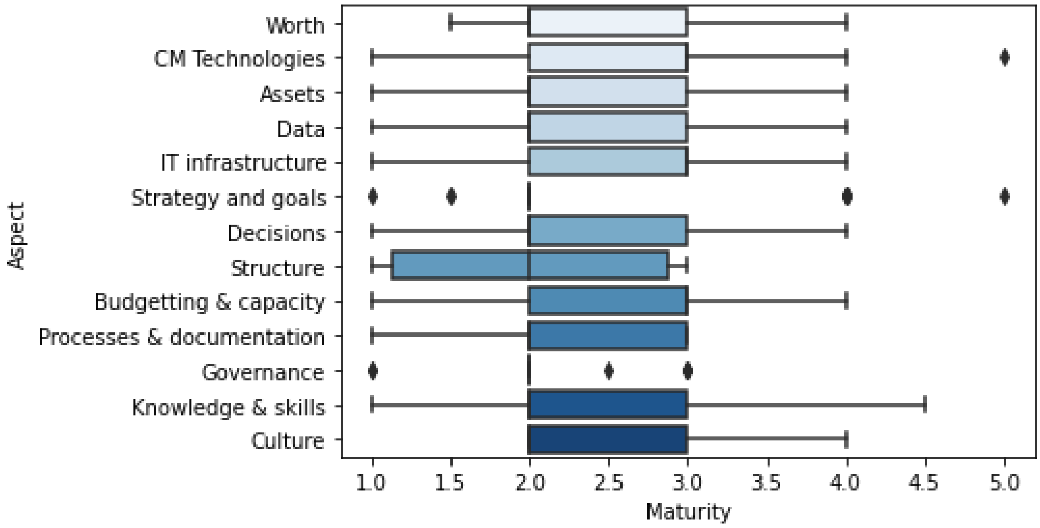

Figure 2.4: Average CBM maturity of the RNLN

have more opportunities to use it and others don't. This is also applicable for the assets, data and IT-infrastructure. The average level for the technologies is rated at level 3 (Planned CBM), for assets, data and IT-infrastructure the averaged level of maturity is 2 (reactive CBM). For technical groups with running/operating installations there are more possibilities to apply CBM, therefor they score higher on the maturity level. However, there are technical groups who do not have a lot of options for CBM. During an interview it became clear that predictive or condition based maintenance is not achievable for every department (DSP, RNLN 09/2022).

2.1.4 Summary of challenges in the current maintenance process of the RNLN

The maintenance structure of the RNLN is divided into three parts: preventive, corrective and condition based maintenance. All these three maintenance approaches face challenges and problems at the RNLN. This section will briefly summarize these challenges. The challenges for preventive, corrective and condition based maintenance came forward in the respective sections 2.1.1, 2.1.2 and 2.1.3. These challenges will be incorporated in the design criteria in section 2.4 to shape the design of the knowing maintenance organization at the RNLN.

Challenges for preventive maintenance:

1. Preventive maintenance plans are based on standard tasks and experience of maintenance engineers. This could mean that some parts are replaced before it is necessary and some parts are not replaced when it is necessary.
2. The lack of information transfer and communication between the ship and maintenance engineers causes that the engineers are not up-to-date of issues on installations, which can lead to incomplete maintenance plans.
3. Information is lost when maintenance is outsourced, because there is no or little control on the executed tasks.

4. The registrations in SAP (creating and closing of work orders) is often incorrect, incomplete or absent. Also, there is little to no control on this process which causes information to get lost.
5. Small periodic maintenance is often not executed due to capacity issues, but the task is checked off as ”executed” in SAP. This causes a disconnect on information between the maintenance staff aboard and maintenance engineers ashore.

Challenges for corrective maintenance:

6. The registrations in SAP (creating and closing of work orders) is often incorrect, incomplete or absent, also the registration in SAP is often not encouraged by higher executives. This challenge is in line with the described challenges in the preventive maintenance process.
7. There is limited feedback processed in the system, which causes that a maintenance engineer doesn’t know (a lot) about the corrective maintenance.

Challenges for condition based maintenance:

8. There is no clear work procedure of CBM embedded in the current organisational structure.
9. There is no set work procedure on condition-data for maintenance engineers, they don’t know how to access the condition-data, and some times they are not willing to work with it. Next to this, it is not mandatory for engineers to incorporate condition information in their work.
10. Currently there is limited capacity to do the manual condition measurements, this causes that less information is available on the condition information of particular vessels.
11. The ship’s crew is responsible for it’s operational readiness, but maintenance engineers are responsible for the operational readiness of installations aboard of those ships. In the current situation, the ship decides if the advice on CBM should be executed or not, maintenance engineering is not involved in this decision.

2.2 Lessons learned from industry cases

In the previous section the current maintenance situation and it's challenges are described, this section will focus on finding ways to improve the predictive maintenance situation at the RNLN by finding lessons learned from industry. This is executed by interviews at four companies, who are currently in the process of implementing predictive maintenance. These companies have been selected such that they are comparable to the RNLN in the organizational structure and assets. Next to this it is important to get a complete overview of the whole spectrum in the maintenance-chain. The four interviewed companies on this thesis are: The Dutch Railways (asset owner), Equans Refrigeration (a technical service provider), Alstom Transportation (OEM/service provider) and The Port of Rotterdam (asset owner). The interviewed company's PdM/CBM processes are described with flow diagrams and are assessed on maturity of condition based maintenance. This is done by composing lean flow diagrams of the maintenance process and by quantifying the level of CBM maturity of the company with the maturity model of van de Kerkhof et al. (2019) in section 2.2.1.

The maintenance performed with condition monitoring is usually a separate maintenance cycle, usually the dominant maintenance strategy is preventive. For example, for a technical service company specialized in refrigeration the condition-based maintenance cycle is shown in figure 2.5. In this figure the cycle of condition monitoring is not explicitly shown, the result of the condition monitoring is a trigger for maintenance (notification) (Technical lead, Equans Refrigeration 08/2022). Also, to increase the effectiveness of the data-driven maintenance they included monthly meetings to optimize the current process. By doing monthly meeting the knowledge on predictive maintenance can be created and the process can be improved. The introduction of PdM did not change the entire maintenance structure, it added to the existing structure by predicting failures before they happen. Another example is creation of condition-based maintenance dashboards at a service provider of transportation, this is shown in figure 2.6. In the case of this company they create a platform where the triggers for maintenance are shown, they usually do not perform the maintenance but they are able to give input for the maintenance plan due to prediction of failing parts/ assets (Manager fleet service, Alstom Transportation 09/2022). These platforms are made for transportation companies to give insights in the operating system, giving insights in the operating efficiency and also being able to predict possible failures. This is possible when the data quality is high and a pattern of decrease in part-functioning can be detected. Another important aspect is that this company does not always get full access to all data of the client because it might be sensitive information, this can decrease the functionality of the predictive model (Manager fleet service, Alstom Transportation 09/2022). Because of the limited access to data and information, the knowledge creating within this company is a difficult process. Also, the project team of this company struggles with implementing the technique within the company because of lack of support and old habits at other departments. The data is used more and more now that the importance of the project became clear and that it can support employees instead of burden them. The next example is of a large train company in the Netherlands, figure 2.7 shows the condition based maintenance flow diagram of this company. The main maintenance strategy of this company is preventive, since it is a large company with many assets this is currently the most efficient and predictable way to schedule maintenance (Maintenance engineer, Dutch Railways 09/2022). However, next to the preventive maintenance they did introduce condition based maintenance with real-time monitoring, which can produce a trigger for corrective maintenance. They started with creating insights in the already monitored systems, after the success they expanded to more (critical) systems. A big lesson from the implementation of condition monitoring at this company is that it is important to create a support and knowledge structure at a high management level and with one or more maintenance engineers (Project manager, Dutch Railways 07/2022). This will give a strong base to expand the support for the implementation of condition monitoring. Using a strong support base the interest for the project can spread by showing the successes and wins that were created. The last company interviewed is a port in the Netherlands, were they are starting to introduce and explore CBM. Currently they are trying to find support for the project and show the importance and added value of data-drive maintenance. They want to increase the availability and reliability of their vessels (Asset manager, Port of Rotterdam 09/2022). The project had a big win with their first implementation step, which generated a lot of interest in the project, the next step is to select the right asset to expand to.

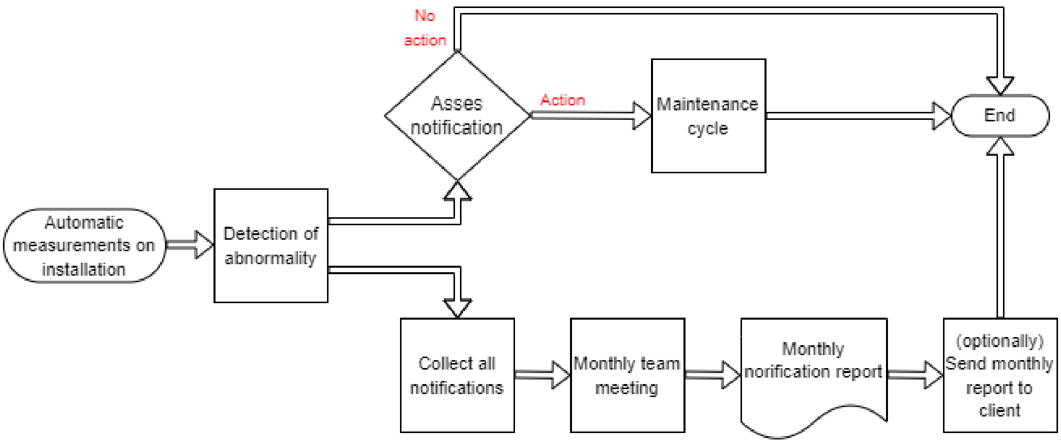

Figure 2.5: Predictive maintenance process of a technical service provider in refrigeration

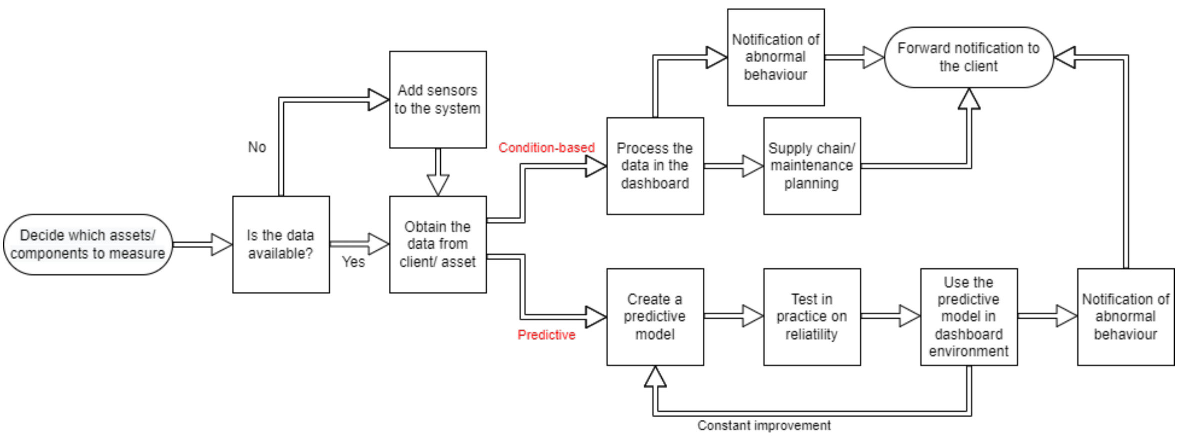

Figure 2.6: CBM process flow diagram of a mobility innovation company

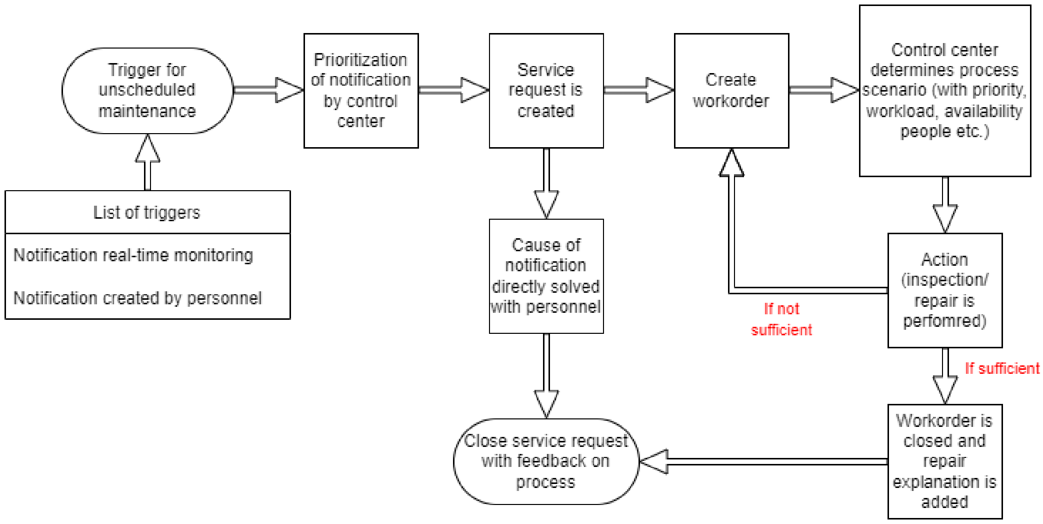

Figure 2.7: CBM process flow diagram of a railway company

2.2.1 CBM maturity of the industry

During this research four companies were interviewed, all of them filled in the condition based maintenance maturity model of van de Kerkhof et al. (2019). The averaged results of the CBM maturity model by industry are shown in figure 2.8, the average maturity for the industry is 3.7. For three of these companies the CBM flow diagram was made, shown in figures 2.5, 2.7 and 2.6
For every company the process of getting to this maturity varied, but there were some similarities in the process. Each of these companies started small and experimental. At first they tried to gain insights in the data that was already available, then expanding to gathering more information and data. Every step in the process was perceived as a win and was used to convince board members of the importance of working with data. The interviewed companies are not fully developed in their CBM maturity. The processes are still not embedded within the company, and it can still be used more efficiently.
The worth of condition based maintenance was by three out of four companies rated at 4: proactive CBM, which is a high evaluation of worth, especially compared to the evaluation of the RNLN, which was averaged at 2: reactive CBM. The same situation is applicable for the condition monitoring technologies, data and decisions. The maturity of IT-infrastructure is more spread among the interviewed companies, it varies between 3 and 5, but this is still higher than the average maturity of 2 at the RNLN. The aspect with the most spread in maturity is the culture, which varies between 2 and 5. Culture is a very difficult aspect and is influenced by the corporate decisions and priorities as well as the willingness of employees.

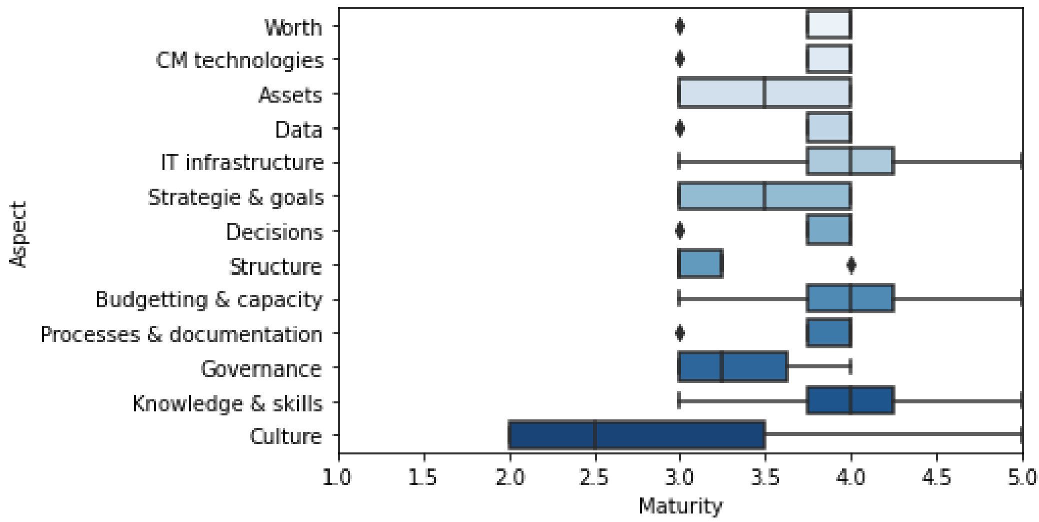

Figure 2.8: Average CBM maturity of the interviewed companies

2.2.2 Summary of challenges and solutions on PdM in industry

Most of the interviewed companies in this section have experience with the implementation of predictive or condition based maintenance, or are trying to implement predictive maintenance themselves. In this section the lessons learned about the challenges and solutions of implementing predictive maintenance are summarized. The challenges and solutions followed from the interviews with these four companies from industry. These challenges and solutions do not represent all challenges in the industry, however they give insights in the challenges and solutions which could be applicable for the RNLN. These challenges and solutions will be incorporated in the design criteria in section 2.4 to shape the design of the knowing maintenance organization at the RNLN.
Challenges:

1. The preventive maintenance strategy is dominant, the predicted failures are often not repaired because of capacity issues and the dominant strategy. If they are repaired the predicted failures are incorporated in the corrective maintenance process (based on interview with Project manager, Dutch Railways (07/2022)).
2. The data availability and quality are very important for the success of predictive maintenance (based on interview with (Manager fleet service, Alstom Transportation 09/2022)).
3. Old habits from engineers and departments can decrease the use of predictive maintenance (based on interview with (Manager fleet service, Alstom Transportation 09/2022)).
4. People on the work floor are often not motivated enough to register performed tasks (based on interview with Project manager, Dutch Railways (07/2022)).

Solutions:

1. By showing the importance and added value of predictive maintenance the interest and willingness of people will increase, this can be done by providing feedback to users and maintainers (based on interview with Project manager, Dutch Railways (07/2022)).

2. It is important to have support from higher management and maintenance engineers to implement predictive maintenance, start with a small group and expand from there (based on interview with Project manager, Dutch Railways (07/2022)).
3. Predictive maintenance should start small, providing insights in data, then monitoring critical assets, showing successes and wins during the process (based on interview with (Manager fleet service, Alstom Transportation 09/2022)).
4. Monthly meetings between users and developers can improve the predictive maintenance process (based on interview with (Technical lead, Equans Refrigeration 08/2022)).

2.3 Literature research

There are several ways to manage information in a company, and specifically for condition based monitoring. In this section four frameworks for information management and decision making will be discussed. Section 2.3.1 describes the steps in a CBM process. Section 2.3.2 describes the knowing organization framework of Choo (1999), which describes how organizational action can be taken. The second framework is described in section 2.3.3, which is the Information Management Practices (IMP) framework of Kettinger & Marchand (2011). Section 2.3.4 describes the OODA loop, which is often used in military environment and it stimulates fast decision making.

2.3.1 Steps in a CBM process

Condition based maintenance is a process where information is gathered by condition monitoring (Jardine et al. 2006). CBM attempts to avoid unnecessary maintenance tasks by taking maintenance actions when there is evidence of abnormal behaviour. According the Jardine et al. (2006) a CBM process consists out of three steps, which are shown in figure 2.9.

- **Data acquisition:** This is where data is obtained from the relevant health system.
- **Data processing:** Data is handled and analysed for a better understanding and interpretation of data. This step also includes data cleaning, because not all data is relevant.
- **Maintenance decision making:** To recommend efficient maintenance policies.

This CBM model is a very general representation of how condition based maintenance works. The data acquisition in this CBM model can be related to the sensing and collecting steps in the information management practices of Kettinger & Marchand (2011) (section 2.3.3), while the data processing can be related to the organizing and processing steps in Kettinger & Marchand (2011) and the conversion and processing steps in Choo (1999). Figure 2.10 shows a general overall

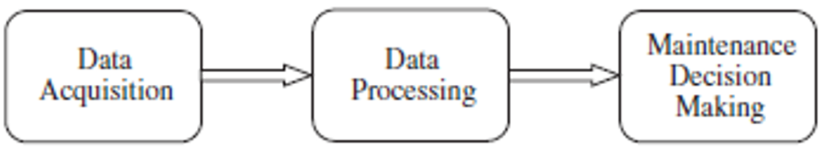

Figure 2.9: The three steps in CBM (Jardine et al. 2006)

condition based maintenance flow diagram based on Sobral & Guedes Soares (2016)Mohammed (2015). In this diagram the process starts with condition monitoring, the first step of which is data acquisition, which is similar to the CBM model of Jardine et al. (2006). Then processing and analysis, after these steps the health status of the system is determined. There will be no action in case there is normal behaviour, the condition monitoring will then continue. In the case of abnormal behaviour the analysis continues with fault diagnostics, then prognostics. All the previous steps from processing to prognostics correspond to the data processing step in Jardine et al. (2006). Then a decision on maintenance is made, just like the CBM steps in Jardine et al. (2006). After which the

CBM flow diagram, in figure 2.10, continues with correction and confirmation. At this point maintenance is performed and the asset has been repaired. Then the condition of the asset is monitored again by the condition monitoring cycle. It is important to consider this overall flow diagram of CBM when forming the design criteria in section 2.4.

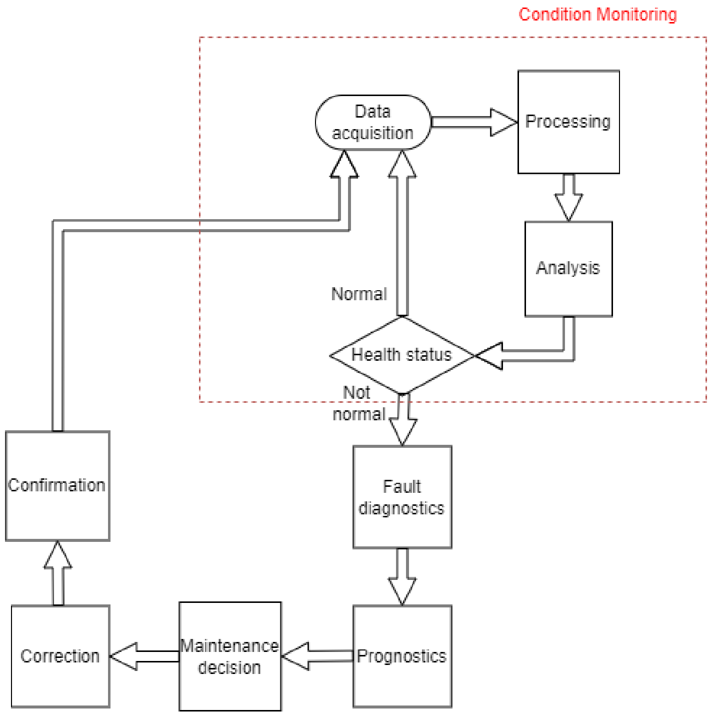

Figure 2.10: Condition based maintenance flow diagram (Sobral & Guedes Soares 2016)(Mohammed 2015)

2.3.2 The knowing organization

If we look at the model of the knowing organization by Choo (1999) shown in figure 2.11, we can identify that the RNLN is currently working on the technical aspects of the knowing organization. Which are the information processing, transformation and interpretation. However, there is currently limited focus on the sensemaking, knowledge creation and decision making aspects of the knowing organization model. In the organizational transition, to predictive maintenance, these three aspects should be taken into account. These three aspects are represented in figure 2.12. Sensemaking is the interpretation of information, people can choose what information is significant and relevant due to experience. Sensemaking is achieved by using beliefs, interpretations and enactments to process signals from the environment. Knowledge creating is the conversion of knowledge, which can be shared and created through training or apprenticeships. Under knowledge we understand cultural knowledge, explicit knowledge and tacit knowledge. Decision making is the key information activity, during this process information about available alternatives is weighted by the relative merits and demerits (Choo 1999). Decisions are often based on preferences, rules and routines and can be influenced by shared meanings and purpose as well as new capabilities and innovations. These three processes should be a dynamic social process where there is space for interruptions and iterations.

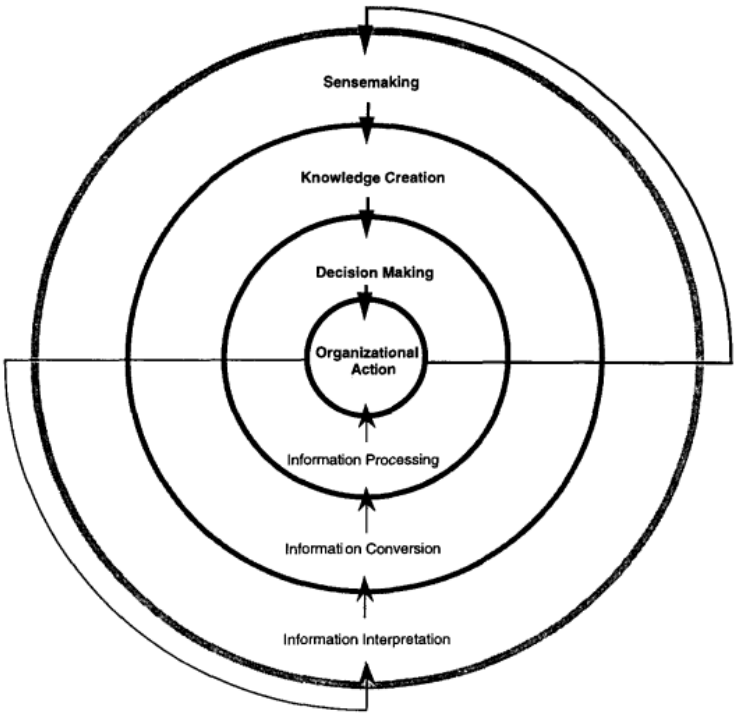

Figure 2.11: The knowing organization (Choo 1999)

2.3.3 Information Management Practices

To understand the information management practices of a company it is important to look at what is needed to understand information. The use of predictive or condition based maintenance is largely based on information management, and how this information will be processed. The IMP framework of Kettinger & Marchand (2011) gives practical insights in the five aspects of information management:

1. Sensing information
2. Collecting information
3. Organizing information
4. Processing information
5. Maintaining information

This framework helps giving insights in the entire process of information management. Sensing information involves how information is detected and identified, including economic social and political changes affecting the business including risks and anticipated problems in the market. Collecting information consists of the systematic process of gathering relevant information, this can be information needed, an overload of information or a select part of the information. Organizing information includes indexing and classifying information for appropriate availability, linking

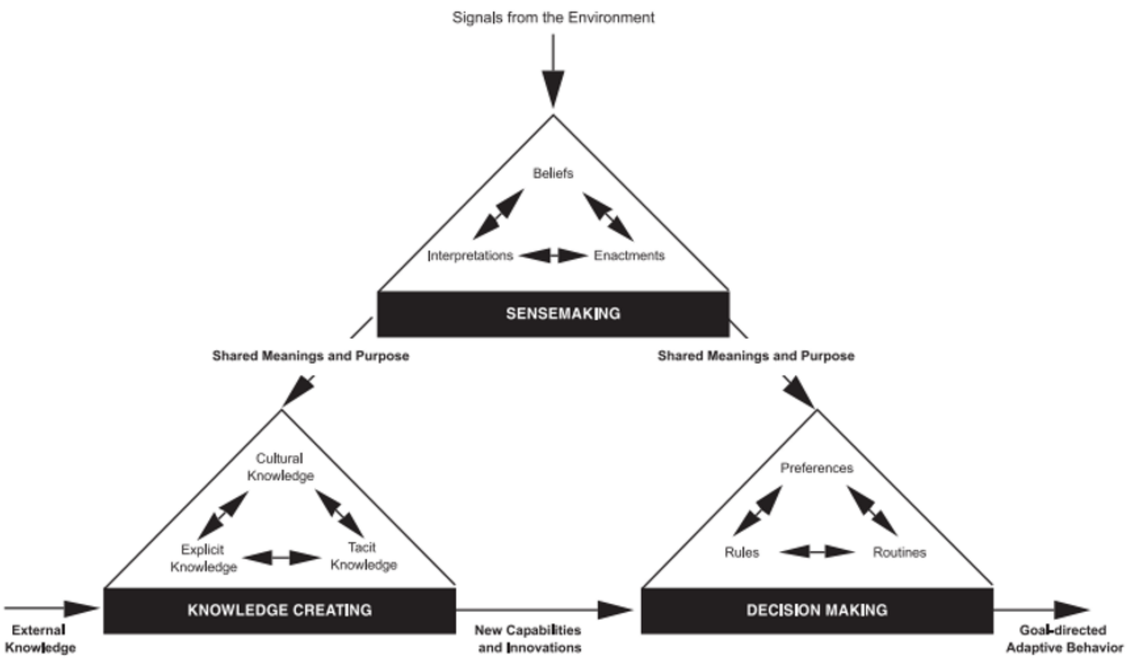

Figure 2.12: Adapted model of the knowing organization (Choo 2001)

databases, as well as training employees for accurately organizing information. Processing information is critical to decision making and involves converting information into useful knowledge by accessing appropriate information, analysing databases, hiring people with analytical skills, training and rewarding employees, as well as evaluating employees. The last aspect is maintaining information, which is a process that involves reusing existing information to avoid collecting the same information again, updating information databases so they remain current, and refreshing data to ensure that people are using the best information possible.

2.3.4 OODA

OODA is the abbreviation of Observe, Orient, Decide & Act. The method is invented by an US Air Force pilot, and is widely used in the Dutch Ministry of Defense to increase decision speed. The OODA loop is shown in figure 2.13.
Observe is the process of constantly monitoring a surrounding for early warning signs (van Brakel 2019), or in the case of PdM the constant measuring of data.
Orient: This is a process based on the observations, from which the possible scenario's are explored. Also, possible options are identified and alternative scenario's are explored (van Brakel 2019). For the implementation of PdM this means that the data is analysed, and context is given to the data. In this orientation step the possible abnormalities are detected.
The next step is a **Decision making** process. In this step a decision is made, in military context on an action, and in PdM context on a maintenance approach.
Act: This step is the execution of the decisions made. In PdM context this will be the execution of maintenance.

It is important to realize that the OODA-loop is not the same as the PDCA-cycle (Plan, Do, Check,

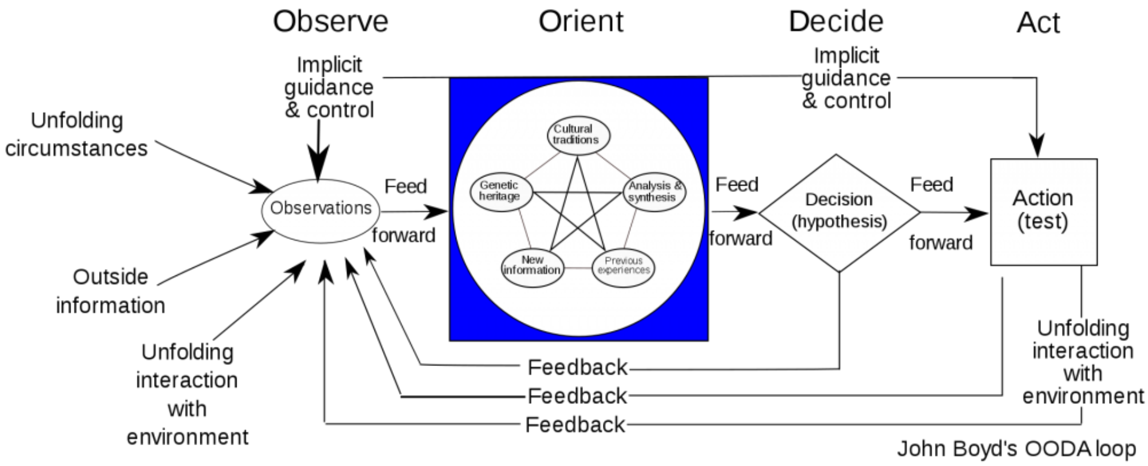

Figure 2.13: The OODA loop (van Brakel 2019)

Act). The PDCA cycle assumes that there is time and space to go through the cycle, and there is a risk that there is no actual decision made in the plan-phase. Even though PDCA is not very stiff, it is designed to tackle problems in management. The OODA loop has a vision on the end result, and can be used in different situations, the OODA loop is also flexible and can be used by anyone. The biggest difference between the two cycles are that PDCA assumes planning and predictability, while OODA assumes that the surroundings can change at any time (Peter 2020).

2.4 Design criteria for a knowing maintenance organization

For any design it is important to have design criteria, they are used to guide the designing process and shape the end product. The design criteria can cover various aspects of the end-product, such as technical, social and organizational criteria. These criteria are formed by the defined objectives of the solution: The current maintenance situation at the RNLN, lessons learned from industry and literature. Table 2.2 gives an overview of the origin of the design criteria. The design criteria can be based on defined challenges at the RNLN or in industry as well as solutions to certain problems in the industry, the criteria can also be based on claims from interviews.

Design criteria for a knowledge improvement process for predictive maintenance at the RNLN:

1. During operations ships should be able to make adequate and independent decisions on maintenance.
2. The design of the future CBM structure should comply with the Sail plan and defence vision (KVMO 2018)(Ministerie van Defensie 2020) on the following aspects:
   (a) Autonomous operating
   (b) Optimization of availability
   (c) Unburden crew
   (d) Directing activities from Den Helder
   (e) The design should be relevant during the entire lifetime of the asset
3. Predictive maintenance should be integrated and practically achievable in the current working methods of the RNLN.
4. The ship should always be informed on critical abnormalities, since they have the end-responsibility of its functionality.
5. Automatic measurements should be processed by an automatic algorithm. These algorithms should be able to learn constantly from new observations and decisions.
6. Engineers should be able to execute assessments on assets and make maintenance plans by using up-to-date health condition of the system and maintenance information.
7. The knowing maintenance organization process should facilitate maintenance engineers to focus their workload on more proactive maintenance tasks instead of reactive tasks.
8. The knowledge improvement process should facilitate a decrease in time between data acquisition and maintenance decision making.
9. The knowing maintenance organization process should be able to process information registration and feedback to create knowledge in the maintenance organization. This knowledge should be constantly improved and managed.

Design criteria	Based on
1	• Described by (Head engineering, RNLN 11/2022)(Head technical services, RNLN 11/2022)
2	• Described in the Defence vision (Ministerie van Defensie 2020), Sail plan (KVMO 2018) and the goals of DfM (Data for Maintenance 2022)
3	• Challenge 8 RNLN • Interview with a Senior maintenance engineer, RNLN (06/2022*b*)
4	• Challenge 11 RNLN • Described by (Head technical services, RNLN 11/2022)(Weapon system manager, RNLN 11/2022)
5	• Interviews conducted with Senior maintenance engineer, RNLN (08/2022*a*) and Senior maintenance engineer, RNLN (06/2022*b*) • Described by (Maritime support, RNLN 11/2022)
6	• Interviews with Senior maintenance engineer, RNLN (09/2022*c*) and Senior support manager, RNLN (08/2022) • Challenge 1, 2, 9 RNLN • Challenge industry 3
7	• Described in input session 3 (Maritime support, RNLN 11/2022) • Described by (Senior maintenance engineer, RNLN 11/2022*d*) • Challenge 10 RNLN
8	• Challenge industry 1 • Observed from literature sections 2.3.4 and 2.3.1 • Interview with Senior support manager, RNLN (08/2022) • described by Head engineering, RNLN (11/2022)
9	• Described by Engineer, RNLN (11/2022) and Senior maintenance engineer, RNLN (11/2022*d*) • Challenge 4 industry • Challenge 2, 3, 4, 6, 7 RNLN • Solution 1 industry • Observed from literature sections 2.3.2 and 2.3.3

Table 2.2: Source of the design criteria

These design criteria are based on the challenges formed in this chapter and the literature research, and input from interviews. Table 2.2 shows the source of each design criteria. Design criteria 1 is based on comments of stakeholders in the PdM process, which will be incorporated in the PdM process. Design criteria 2 is based on the goals and visions described by the RNLN. Design criteria 3 is based on challenge 8 of the RNLN, such that the designed PdM process will fit better within the organisation. This will be demonstrated by a use case of the design. Design criteria 4 is based on challenge 11 of the RNLN, which will ensure that the ship is always up-to-date and end-responsible for its operational functionality. The challenge should be solved by incorporating engineers in the decision making process to discard maintenance advice on condition information. Design criteria 6 is based on challenges 1,2 and 9 of the RNLN and challenge 3 of the industry. This criteria will stimulate engineers to work with PdM, plan maintenance accordingly and be kept up-to-date. When engineers have to work with this information the willingness of using the information will increase, because they need to. Design criteria 7 refers to challenge 10 of the RNLN. With automatic measurements the workload decreases on taking measurements, also when the PdM system works the maintenance engineers will have more insight in the system and more time to focus on other work. Design criteria 8 is related to the time-related decision making of the OODA-loop, and the CBM process of Jardine et al. (2006). Design criteria 8 is based on challenges 2,3,4,6 and 7 at the RNLN, as well as challenges 4 in industry. The PdM process could increase knowledge and information transfer in the maintenance organization of the RNLN, this should cause information to not be lost and stimulate employees to be engaged. Solution 1 in industry can be related to this design criteria, it is concluded that feedback will help to increase willingness and involvement. This design criteria is also related to the knowing organization structure and information management.

2.5 Chapter summary

This chapter contained three main elements, current maintenance processes, lessons learned from industry and literature review, which will give input on the design of a knowing PdM process.
The current maintenance process at the RNLN is described by making use of lean flow diagrams, these give insights in the real maintenance situation. The maintenance process flow diagrams of the RNLN show the actual maintenance situation at the RNLN. A lean flow diagram is made for the current preventive maintenance, corrective maintenance and condition based maintenance processes. Then the CBM maturity of the Royal Netherlands Navy is defined by getting 23 inputs in the 13 aspects of CBM maturity. Resulting in an average CBM maturity of 2.4. By making the current maintenance processes insightful with lean process diagrams and a maturity assessment, the first sub-research question is answered. In section 2.1.4 the challenges of the current maintenance processes are listed, which are used as an input for the design criteria.
To gain insights in lessons learned from industry, on the aspects of PdM, four companies were interviewed. For these companies the condition based maintenance is made insightful by lean flow diagrams. Also, these companies filled in the CBM maturity model, to get an average maturity of 3.7. From the lessons learned from industry the knowledge on predictive maintenance can be improved. The lessons learned from industry can be a starting point for a knowledge improvement process.
Literature describes several types of information management frameworks, which can be used to structure the knowledge and information processing in a company. These information management and decision making frameworks will be used to design the knowledge improvement process for predictive maintenance. By combining the information from literature with the lessons learned from industry the second research question can be answered. The lessons learned from industry give an insight in the implementation of predictive maintenance, and how knowledge can be created in such a process. The literature in section 2.3 added to this with research on information and decision making frameworks which can be used in a design for a knowledge improvement process for predictive maintenance.
All the gathered information in sections 2.1, 2.2 and 2.3 formed the basis for the design criteria in section 2.4. The design criteria were formed using the challenges and solutions from the RNLN and industry, information from literature, and input from stakeholders in the PdM process. These design criteria will be used to design a knowing predictive maintenance organization by defining a knowledge improvement process based on the predictive maintenance process for the maintenance organization of the RNLN.

Chapter 3

Design and development of a knowledge improvement process for PdM

This chapter shows the design and development of a knowledge improvement process for the predictive maintenance organization at the Royal Netherlands Navy. The knowledge improvement process is facilitated by a predictive maintenance process for the maintenance department of the RNLN. This chapter is based on the third step in the DSRM of Peffers et al. (2007), where the design is developed based on the design objectives in chapter 2. In section 3.1 a predictive maintenance process for the Royal Netherlands Navy is developed, answering sub-research question 3: **How should the future predictive maintenance process within the RNLN be structured?** Section 3.2 shows the design and development of a knowing predictive maintenance organization by a Knowledge Improvement Process. The knowledge improvement process will be applied to the designed predictive maintenance process. By the creation of a Knowledge Improvement Process, research question 4 will be answered: **How can knowledge be created to improve decision making within the predictive maintenance process?**

3.1 A PdM process for the Royal Netherlands Navy

A knowledge improvement process for predictive maintenance will be designed in this thesis, to facilitate this a predictive maintenance process is designed in this section. The predictive maintenance process is designed by using the design criteria in section 2.4.

The CBM maturity of the RNLN can be compared to the CBM maturity of the interviewed companies in the industry, which is done in figure 3.1. The CBM maturity result of the industry does not represent all companies in the industry, it is an average of the four interviewed companies in this thesis. The CBM maturity scores in figure 3.1 are averaged and rounded. From this figure we can conclude that the RNLN can improve their CBM maturity by learning from the interviewed companies. In some aspects a maturity increase of 2 points can be achieved, for other aspects the maturity can be increased by 1 point.

Se can observe the condition monitoring technologies used at the RNLN, according to the maturity

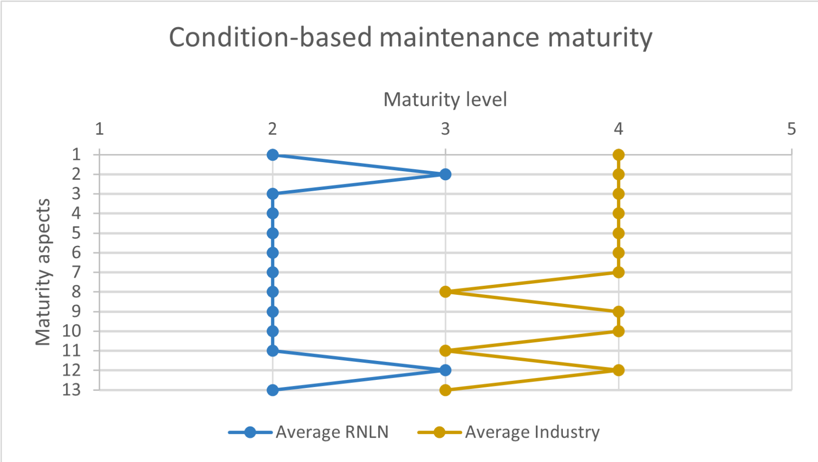

Figure 3.1: Averaged and rounded CBM maturity of the RNLN and industry

model, CBM perceived as a proven technology but is not yet structurally used. To upgrade the CBM technology the RNLN should structurally apply condition monitoring techniques on assets and explore it's possibilities, which will be done during the implementation of the Combat Support Ship (CSS). Another topic in the CBM maturity is the decision making, which currently has a maturity of 2. Currently, condition monitoring is used by the ship to make decisions on maintenance, also a few maintenance engineers use the condition information for maintenance plans. The decision making would benefit from periodic information on the condition of assets, improving the maturity to 3. The current work process for condition based maintenance is rated an average of 2 for maturity, described by limited documentation and communication of the analysis and no defined process for inspections or condition based maintenance. This can improve by using a predictive maintenance process, and embedding this in the organizational structure. Another topic on the maturity model is the culture in a company, which is currently rated by 2. The current maturity, according to van de Kerkhof (2020), is focused on corrective maintenance, where people are busy with unexpected and urgent problems. Also, according to van de Kerkhof (2020), the organization exists out of a lot of un-connected teams, in the RNLN these groups are maintenance groups and technical groups. This can be improved by process- and planning -oriented working (van de Kerkhof 2020).

The development of the predictive maintenance process started by assessing the current maintenance process (section 2.1) and the predictive maintenance processes from the interviewed companies (section 2.2). From the predictive maintenance processes in the industry we concluded that a trigger for maintenance should be created, after which a maintenance process of corrective nature can start. From industry it also became clear that the corrective maintenance process should be controlled and registration of information is a key component. To make this predictive maintenance process applicable for the navy the decision making should be split up between the ship and engineering, since the ship always has the end-responsibility. Predictive maintenance for the RNLN could be categorized in long and short term impact, and prioritized on urgency to determine which notification will be assessed by ship or engineering. The allocation process will ensure that the notifications will be send to a correct "owner". During the allocation the ship should always be informed on the abnormalities of the system, but does not always have to be the owner of the notification. If an abnormality has impact on the long term the notification owner can be an maintenance engineer of a specific installation. The maintenance engineer can then plan the predictive maintenance. Another requirement for the predictive maintenance process is that engineers and the ship should be able to communicate on the abnormalities. Often, for the ship, this communication happens through the operational engineering department. However, maintenance engineers and the ship can still communicate on the appropriate maintenance strategy for an installation. For every maintenance action a work order should be made, it does not matter if this action is predictive, preventive or corrective. So, if the ship or an engineer decides that maintenance should be executed a work order should be made. An important aspect of the predictive maintenance process should be the reporting of executed maintenance tasks, abnormalities and feedback. By collecting information the accuracy of the predictive maintenance analysis could increase. The initial design is reviewed with engineers and stakeholders in the predictive maintenance process, after which the design in figure 3.2 was created. This process flow diagram is made using lean flow diagram principles. In this diagram the blue squares represent an action in SAP, the dotted lines represent an overarching process (algorithm improvement process & maintenance planning process). Below the maintenance flow process is explained, every bolt phrase/word stands for an action in figure 3.2.

- **Measure:** Measurements on assets will be performed, either automatically with sensors or manually. Not all measurements are automatic because the transition from manual periodic measurements to automatic measurements will take time to introduce, and it is not always achievable.
- **Notify:** As a result of the measurements a notification is created in SAP, this notification should be assigned to the correct person in the next step.
- **Allocation:** The notification is allocated to an owner, the owner will receive the notification in SAP. For every notification the ship should be informed about the abnormality, they do not always have to be the owner of the corresponding notification (For example an abnormality with impact on the long term, then engineering is owner but the ship is informed).
- **Assessment by ship:** Every notification needs to be processed, in this step there are two possible outcomes: Maintenance will be performed; or the notification will be deferred to (operational) engineering. It is possible that a the source of a notification can not be repaired aboard of a ship due to capacity or insufficient resources, in this case installation or maintenance engineers will be contacted. It is also possible that the notification will be passed on to operational engineering to remotely assist in maintenance. Notifications of which the ship thinks are irrelevant will be deferred to engineering for a second check before discarding it. During this assessment step there could be several actions to find the cause or source of a notification, for example extra measurements or looking back in historical data.
- **Assessment by engineering:** Engineering is a large department at the maintenance organization of the RNLN. In this flow diagram engineering can be 2 groups: Operational engineering and maintenance engineers. Operational engineering has almost all contact with the ships, when necessary they will help installation/maintenance engineers for assistance.

The installation/maintenance engineers are responsible for the functionality of their assets. Engineers have three possible routes of action:

1. Advance the notification to the ship to execute maintenance on the short-term.
2. **Plan extra maintenance on short term:** Extra maintenance can be planned on short term, this falls outside the scheduled/planned maintenance moments. This can happen when the ship is not capable of performing the maintenance but the priority is high, an external company or the maintenance organization (DMI) can resolve the problem.
3. **Adopt in scheduled/planned maintenance** When a breakdown is predicted on the long term it can be involved in the scheduled/planned maintenance. It is also possible to leave out maintenance tasks in this maintenance period because of condition information. By adding or removing maintenance tasks from the upcoming planned maintenance period it does not main that the standard maintenance plan is adjusted, this happens in the ”maintenance planning process”

During this assessment step there could be several actions to find the cause or source of a notification, for example extra measurements or looking back in historical data.

- **Make work order:** When maintenance needs to be performed, this should also be registered in SAP by a work order.
- **Conduct maintenance:** A maintenance task is performed, it does not matter where this is or who it does (as long as it is documented and descried in the work order). Maintenance can take place aboard, in the workshop by mechanics of the DMI, mechanics aboard, or external mechanics.
- **Check:** The functionality of an installation should be checked before it can be used again, this can be a check with data or a manual. If the functionality is not correct after the check some small adjustments can be done, but if this is still not sufficient the process flow goes to the next step (report).
- **Report:** This is an important step in the process flow, it can gives insight in the capacity and accuracy of the algorithm but also gives engineers valuable insights in the performed tasks. Currently it is also mandatory to enter why an order is closed, the reality is that a lot of orders are closed with ”executed, no remarks” but the tasks are not performed or not completely performed. There is currently no check on the validity of work orders due to capacity shortages. This step is not new to the maintenance process but it should gain more priority, also the description of the report should be more elaborate. If the functionality after a repair is still not sufficient the notification will be re-assigned in allocation to find a new solution to the problem.
- **Close:** The work order is closed
- **Algorithm improvement process:** The algorithm processes data from measurements and prioritizes them, in this process it is possible to create false-positives or false-negatives. To improve the algorithm over time it is important that the predicted information (notify) is compared to the performed maintenance (report).

- **Maintenance planning process:** This is the overarching control process on maintenance. Currently the basis for maintenance is an outdated standard maintenance plan and the experience of engineers. It is important that this process becomes standard, therefor for every asset there should be a small standard maintenance list and a big optional maintenance list. The standard maintenance list will be complemented with tasks from the optional list based on the condition of the asset. The standard maintenance list can be kept up to date with condition information and frequency of repairs.

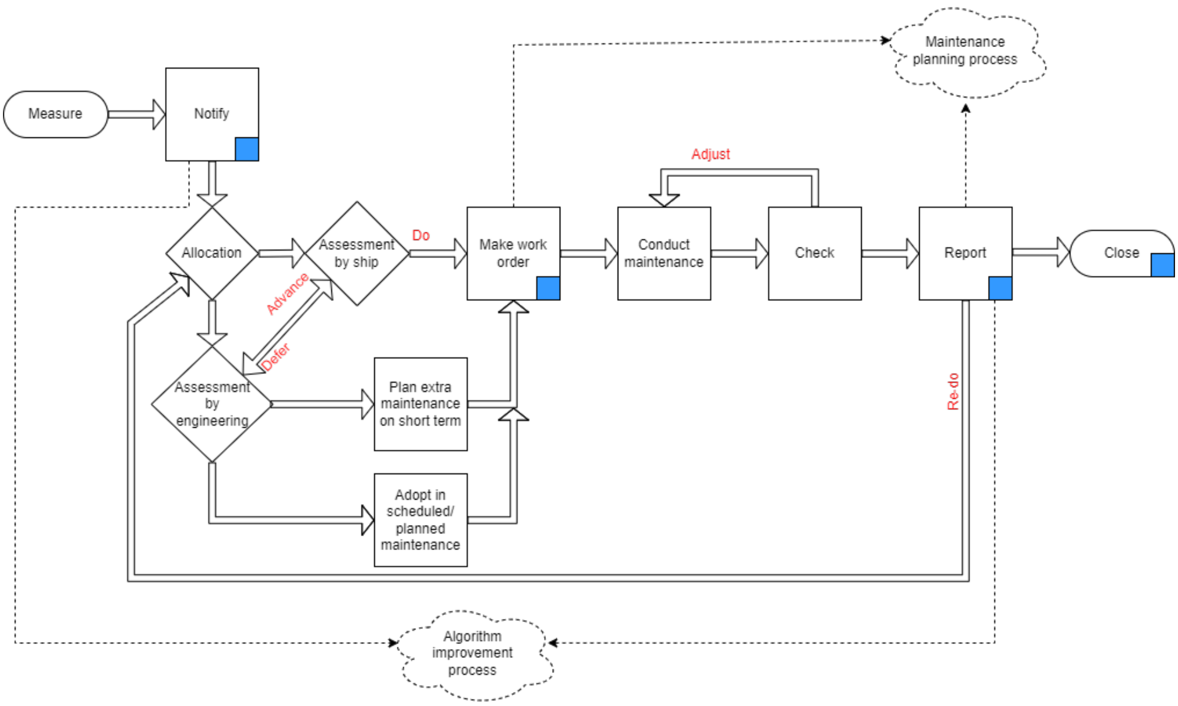

Figure 3.2: Designed PdM maintenance situation for the RNLN

3.1.1 Review on the PdM process for the RNLN

The design of the PdM process is reviewed and validated in the first input session with stakeholders from the PdM process, the participants of the input session are shown in figure 1.1 in section 1.5.3. The participants represent the whole spectrum of stakeholders in the PdM process. The applicability and validity of the designed predictive maintenance process was discussed. During the input session the task of operational engineering was discussed, who are often in contact with the ship and not the maintenance engineers. Operational engineering is included in the assessment by engineering, because they essentially have the same function. An opinion on the design is that the current standard maintenance plan should be reduced to a minimum, which should be added by maintenance tasks based on the health, condition and measurements of the asset (Weapon system manager, RNLN 11/2022). The applicability of the designed predictive maintenance situation was discussed by using cases: (1) propeller shaft functionality, (2) Excessive vibration on a radar, (3) pressure difference on a cooling system.

Case 1: Propeller shaft functionality
The functionality of a propeller shaft is usually assessed every week, which is a task in the SAP system, and the propulsion group is responsible for it's functionality(Weapon system manager, RNLN 11/2022). With predictive maintenance you could measure the functionality of the propeller, and any abnormalities or vibrations. A notification for predictive maintenance could be created when an abnormality is detected. The head of the propulsion group is then responsible for the execution of the maintenance. He should not be able to close a work order without action according the the participants of the input session (Engineer, RNLN 11/2022), because all notifications need to be taken seriously. The crew aboard of the ship can defer the notification to the engineering department. In the current design it is not possible for an engineer to discard a notification, for example when it is faulty. A design iteration should be that engineers can discard notifications and not perform maintenance, which is included in the design iteration in figure 3.3. Also, when the notification is discarded the algorithm improvement process can improve the analysis of the data to reduce false-positives.

Case 2: Excessive vibration on a radar
In the predictive maintenance diagram the vibrations on the radar can be measured and analysed. "In the designed PdM process there is no analysis action, which is something different from measurement, so that should be added to the design" (Manager, RNLN 11/2022*a*). The created notification from the analysis will go to the installation manager, he will decide what to do and if it is urgent or not urgent (Head engineering, RNLN 11/2022). He can then also decide whether the radar should be shut down or not (Weapon system manager, RNLN 11/2022). "In the current process we don't know what is happening to a lot of systems, we are just doing something" (Manager CPA, RNLN 11/2022). When the notification is urgent the engineer can advance the notification to the ship and plan maintenance accordingly.

Case 3: Pressure difference on a cooling system
There should be a pressure measurement on the cooling system, when an abnormality is detected it should be notified to the ship and engineering. The ship should be the first to take action if the pressure difference is really high, and can also turn it off when necessary. When it is not of great urgency the engineers are the owner of the notification and the maintenance will be scheduled in the next maintenance period.

After discussing the cases all the participants of the input session agreed that, with the two improvements, the design would be valid and applicable for the RNLN. The improved design is shown in figure 3.3, the improvements are the addition of an analyze step after the measurements and the possibility for engineers to discard a notification and take no action. These were added because "measure" did not cover the analysis of the data, and in the first design it was not possible to discard an incorrect or insignificant or incorrect notification. The validated and reviewed design is an answer to research question 3, where a predictive maintenance process is designed for the RNLN.

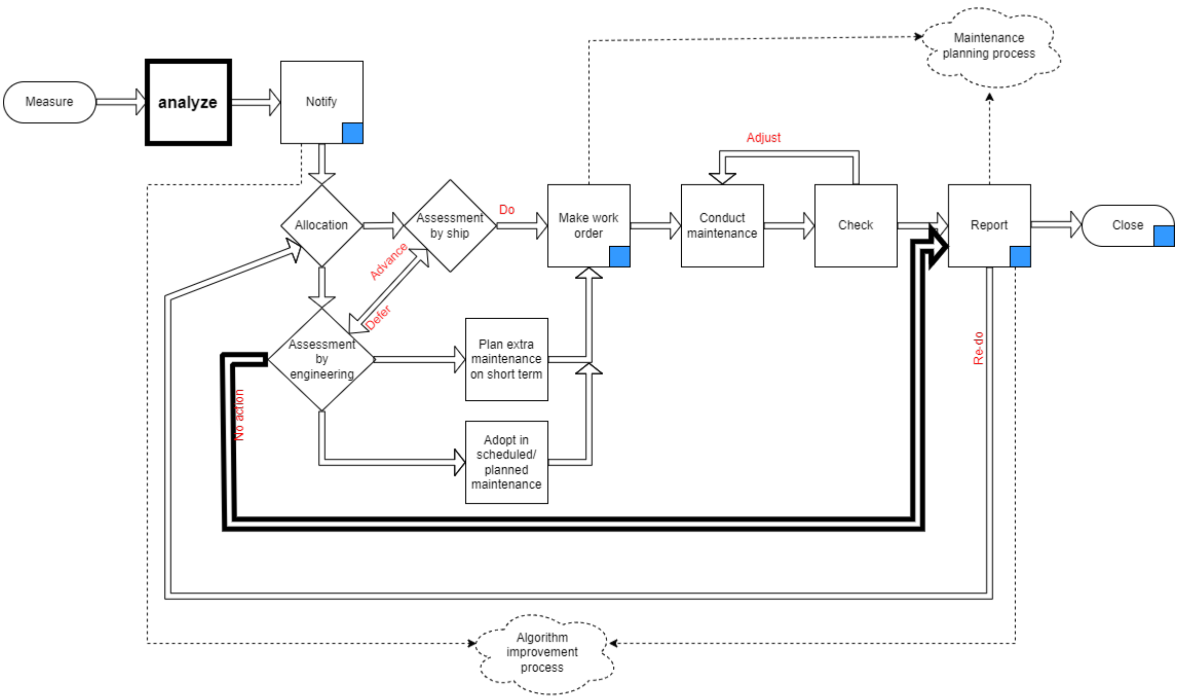

Figure 3.3: Designed PdM structure for the RNLN after a review iteration

3.2 Building a knowing maintenance organization

In this section a Predictive Maintenance Knowledge Improvement Process (PdM KIP) is designed, with which a knowing predictive maintenance organization is proposed for the RNLN. A knowing organization is investigated by including the information management and decision making frameworks (section 2.3) in the designed predictive maintenance process, and discovering where and how knowledge can be improved in the predictive maintenance process. The information management and decision making frameworks are analysed on the designed predictive maintenance organization in section 3.2.1. In section 3.2.2 the knowledge improvement process for predictive maintenance is designed for the maintenance organization of the RNLN.

3.2.1 Knowledge creation at the RNLN

To create a knowing organization we project information improvement frameworks and decision making frameworks on the designed PdM structure. Figure 3.4 shows the projection of the four frameworks described in section 2.3. The framework of Jardine et al. (2006) is shown by green squares, the knowing organization of Choo (1999) are purple triangles, the aspects of the OODA-loop are orange diamonds, and the information management practices of (Kettinger & Marchand 2011) are blue circles. Most frameworks are concentrated on the left side of the diagram, this is where data is processed and decisions are made. However, all aspects in the diagram are covered. This shows that the researched literature is applicable on the designed PdM structure and covers all aspects of the PdM process. To give a structured overview on the overlap and applicability of the frameworks figure 3.5 is made. Next to this we can see that all the aspects of the PdM process are covered by the four frameworks. However, the execution and registration of the maintenance (bottom half of figure 3.5) are less represented than the information processing and decision making.

Figure 3.5 shows that the knowing organization framework of (Choo 1999) can be applied three times in the predictive maintenance process. In each loop in figure 3.6 the knowing organization steps (sense making, knowledge creation, decision making) are executed. In the measurement and analysis the sensemaking happens on the data, which is interpreted into knowledge creation. The decision made is whether a notification needs to be created, or if the condition of the asset is still correct. The second loops shows the sensemaking of engineers aboard and ashore, who need to assess the notification and then, with their knowledge, need to make a decision on the maintenance of the asset. The last knowing organization loop in figure 3.6 is executed during and after maintenance. Sensemaking is done during the execution of maintenance, when the checks are performed the mechanic will create knowledge on the condition and functionality of the asset. A decision needs to be made on the functionality of the asset (In the report stage), is it good then the work order can be closed, is it not good another maintenance task should be done. The knowing organization loops can also be plotted on the maintenance planning process and the algorithm improvement process, which are stand-alone processes.
Figure 3.7 shows the DIKW pyramid, which describes the difference between data, information, knowledge and wisdom. In the PdM structure we identify data with ”measure”, which is signals without a meaning, combining this with the meaning of this data it becomes information. In the

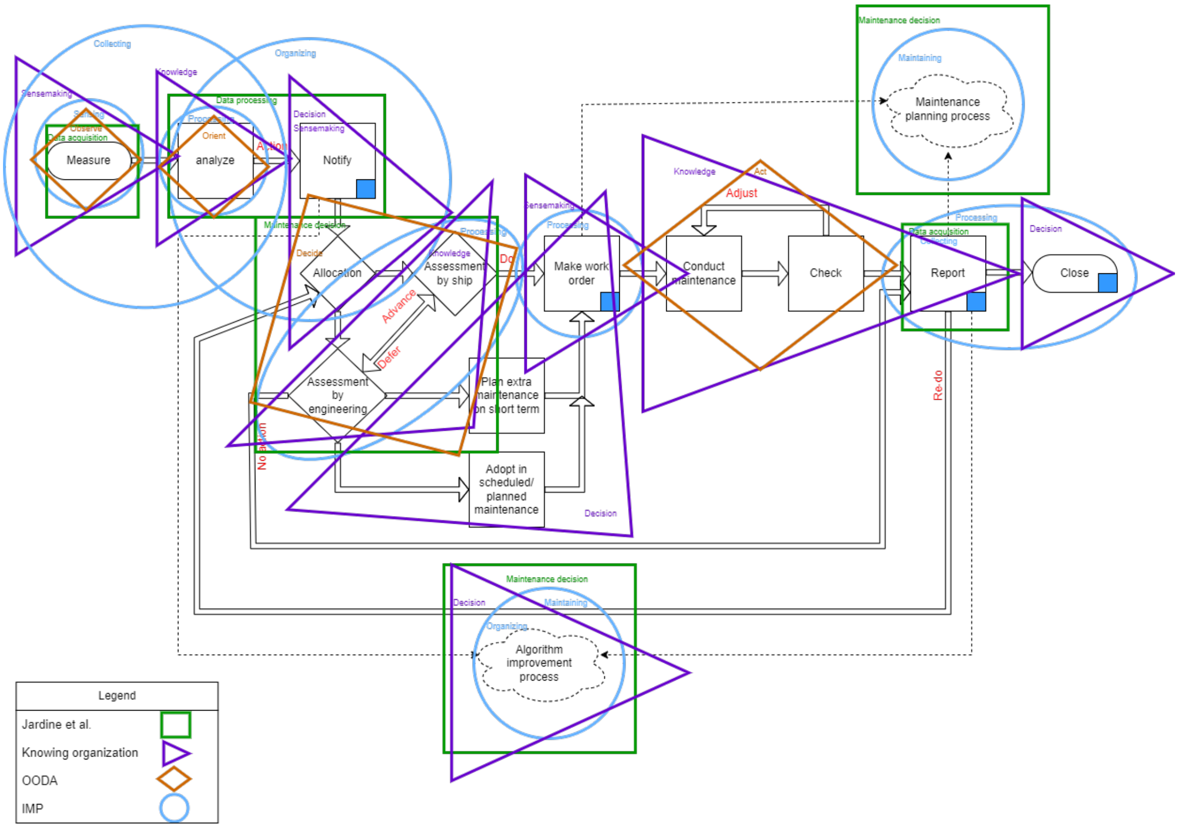

Figure 3.4: Visualization of the applicability of the information management and decision making frameworks on the proposed PdM process

block analyze, this information becomes knowledge by giving the information a meaning. Knowledge in the PdM structure is generated by notification, the assessment by ship and engineering, reporting and in the algorithm improvement process. In all these areas of the predictive maintenance process the knowledge can be improved, in some more than others. For example, the knowledge creation at the data-processing and the knowledge creation with assessment by engineering and ship are often well organized. However, when the maintenance is executed knowledge is created but often not transferred. An example for knowledge loss is when a ship has trouble with an installation they can ask assistance from maintenance engineers, who will propose a maintenance strategy. After the maintenance is executed the maintenance engineer is not informed on the effectiveness of the maintenance strategy or the functionality of the installation (Head engineering, RNLN 11/2022)(Head technical services, RNLN 11/2022). To improve this process and to create a knowing maintenance organization for the RNLN a knowledge improvement process is designed.

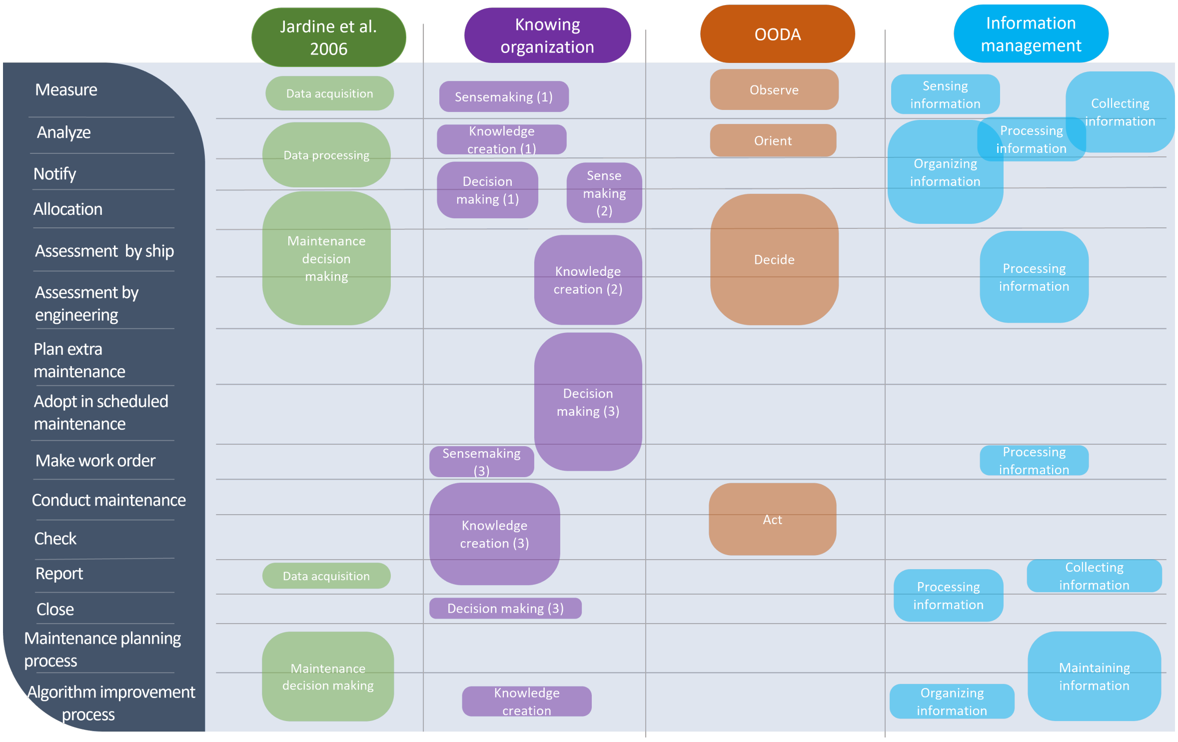

Figure 3.5: The applicability of frameworks on every step in the proposed PdM structure

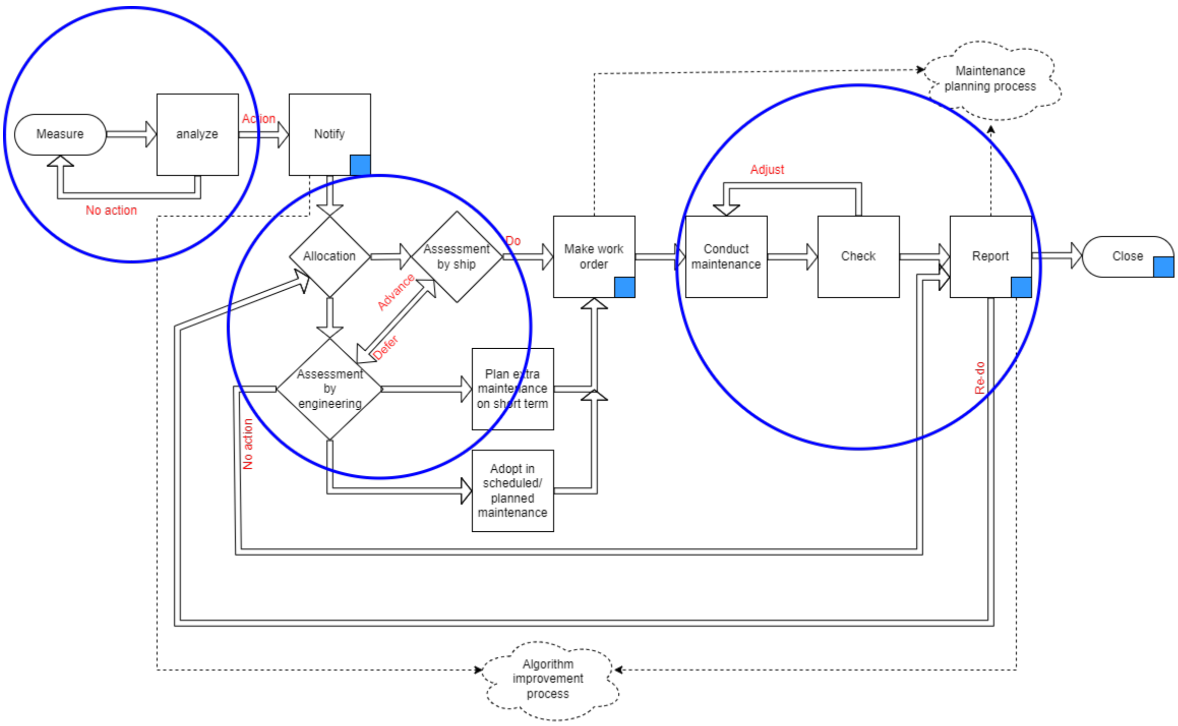

Figure 3.6: The applicability of the knowing organization by Choo (1999) on the proposed PdM structure

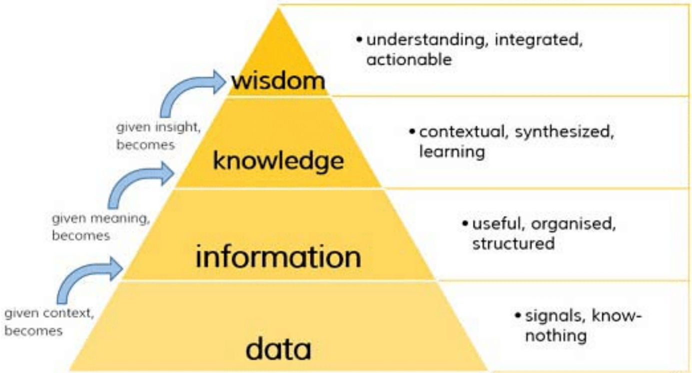

Figure 3.7: DIKW pyramid (Soloviev 2016)

3.2.2 The Predictive Maintenance Knowledge Improvement Process

When meaning is given to information it can become knowledge (Baldassarre 2016), which can help to improve the maintenance and functionality of installations. In the maintenance organization of the RNLN, knowledge is scarcely created or it's lost during transferring and processing (Maritime support, RNLN 11/2022). People at the maintenance organization of the RNLN blame each other for the incorrect or incomplete registration in the SAP system, however according to Maritime support, RNLN (11/2022) this is not the main issue. The main issue is the shortage of people at the RNLN who should process the information into knowledge, as well as control the information registration process. The resource capacity issues causes less information analysis and less control and feedback on the information registration. By including a predictive maintenance knowledge improvement process in the work processes of the RNLN the knowledge within the maintenance organization can increase.

The PdM KIP is developed to improve knowledge creation within the predictive maintenance process. At the RNLN knowledge is lost in the maintenance process, especially with execution and reporting of the tasks (Senior maintenance engineer, RNLN 11/2022*d*). The PdM KIP focuses on the inclusion of knowledge improvement in the maintenance process. The PdM KIP is designed based to the CBM framework of Jardine et al. (2006), where the tree steps are: data acquisition, data processing, and maintenance decision making. After decision making the maintenance is executed, after which the knowledge improvement process will begin. The PdM KIP is designed as a four step step process, and is shown in figure 3.8. The output of the PdM KIP will be inserted back into the data processing step of the predictive mainenance process. This predictive maintenance knowledge improvement process has similarities with Maintenance Feedback Analysis (MFA) (Braaksma 2012). The MFA is a maintenance feedback process as an extension to RCM/FMECA. The MFA process is executed to improve the RCM/FMECA, so the frequency is based on months or years. The knowledge improvement process focuses on predictive maintenance and is executed constantly, every few seconds for the check on data, and also in a high frequency for manual input in SAP. The PdM KIP is therefor a unique process which is applicable to the predictive maintenance process, which is different than the MFA process.

The PdM KIP is created because there is a need for knowledge creation within the RNLN and industry, which is concluded from all the interviews (Asset manager, Port of Rotterdam 09/2022) (Senior maintenance engineer, RNLN 09/2022*c*) (Senior support manager, RNLN 08/2022). Which also comes forward from the challenges described in sections 2.1.4 and 2.2.2. The PdM KIP can improve the challenges 1,2,3,4,6,7 and 9 of the RNLN, and challenges 2,3,4 of the industry. These challenges focus on the lack of information, information loss, registration of information and feedback in the maintenance process. The PdM KIP aims to improve this process. The four steps of the PdM KIP are constantly looping on data and information. For data we assume the functionality of installations and equipment before and after maintenance is executed. Knowledge can be improved with this data by looking at the before and after functionality and determining if the maintenance approach was correct and if the maintenance had effect on the functionality of the system. Information is also processed in the knowledge improvement process, under information we understand the input and feedback of maintainers and engineers in the SAP system. An example, when a mechanic executed maintenance on an installation and he has a comment or possible improvement, this can be registered in the SAP system (Senior maintenance engineer, RNLN 08/2022*a*). In the PdM KIP the information input of the mechanic is analysed on accuracy and applicability. When a responsible maintenance engineer decides that the input is accurate he can give feedback to the mechanic on his input. This will engage mechanics and reduce the gap between engineers and mechanics, which is also confirmed by Maritime support, RNLN (11/2022).

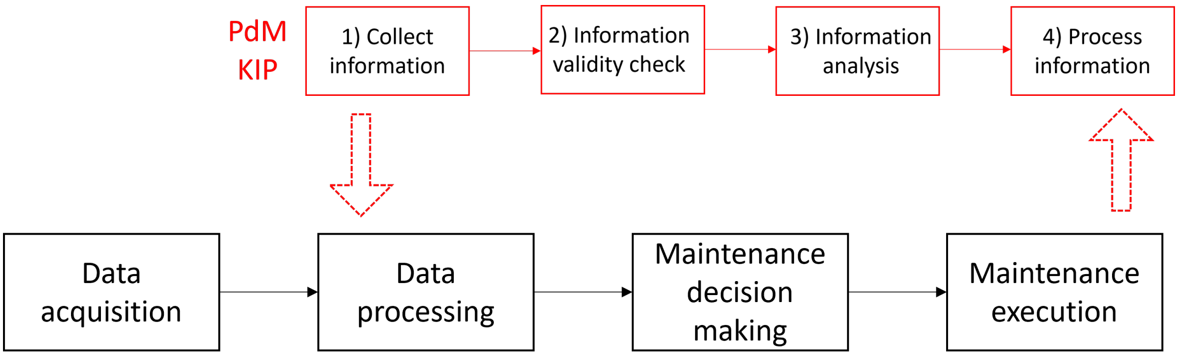

Figure 3.8: Predictive Maintenance Knowledge Improvement Process (PdM KIP) as an overarching process for predictive maintenance

The four steps in the PdM KIP are: (1) Collect information, (2) information validity check, (3) information analysis, (4) process information. These steps are described below.

1: Collect information

The collection of information is the first step in the PdM KIP. For the RNLN the collection of information will happen in SAP and in the algorithm improvement process. The information that is collected is data and information on maintenance and functionality of installations. Information can be input on the performed maintenance or predictions as well as the executed maintenance tasks. The data is the performance before and after maintenance. To do this, it is very important that maintainers report their findings when closing an SAP order. In the SAP system it is possible to register information, which is coupled to a user (Maritime support, RNLN 11/2022). The algorithm improvement process will look into the data before and after maintenance, the information in SAP can be coupled to the data in the information improvement process. The data and information gathered can cause knowledge creation in this process.

2: Information validity check

The validity check is on the information and data retrieved in the first step. The check will make sure that the information and data is accurate and valid. An example of a validity check is an abnormal observation in a data measurement after a maintenance activity. The validity check could be to make sure that the incoming data is correct. The data could contain an offset or there could be a calibration error (Manager CPA, RNLN 11/2022). Another option is that the sensor is not correctly attached on the installation after maintenance, this could lead to absent or incorrect data on the installation. The validity check on information input in SAP could exist of corresponding the information with the data of an installation. For example, a mechanic could indicate that an installation is not running consistently, then a maintenance engineer can check in the data system if the installation is showing any abnormality (Senior maintenance engineer, RNLN 11/2022*d*).

3: Information analysis

The third step in the PdM KIP is the analysis of the information. This is done by processing the feedback and analysing data. Information can be analysed by checking the number of input requests on a certain topic and it's history. The analysis can show if a part fails consistently, or an installation is not functioning properly and it is a reoccurring event. The maintenance engineer could then take action on implementing an improvement for the installation (Senior maintenance engineer, RNLN 11/2022*d*). An analysis on data could be to analyse trends in the behaviour of an installation. For example, an analysis on the before and after functionality of an installation or part. If the functionality after maintenance shows a decreased vibration pattern this will most likely mean that the maintenance is well performed and that it helped in the functionality of the system (Manager CPA, RNLN 11/2022).

4: Process information

The last step in the predictive maintenance knowledge improvement process is to process the created information into knowledge, this is the most important step of the PdM KIP. Knowledge is created by embedding the information in the PdM structure and improving from it. The output of the PdM KIP is processed in all places in the PdM process where knowledge is created. According to section 3.2.1 this is at the analysis, assessment by ship, assessment by engineering, conduct maintenance, check, report, and the knowledge improvement process.

A form of processing can be to pro-actively give feedback to reporters or engineers about the executed maintenance. If a reporter gets feedback on this matter it will most likely improve his involvement in the PdM and PdM KIP process and he will be more willing to report on maintenance (Maritime support, RNLN 11/2022). For engineers this is also important, because they can see what happened to an installation after they decided to execute maintenance. Processing information can also be adopting adjustments in the algorithm, for example when a false-positive or false-negative was detected. Then the algorithm can be improved with the gained knowledge. This step is important to create knowledge improvement by adjusting, learning and remembering.

3.3 Chapter summary

In this chapter a knowing predictive maintenance organization is proposed for the RNLN. This is done by designing a knowledge improvement process for the predictive maintenance organization of the RNLN.

The Knowledge Improvement Process will help to secure knowledge in the maintenance organization of the RNLN. The four iterative steps will be executed every few seconds for data improvement, and will also be executed daily to improve the inputs in SAP to provide feedback to engineers and maintainers. This PdM KIP is unique and can be applied to predictive maintenance processes. The PdM KIP is an overarching process on the CBM steps defined by Jardine et al. (2006). The framework of Jardine et al. (2006) describes tree steps in a CBM process, which does not consider the execution and improvement of maintenance. The maintenance can be improved by learning and adding knowledge to a maintenance process by collecting information and processing the gained knowledge in the data or information processing of a predictive maintenance process. The Information Management Practices (IMP) of Kettinger & Marchand (2011) is mainly focused on data and information handling within a process. This framework can be applied to the predictive maintenance situation, where data and information is handled. The PdM KIP is different from the IMP process because it is aimed to improve knowledge in the predictive maintenance process, where the IMP framework aims to process data and information. When looking at the DIKW pyramid in figure 3.7, the IMP framework is focused on the data and information processes, where the PdM KIP aims on the knowledge process. The knowing organization of Choo (1999) is a process which focuses on the information process and the decision making aspects. The decision making aspects are: sensemaking, knowledge creation and decision making. However, Choo (1999) does not include the improvement of knowledge nor the creation of a space for knowledge improvement, and how this can be used in a predictive maintenance organization. The PdM KIP describes the knowledge improvement for a predictive maintenance organization, which is not done in the knowing organization process. Decision making in PdM can be improved by providing more knowledge to the decision maker, who can then make a better educated decision. The OODA-loop does not generate a space for knowledge creation as well as how this is executed for a predictive maintenance organization. The PdM KIP generates and improves knowledge which can lead to a better decision making.

This chapter answers sub-research question 3 and 4. Sub-research question 3 is answered by developing a predictive maintenance process for the RNLN, which can be implemented in the current maintenance processes. This process was developed using the input from industry, literature and the knowledge from employees of the RNLN. Sub-research question 4 is answered by designing a Predictive Maintenance Knowledge Improvement Process for the RNLN. This PdM KIP shows the improvement of knowledge in a predictive maintenance structure.

Chapter 4

Demonstrating the knowing predictive maintenance process by a case study of the CSS

A case study is conducted to demonstrate the designed knowledge improvement process for predictive maintenance. A case study is in line with the design research framework of Peffers et al. (2007), where the case study (and thus this chapter) will represent the fourth step: Demonstration. The goal of this case study is to demonstrate that knowledge is created with the PdM KIP. In this chapter sub-research question 5 will be answered: **How can knowledge creation within the newly developed PdM KIP process be demonstrated using a use case, based on the introduction of the Combat Support Ship?**

4.1 Background information on the case study

The case study is based on the transition from preventive maintenance to predictive maintenance at the RNLN. This shift in maintenance focus will become tangible with in the introduction of CSS the ”Den Helder”. This ship will be operational in 2024, aboard of this ship will be about 500 sensors which can be used for condition monitoring and predictive maintenance. Currently it is not clear how the data will be used to operate the CSS and how it will influence the maintenance. Also, it is not known how the organization should adapt, how the data is going to be analyzed and who will be responsible (Senior support manager, RNLN 08/2022). The introduction of the CSS is fast approaching, however the first two years of it’s operation data-driven maintenance can not be executed due to contractual agreements with the supplier (Senior support manager, RNLN 08/2022). This gives some time for the organization to change and for the data-infrastructure to mature and for knowledge to be created. The main problems of the current maintenance process are described in section 1.3, next to this there are some problems expected with the implementation of predictive maintenance on the CSS:

1. Currently information from old systems is used to define the maintenance plan of the CSS, this information is outdated or incomplete. Also, this information is based on different systems and a different ship (which can mean a different usage profile) (Senior support manager, RNLN

08/2022);

2. For engineers it is not clear how the data should be used in the maintenance process (Senior support manager, RNLN 08/2022);

3. The communication between the maintenance department, the standard setter (DMO) and the ships is often insufficient. These departments often don't understand each other due to lack of communication (Mechanic, RNLN 10/2022).

4.1.1 Organization of the input sessions

To demonstrate and validate the design three ”input sessions” were organized for stakeholders in predictive maintenance process, focusing on the introduction of the CSS. The first session entailed reviewing the designed predictive maintenance process. It is important to have an interactive session with the stakeholders and review the feasibility of the design. In the second input session the validated predictive maintenance process was demonstrated with the knowledge improvement process by the use of a case study. The third, and last, input session gave stakeholders/ participants the opportunity to give feedback on the designedPdM KIP, the demonstration, case study, and the organization of the input sessions.
The participants of the input sessions are stakeholders of the designed knowledge improvement process for predictive maintenance and represent all involved parts in the PdM process (for the CSS) at the RNLN. Departments that should be involved are:

1. Data for maintenance (Data for Maintenance - department within the RNLN (DfM))
2. Condition and performance analysis (CPA)
3. Maintenance engineering department at the RNLN
4. Standard setter department at the RNLN (DMO)
5. Technical services of a ship

An overview of participants is shown in figure 1.1, in section 1.5.3. The input sessions were organized at the RNLN, where a total of 13 people participated over the tree sessions. Figure 4.1 shows the organization of an input session, where 10 people were present. Every input session took two hours, which started with a presentation where the previous input session would be recapped (for the people who couldn't be there). The next phase in the input session changed for every individual session. The first input session was used to discuss the predictive maintenance process and possible additions or questions to the process. The second input session was used to give insights in the knowledge improvement process for predictive maintenance using the CSS case study and the frameworks of the knowing organization (Choo 1999), and the IMP (Kettinger & Marchand 2011). The last input session was mainly used to further describe and test the knowledge improvement process for predictive maintenance at the RNLN. The last input session was also used to get feedback on the input sessions, such as organization but also on the PdM KIP, and the PdM process.

Figure 4.1: Execution of an input session

4.2 Demonstration of the knowledge improvement process for predictive maintenance

The goal of the demonstration is to show the validity and function of the PdM KIP, by using a case study. The participants represent a good spectrum of all stakeholders of predictive maintenance on the CSS, as defined in section 4.1.1. There was no head of technical services present, but he was given the opportunity to comment on the conclusions of the input session.
Before the case study was conducted a last alteration to the PdM process for the RNLN was made, which is shown in figure 4.2. This addition was made because of input in the beginning of the input session (Manager, RNLN 11/2022*a*)(Manager, RNLN 11/2022*b*). The addition to the maintenance process is the feedback option from ”analyze” to ”measure”. This was added because there was no option for false-negatives or false-positives in data to be discarded in the analyze state in the PdM process. The final PdM process (figure 4.2) is used in the demonstration and evaluation of the PdM KIP. The change does not influence the design of the PdM KIP.

The Knowledge Improvement process for the predictive maintenance process is demonstrated using a case study of the CSS for the RNLN. The demonstration of the PdM KIP is applicable in seven area's, displayed in figure 4.3. The green arrows represent the input in the PdM KIP, and the orange arrows represent the output of the PdM KIP. The execution of maintenance, the check on the functionality after maintenance and reporting of the maintenance often happens by the same person, which is the mechanic who is performing the maintenance. The knowledge can be created in the conducing step in a way that a mechanic knows how to better perform maintenance. Knowledge can also be created in the functionality checking of an installation because this gives insight in the performed maintenance and functionality of the system. Reporting is an important step, and knowledge is created in this step, but knowledge can also be improved in this step. Knowledge can be improved by the way things are reported in the system, and to which extend they are reported in the system. The execution, checking and reporting of maintenance often happen by one person, that is why these areas of knowledge improvement are demonstrated together (case 1). The PdM KIP

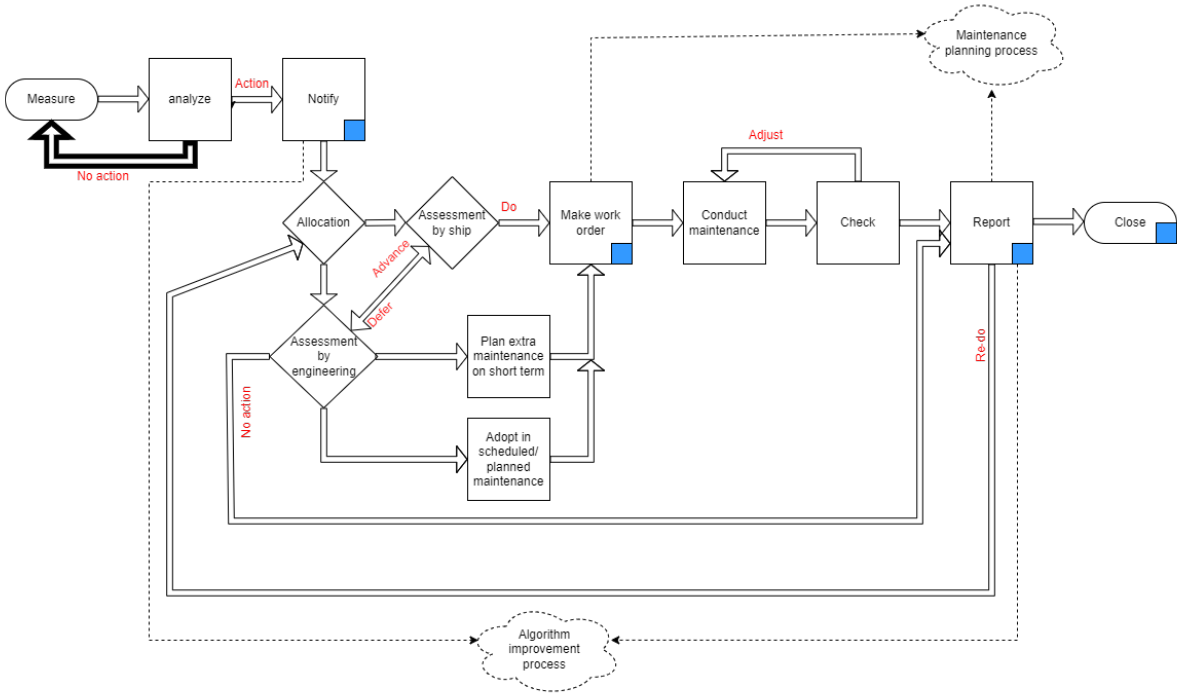

Figure 4.2: Final design of the PdM process for the RNLN

was demonstrated during the third input sessions. In this session the PdM KIP was explained to the participants after which the case of the PdM aboard of the CSS was applied to the design.

Case 1 - Knowledge improvement in the execution and reporting of maintenance
When a mechanic has to report in SAP it is important that this is correctly executed, because then step 1 of the PdM KIP can be executed (step 1, collect information). To do this, maintainers can be stimulated by their managers or by obtaining feedback about their input. In SAP it is known who closes and reports a work order, so when a maintenance engineer can check the input of the maintainer (step 2, information validity check). The maintenance engineer can then do an analysis on the information and what he should do with it (step 3, information analysis). At last, the maintenance engineer can give feedback to the reporter or maintainer (step 4, process information). The participants agreed that feedback will increase the willingness of maintainers to correctly report on their executed maintenance tasks (Maritime support, RNLN 11/2022) (Head engineering, RNLN 11/2022).

Case 2 - Knowledge improvement for maintenance engineers
When, on the CSS, a predictive abnormality is detected a maintenance engineer can decide to execute maintenance and this can be executed by the ship. In the current situation the maintenance engineer does not get information back about the functionality of the installation after repair. With the PdM KIP this can be improved by receiving information or feedback from the maintainers aboard, as well as data of the installation (step 1, collect information). The maintenance engineer can verify the information on data with the provided feedback (step 2, information validity check).

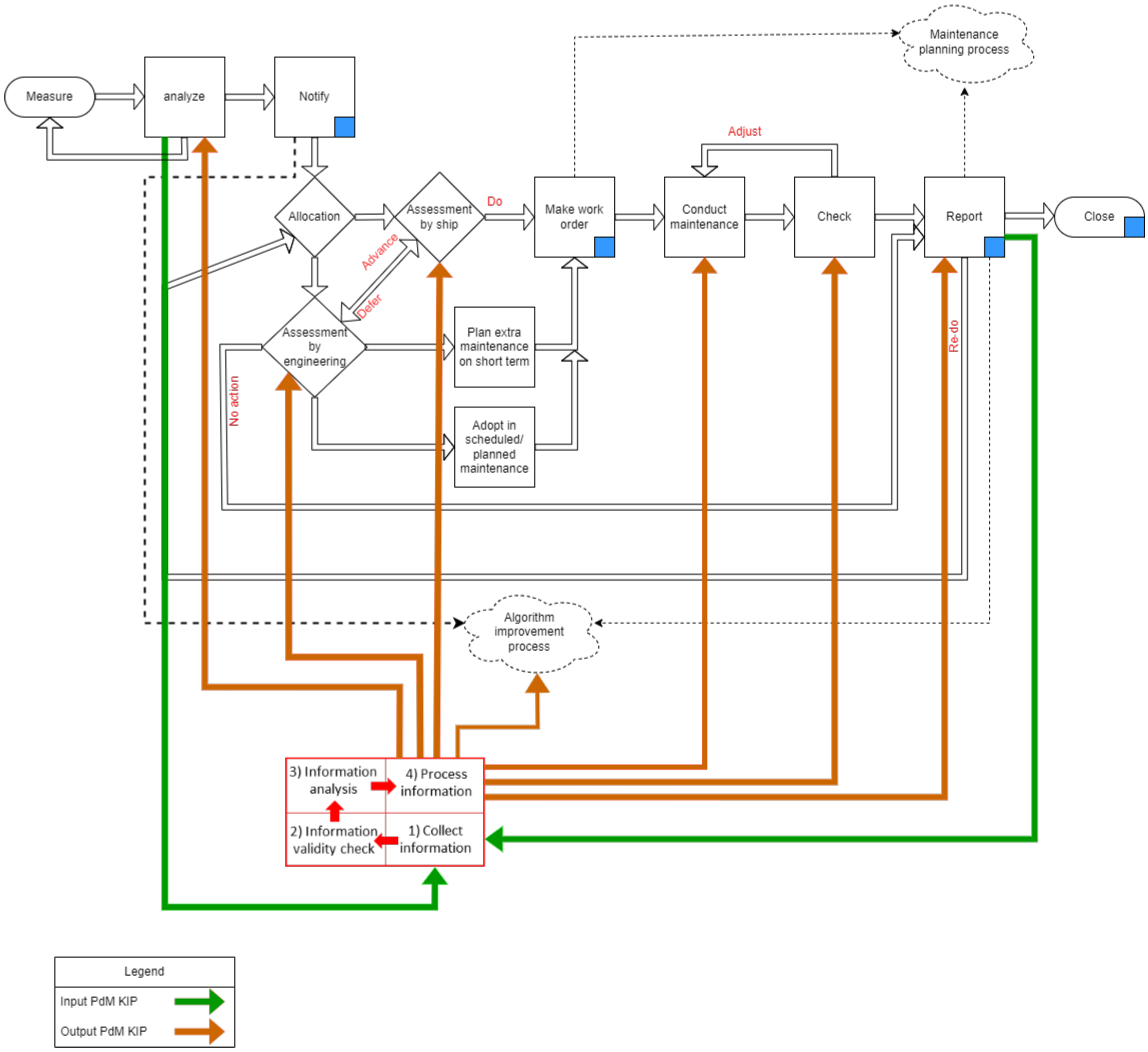

Figure 4.3: PdM KIP displayed in the PdM process of the RNLN

Then he can analyse the current operation of the installation and compare it with the data before repair (step 3, information analysis). The last step is to process the information, such that the installation engineer can make better decisions in the future.

Case 3 - Knowledge improvement for maintenance staff aboard

Data analysis can show abnormalities on systems aboard of the CSS. These abnormality, when critical enough, will create a notification for the maintenance staff aboard. The knowledge in this decision making process can be increased such that better and faster decisions can be made. After the maintenance is performed aboard, information is gathered about the decision on maintenance, functionality of the system and the performed maintenance (step 1, collect information). The information can then be checked by a maintenance engineer to check if the maintenance was well executed and if the data is correct with the reports (step 2, information validity check). Then the information can be analyzed, the maintenance engineer can check if the decision on maintenance was the most optimal and if he would have recommended any other action and check this conclusion with the functionality of the installation (step 3, information analysis). The last step is to give feedback to the maintenance decision maker aboard (step 4, process information), this is valuable to increase the knowledge aboard and improve decision making.

Case 4 - Knowledge creation for the prediction algorithm
The data from measurements are analysed and processed in the ”analyze” action in the PdM process. The algorithm improvement process is added to the PdM process to improve the algorithm, and the knowledge about data analysis and processing for the assets of the RNLN. The case demonstration of the analyze action and the algorithm improvement process are combined. An abnormality detection could be a false-positive, which is detected by a maintenance engineer and reported in the SAP system. The data from the SAP report and the functionality data of the installation (aboard of the CSS) are collected (step 1, collect information). The validity of the data is checked, as well as the validity of the reasons of the maintenance engineer to not perform maintenance (step 2, information validity check). The data of the installation is analysed to see why the false-positive was generated, combined with the information of the maintenance engineer (step 3, information analysis). The knowledge can be processed by improving the algorithm such that the false-positive is no longer created (step 4, process information).

4.3 Chapter summary

In this chapter the designed Predictive Maintenance Knowledge Improvement Process (PdM KIP) for the Royal Netherlands Navy was demonstrated by the use of the case study of the CSS, answering sub-research question 5 in the DSRM of Peffers et al. (2007). All the seven output areas of the PdM KIP were demonstrated by four cases. This case study was conducted with the use of stakeholders in the PdM process, they actively participated in the demonstration. The attendees were a good representation of all stakeholders in the predictive maintenance process, so all perspectives are covered. The four cases in the case study were based on the introduction of the CSS at the RNLN. All the output domains of the PdM KIP were demonstrated to the participants of the input sessions. The demonstration showed the importance for the users of the PdM process to use the PdM KIP, and embed this process in the organizational structure of the RNLN (Manager DMO, RNLN 11/2022). If the PdM KIP is not embedded in the organizational structure of the RNLN it will not be used and knowledge can not be improved in the predictive maintenance process. When the knowledge improvement process has been embedded and used it can improve the knowledge of engineers ashore and aboard, as well as maintainers (Head engineering, RNLN 11/2022). Also, the willingness to correctly and thoroughly register information in the SAP system can improve (Maritime support, RNLN 11/2022).

Chapter 5

Evaluation of the PdM KIP

In this chapter the evaluation of the knowledge improvement process for predictive maintenance is described, which corresponds to step 5 in the DSRM of Peffers et al. (2007). The evaluation, in section 5.1, is based on the input of the participants of the input sessions, who represent all stakeholders in the PdM process at the RNLN. Section 5.2 provides an evaluation of the proposed PdM KIP, it's design requirements, design process and outcome. This chapter answers sub-research question 6: **How can knowledge creation within the newly developed PdM process be evaluated?**

5.1 Evaluation by participants

The PdM KIP is evaluated by the participants by verbal feedback and through a survey during the third input session. The survey is attached in appendix section A. The main challenges for the proposed design, according to the participants of the evaluation session, are:

1. The biggest pitfall of the PdM process was identified to be the correct registration of information in SAP, and the correct allocation of notification to the ship and engineering.

2. The communication between engineering and the ship cam improve to gain knowledge creation, this can be done by using the PdM KIP. The current pitfalls in the maintenance were identified and applied to the PdM KIP, this was done to evaluate the working principles of the PdM KIP.

3. The maintainers aboard should be stimulated to register information about maintenance and possible improvements in SAP. According to the participants, this can be stimulated by the PdM KIP when it is embedded within the organization of the RNLN. When engineers have no input, they don't know what is going on aboard, and they can't do any analysis.

The overall feedback was that the PdM KIP is applicable to the maintenance organization of the RNLN, and that it fits within the current operating procedures. This evaluation was conducted by participants of the third input session, the overall conclusion from this evaluation is that the PdM KIP can improve the knowledge in a predictive maintenance organization but it should be embedded well. For the RNLN this means that the PdM KIP should become a part of the organizational processes and it should get support from higher management. The data literacy, the training and the usage of the SAP system, were evaluated as the highest priorities for knowledge creation within the predictive maintenance process. The shortage in personnel is preventing a control on the reporting in SAP, the personnel shortage is also causing a lack in training in the use of the SAP system.

5.2 Evaluation of the design

This section is an evaluation of the proposed PdM KIP and it's design process. The PdM KIP is evaluated on the design criteria, design iterations and it's applicability for the RNLN. The design of the PdM KIP was formed using nine design criteria, described in section 2.4. The design criteria gave direction to the design process and outcome. The use and outcome of the design criteria are evaluated below. Every number represented the corresponding design criteria in section 2.4.

1. The first design criteria stated that the crew of a ship should be able to make adequate and independent decisions on maintenance during operations. This design criteria was processed in the design by including the ship in the decision making, and keeping it as end-responsible stakeholder in the PdM process. However, abnormalities can not be discarded, these will be advanced to the engineering department such that they could be incorporated in long term maintenance planning.

2. The second design criteria covered the vision of the RNLN on data-driven maintenance, the aspects were: autonomous operating, optimization of availability, unburden crew, directing activities from Den Helder, design relevance over the entire lifetime of the asset. This is a general design criteria, which was achieved by introducing the PdM process at the RNLN. These criteria will not be immediately fulfilled, for example it will take time to unburden crew and optimize the availability.

3. The predictive maintenance knowledge improvement process should be integrated in the current working methods of the RNLN. According to the interviews with industry (Maintenance engineer, Dutch Railways 09/2022)(Technical lead, Equans Refrigeration 08/2022) the PdM process is integrated in the work processes when a predictive trigger is adopted in the, already existent, (corrective) maintenance process flow. The developed Knowledge Improvement Process are integrated within the current working methods according to stakeholders in the maintenance process, which is evaluated in section 5.1 (Maritime support, RNLN 11/2022)(Senior maintenance engineer, RNLN 11/2022*d*). This shows the potential of the proposed PdM KIP design, however the execution of the integration of this process is crucial to have an efficient integral process.

4. The ship should always be informed on critical abnormalities, which is facilitated by the allocation step in the PdM process. The decision making and abnormality detection can be improved using the PdM KIP. This design criteria is mainly focused on the PdM process and the decision making in a critical situation, and does not shape the outcome of the PdM KIP process. For a future design process the design criteria could focus more on the design of the Knowledge Improvement Process.

5. The automatic measurements are done by sensors on critical installations, this data is processed in the analysis step. The information creation in the analysis step can be improved using the

PdM KIP. Also, the algorithm improvement process will ensure the assessment of data, where knowledge is also processed using the PdM KIP. In this way the algorithm and assessment of data can be improved in multiple aspects using the PdM KIP. However, this can only be done if the PdM KIP is well incorporated in the organizational structure of the RNLN.

6. The sixth design criteria is focused on maintenance engineers, who should be able to execute assessments on assets for maintenance plans by using up-to-date health information. By improving the knowledge in the (predictive) maintenance process the maintenance engineers can more accurately determine the health state of an asset. The health of an asset can be determined using data and information from the algorithm and automatic measurements, as well as input data in the SAP system. The input in the SAP system will greatly improve the knowledge of maintenance engineers and therefor their ability to make maintenance plans.

7. The Knowledge Improvement Process can facilitate a switch in workload for maintenance on the long term, however on the short term it will not generate a shift in tasks. This is determined by the evaluation by participants during the input sessions. The introduction of predictive maintenance and the PdM KIP will possibly generate more work for engineers in the beginning, however on the long-term it is expected to unburden crew and decrease the work load.

8. The eighth design criteria is that the PdM KIP should facilitate a decrease in time between the data acquisition and decision making steps in a predictive maintenance process. The gained knowledge can give insights in the functionality and health of a system, which can lead to a more accurate maintenance decision. In the current maintenance process the data acquisition and processing is done manually, and therefor takes a lot of time. In the PdM process the knowledge is improved with the use of the PdM KIP, causing more accurate and potentially faster decision making. However, a decrease in decision time is not assessed and can not be confirmed.

9. The PdM KIP is a continuous process, which aims to improve knowledge in the predictive maintenance process. The Knowledge Improvement Process is designed to improve knowledge by generating feedback and knowledge for employees. During the input sessions it became clear that the addition of feedback in the predictive maintenance process can cause an increase in information registration, and thus increase knowledge in the PdM process. The knowledge should be managed and embedded in the organizational structure of the RNLN, this is such that effectiveness of the PdM KIP can be secured.

The predictive maintenance knowledge improvement process was created using input from stakeholders in the PdM process and design criteria. The design of the PdM KIP was demonstrated and evaluated in the three input sessions. The input sessions were performed to validate and optimize the design and it's applicability to the maintenance organization of the RNLN. During the execution of these input sessions it became clear that, from the participant's perspective, the sessions were very helpful to inform participants on predictive maintenance and knowledge creation. This observation shifted the main goal from the input sessions from receiving input and information to providing information and enthuse the participants for predictive maintenance. The input session facilitated participants to meet each other, get informed about predictive maintenance and work towards predictive maintenance in the maintenance organization.

During the input session the participants group agreed on two design iterations, these changes are shown in figure 5.1. The ones in the figure represent the first design iteration, where two changes were made. The twos in the in figure represent the second design iteration, where one change was made. The first design iteration was the addition of an analysis action and the option for engineers to discard a notification. These design iterations made the PdM process for the RNLN complete. The PdM KIP is applied to this PdM process. The design of the PdM KIP did not have any design iterations, however the visualization of the PdM KIP did raise some questions. The output of the PdM KIP does not only apply to the data processing step, as shown in figure 3.8. The outcome does also apply to the decision making and algorithm improvement steps, like shown in figure 4.3. It is important to realize that the PdM KIP is an overarching process where knowledge creation in the PdM context is shown. The Predictive Maintenance Knowledge Improvement Process is shown in figure 5.2. The PdM KIP is an overarching four step process for predictive maintenance which can be used for knowledge creation and knowledge improvement.

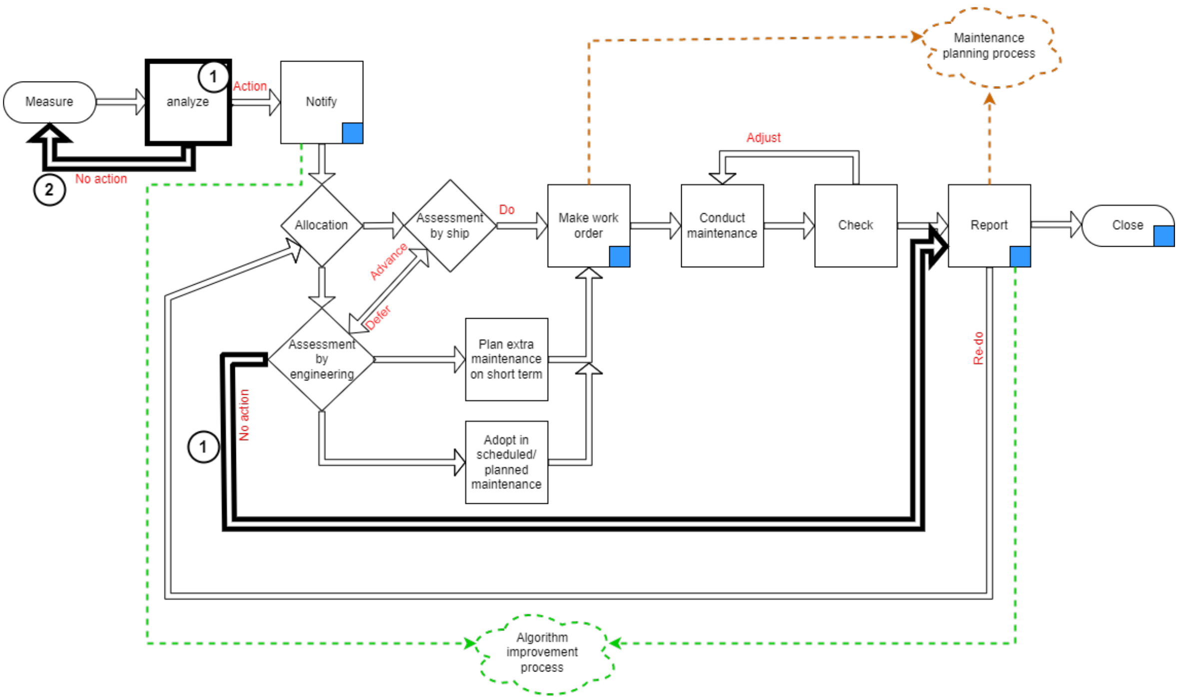

Figure 5.1: Design iterations of the PdM process

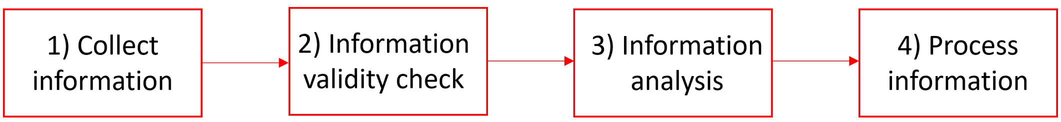

Figure 5.2: PdM Knowledge Improvement Process

In section 1.3 five main challenges were described for the maintenance processes at the RNLN. The

first challenge was data entry and data quality, this challenge can be improved with the usage of the PdM KIP by providing feedback to the users of the information systems. Next to this, by the use of data-driven maintenance the data in the systems should become up-to-date and accurate. However, this can not be guaranteed, since the effectiveness of the PdM KIP depends on the implementation of this process within the organizational structure of the RNLN.
The next challenge was policy and standards, currently there is no clear work procedures for PdM or CBM embedded in the organizational structure. The evaluation of the participants of the input session showed that the PdM KIP should be embedded in the organizational structure and work processes before it becomes effective. Similarly has been determined for the first challenge, the use of the PdM KIP depends on the ability to embed the process in the organizational structure.
The third challenge was resource capacity, which described the shortage in people. On the long term, the PdM KIP aims to re-direct the work efforts from maintenance engineers from corrective to preventive maintenance. However, on the short term the work load could increase since the processes should be introduced and embedded in the current work procedures.
The next challenge was data literacy, which can be improved by training employees such that they know how to work with PdM. To make the urge of learning bigger it would be beneficial to implement the PdM KIP in the organizational structure and make it's use mandatory. The feedback in the PdM KIP should cause an increase in interest of PdM. The use of the predictive maintenance process and the PdM KIP will start with a small group of engineers, where successes can be generated to spark the interest of more engineers. This process will take time and effort because people should be convinced of the use of the PdM KIP by showing successes.
The last general challenge of the RNLN was autonomy, which can not entirely change due to the operations at the RNLN. The organizational operation will still be similar, causing the ship to be end-responsible for all installations. However, with the use of the PdM KIP the knowledge of engineers ashore and people aboard can be improved by providing each other with information and feedback. Also, by re-directing low priority abnormalities to engineers ashore there is no information loss on the condition of assets. This could benefit the knowledge of engineers aboard and ashore.

Section 4.1 describes three challenges involved in the implementation of predictive maintenance on the Combat Support Ship (CSS). The first challenge is that the maintenance plans are outdated and incorrect. With the implementation of the new CSS this documentation problem could be solved by having correct maintenance plans from the beginning. However, due to shortages in personnel it is unlikely for the RNLN to keep the maintenance plan up-to-date. The second challenge was that engineers do not know how the data should be used. With the use of the PdM KIP knowledge creation and improvement is facilitated. This knowledge can be used by engineers to learn about how to use data in their work. The last challenge was the communication between the DMI, DMO and the ship. When the PdM KIP is used properly this can lead to knowledge creation in a (to be designed) (virtual) space of the RNLN which all departments can access. In this way knowledge can be shared between departments without additional effort. This is all conditional for the PdM KIP to be implemented in the RNLN's organizational structure such that it will be used properly.

5.3 Summary of the evaluated PdM KIP

The Predictive Maintenance Knowledge Improvement Process (PdM KIP) is evaluated in this chapter using on the third input session, opinion of participants and the design evaluation. The goal of the three input sessions with participants changed from solely gathering information and feedback to providing information on predictive maintenance and enthuse participants. The evaluation by participants was executed with a survey, which was filled in in the third input session. The participants who filled in the evaluation survey are documented in table 1.1 in input session 3. The feedback of the participants was overall positive, however they still remain sceptic until the working principle of the PdM KIP is proven. The biggest challenge for the success of the PdM KIP, according to the participants, was to embed the process in the current organizational structure such that people will use the proposed process.

In the evaluation of the proposed design the design criteria were evaluated on their applicability and execution. All design criteria were taken into account when the PdM KIP was developed. The final design of the predictive maintenance process was generated using two design iterations, shown in figure 5.1. These design iterations were formed with the expertise and help of participants of the input sessions. The predictive maintenance process is complete after the two design iterations, such that the PdM KIP can be applied to this process. The Knowledge Improvement Process is a four step loop, which will stimulate knowledge creation in the predictive maintenance process of the RNLN. The input of the PdM KIP is registered information in the SAP system, data provided by the predictive maintenance algorithm, or decision making information of engineers or the ship. This information is collected and validated on accuracy and applicability, this step is important to have valid and complete information. The information is analysed and processed into knowledge, which can be used as feedback for engineers aboard and ashore as well as mechanics.

Chapter 6

Conclusion, discussion & management implications

This chapter will show the conclusion, discussion and recommendations on the work delivered in this thesis. The conclusion, in section 6.1 will give answer to the main research question. The discussion will discuss the execution and outcome of this thesis in section 6.2. In section 6.3 management implementations are provided to the RNLN about future research, the applicability and implementation of the proposed design.

6.1 Conclusion

The conclusion in this section will answer the research question of this thesis: **How can knowledge be enhanced in the predictive maintenance process of the RNLN's maintenance department with the aim to improve maintenance decision making?** To answer this question it is important to realize what organizational knowledge entails, according to Nonaka et al. (2006) "organizational knowledge creation is the process of making available and amplifying knowledge created by individuals as well as crystallizing and connecting it to an organization's knowledge system". For the knowledge creation at the RNLN this means that knowledge should be created and captured in the maintenance department. Knowledge is created by giving meaning and context to data from assets and information from decision making and executed maintenance tasks. This information and data is used in the PdM KIP to improve and amplify the knowledge in the predictive maintenance process and connecting knowledge by crystallizing it in the organizational structure. By creating and improving knowledge in the predictive maintenance process decision makers in the maintenance process have more knowledge. This knowledge will help maintenance decision makers (e.g. maintenance engineers) to make more adequate decisions on maintenance.

Knowledge is made available by giving meaning to information in the predictive maintenance process. This information is created in the predictive maintenance process and is the input for the PdM KIP, where this knowledge is improved. In section 3.2.1 it is determined that knowledge is created in the following steps of the PdM process (in alignment with the knowing organization of (Choo 1999)): analyze, assessment by ship, assessment by engineering, conduct maintenance, check, report, algorithm improvement process. In the designed Knowledge Improvement Process knowledge is improved for the predictive maintenance context. The collection and validity check on the information is needed to filter out incorrect or unnecessary information in the PdM KIP. After this, the information is analyzed and processed. The processing of the information is the most important step in the PdM KIP, because this step will connect knowledge improvement to the organization's knowledge system. This step will make sure that the knowledge is crystallized and connected to the organization's knowledge system, i.e. capturing knowledge. This knowledge is captured by giving feedback to engineers aboard or ashore as well as maintainers. Another way to capture knowledge is to improve the analysis algorithm, maintenance decision making and by communicating the effect of these decisions on the maintenance execution and performance of assets. The creation and improvement of knowledge is validated and evaluated by stakeholders in the PdM process at the maintenance department of the RNLN. The PdM KIP is based on input and interviews conducted at the maintenance department of the RNLN and substantiated with examples from industry and literature. For the RNLN we can conclude that the design process of the PdM KIP was of greater value that the outcome of the design. During the process and the input sessions the participants were informed and involved with the creation of a (future) predictive maintenance process. The input sessions encouraged the participants to work together and share information on (predictive) maintenance. The PdM KIP should be embraced by the maintenance department of the RNLN to continue knowledge sharing, creation and improvement within the (predictive) maintenance process.

6.2 Discussion

A Predictive Maintenance Knowledge Improvement Process (PdM KIP) is proposed for the maintenance organization of the RNLN. This design was tested, validated, demonstrated and evaluated over the course of this research, with the help of experts and stakeholders from the maintenance department of the RNLN. The design is a general and good design, which is very well applicable for the maintenance organization of the RNLN, according to the evaluation of the input session participants. However, the steps in the design are very general, and the execution of these steps are of big influence on the effectiveness of the use of knowledge improvement in the PdM process. Next to this, the use of the PdM KIP process will depend on the implementation in the organizational structure of the RNLN. The Knowledge Improvement Process is designed to guide the improvement of knowledge within a predictive maintenance organization. The design is based on the principles of the knowing organization of Choo (2001) and information management practices of Kettinger & Marchand (2011), and is shaped with the use of the Maintenance Feedback Analysis (Braaksma 2012) and the CBM execution steps (Jardine et al. 2006). The general structure of the Maintenance Feedback Analysis was used to design a step-wise approach for the PdM KIP, and the CBM steps in Jardine et al. (2006) formed the input and output steps for the PdM KIP. The PdM KIP adds value to literature by describing knowledge creation in the predictive maintenance context. Since knowledge creation is dependant on it's context the PdM KIP provides a guide for knowledge creation within predictive maintenance, which could improve the predictive maintenance process.

The development of the PdM KIP was an interesting process, where a lot of input from different people was needed. Most of these people had different expectations and opinions about predictive maintenance, often there was limited realization that knowledge creation and effective information transfer is crucial for the (predictive) maintenance process. Several interviews were conducted and information was gathered from theRNLN and the industry (table 1.1 in section 1.5.3). The most difficult part of the research was the identification of the current maintenance process of the RNLN, and pinpointing what the most prominent challenge is in the current work method and process. I spoke to a lot of people in the organization, who all have a different opinion and view on the maintenance within the RNLN. Using all the opinions the current maintenance processes flow were described, however this took a lot of time. Then the predictive maintenance process for the RNLN was designed, which was an iterative process with a lot of involvement of engineers and participants of the input sessions. The input sessions were fun to organize and were of big importance in the creation of the PdM KIP, as well as the execution of the case study and evaluation. During the input session the focus was mainly on the PdM process flow chart, which made the predictive maintenance process very clear and insightful for all participants. However, the knowledge creation within this process was an underrated topic and less discussed. The participants preferred to talk about the practical implementation and use of PdM, and the knowledge creation and knowledge improvement sparked less interest. This caused the input sessions to become more educational for participants to inform about predictive maintenance and enthuse them about this topic.

The PdM KIP is developed for the predictive maintenance process of the RNLN, this process is quite specific for the organization. The assessment by ship is an important part for the RNLN, because it enables the ship to make decisions during mission. However, the assessment by ship does not usually happen in other shipping companies. Often the maintainers ashore are in charge of the functionality of the ship. Therefore the designed PdM process is not directly applicable for any shipping company or any company in particular, besides the RNLN. The PdM process can be adapted to any company wanting to implement predictive maintenance. The building blocks that will not change are: measure, analyze, notify, make work order, conduct maintenance, check, report and close. These steps are essential for a predictive maintenance process. The assessment and decision making steps in the PdM process can be adapted for any organization, depending on how decisions are made and the impact of those decisions. The algorithm improvement process and maintenance planning process are stand-alone processes which are involved with predictive maintenance. For future research these processes should be developed to gain a complete picture of predictive maintenance at the RNLN. The PdM KIP can be applied to any operational predictive maintenance process where information is also registered in a SAP system (or any similar system). The four steps in the PdM KIP process can help to improve knowledge within a predictive maintenance context and facilitate a better decision making process. The steps in the PdM KIP process are very general, which means that the interpretation of these steps could differ per company. This could cause challenges with the use of the PdM KIP due to interpretation challenges of the steps in the design. For example, for a company the information analysis could be very different from the RNLN, which demands different techniques or even systems.

Looking back at the visualization of the PdM KIP, the design could be displayed in another way. The Knowledge Improvement Process is a process which can be repeated with different types of knowledge input and could produce different types of knowledge output. To keep the process general the CBM steps of Jardine et al. (2006) were taken as a reference point, however the PdM KIP can have output in the data processing and maintenance decision making steps of Jardine et al. (2006). This shows that the PdM KIP is an overarching process which can be used to improve knowledge in a predictive maintenance process. The steps in the PdM KIP itself (collect information, information validity check, information analysis, process information) are well applicable in the PdM context, as is evaluated in chapter 5.

The proposed PdM KIP has some design limitations. The design was made based on interviews and the organized input sessions. The invitations for the input sessions were distributed such that all the stakeholders in the PdM process would be represented. However, there are some stakeholders that could have been added to these input sessions to get a better overview. First of all, there was no head of technical services aboard present during the input sessions, they were invited but were not able to attend. However, they were given the opportunity to give input, because at the end of every input session the conclusions were distributed and all invited stakeholders could give feedback on it. Also, since the case was focused on the introduction of the CSS the managers and engineers involved with that project were invited. This meant that the participants were all from the same vessel group, and that the other vessels were not taken into account. Next to this, (maintenance) engineers will be the main users of the PdM process and PdM KIP, however only one maintenance engineer was present during two of the input sessions. The group of maintenance engineers could have been better represented to gain more insights in the end-user's opinion. The next limitation in this research is that only one case study was executed to demonstrate the functionality of the PdM KIP. Within this case study there were multiple examples where the PdM KIP could be applied, and it was sufficient for the participants of the input sessions. However, the addition of another case study (possibly in another vessel category) could have given other insights in the use of the PdM KIP.

The design criteria in section 2.4 were defined to give direction to the design of the PdM KIP. Some of these design criteria are very general or are mostly used for the development of the PdM process. The specific design criteria for the PdM KIP were criteria 7,8 and 9. These three design criteria were not a lot to specifically design a knowledge improvement process for the RNLN. The design criteria were mostly based on the literature research in section 2.3, where knowledge creation and decision making was explored. The design criteria were also based on the challenges defined by the interviews at the RNLN and the challenges and solutions observed at the interviewed companies. For future reference, the design criteria could be expanded to be more specific into a direction for the knowledge improvement process. However, it is difficult to define design criteria for a knowledge improvement process in predictive maintenance before the PdM process is developed.

In the process of problem identification I could have gained more efficient insights in the maintenance department of the RNLN. This organization is large and quite complicated with all it's organizational structures, in this research the insights were gained by conducting interviews and exploring ”on the go”. After a few months I finally had an interview where everything became clear, if I had known this information earlier it would have helped me in the approach of this research.

The Design Science Research Methodology (DSRM) of Peffers et al. (2007) guided the design of the PdM KIP and the structure of this thesis. This DSRM consists out of six steps: Identify the problem and motivate; define the objectives of a solution; design and development; demonstration; evaluation; and communication. This research framework supported the structure of the execution of this research, if this framework wasn't used the research would have been less structured.
The identification of the problem was described in chapter 1. This problem identification was mainly based on the input from interviews of which the output was five main problems. From these problems the data entry and quality as well as the data literacy were the most challenging for the design of the PdM KIP. The problem identification was the most difficult step in the DSRM approach because there were a lot of people with different opinions and views on the problem. Eventually, the interviews were documented in Atlas.ti to find patterns. This helped a lot to find the main problems for the maintenance organization of the RNLN.
The second step was to define the objectives for a solution, this step was very elaborately executed. To define the objectives of a solution nine interviews were executed at the RNLN, these were needed to define the current situation, challenges and opportunities. Additionally four companies were approached for an interview to gain insights in the PdM process at other companies, a total of five interviews were conducted. All these people were also asked to fill in a CBM maturity model to determine the current maturity of the RNLN and the maturity of companies in the industry. This maturity model was scored by 21 people at the RNLN and one person at each interviewed company. The CBM maturity of the RNLN is a quite accurate approximation of the current CBM situation, however the CBM situation at the companies can not be considered accurate. At every company only one person filled in the maturity model, which is not sufficient for an accurate representation of that company. Also, these companies were very active with the introduction of CBM or PdM, a lot of other companies in the industry are not this active in this context. Also, in the interviews no shipping company was included, which would have been nice to see what their view PdM is. The last input for objectives research was literature, where frameworks in the knowledge creation and decision making aspects were used. These frameworks formed a structured base for the development of the PdM KIP.
The design and development of the PdM KIP was executed after the development of the PdM process for the RNLN, which took up a lot of time. Because of the many perspectives and input provided by the interviews the design of the PdM process took up a lot of time. The design process of the PdM KIP followed from the challenge that knowledge was lost in the maintenance processes of the RNLN as well as for the companies in industry. When the PdM process was defined the design of the PdM KIP followed after a view drafts.
The fourth activity in the DSRM is the demonstration of the PdM KIP, this was done in third input session. The first two input sessions were used to validate the PdM process and to demonstrate the frameworks of Choo (1999) and Kettinger & Marchand (2011) in the PdM process. The use of the proposed design was demonstrated by a case study where four instances of the problem were used. The participants of the input sessions were very actively involved, which made the execution of

these sessions very pleasant and the outcome very useful. Some of the time spent in the input sessions was used for information distribution among the participants of the input session, where they were informed on the project DfM. This was not lost time, because it made them more involved with the PdM process, and I still got the desired results from the input sessions.
The evaluation of the PdM KIP was executed by the participants and by an own reflection. The evaluation of participants was based on verbal feedback and an survey. This survey was transcribed in section 5.1, and gained good insights in the applicability of the PdM KIP.
The communication of the developed design will be executed by publishing this paper and a business presentation at the RNLN.

6.3 Management implications

The management implications in this section can help the RNLN to investigate future research opportunities or to improve the use of the PdM KIP. The first recommendation on this work is to further implement the proposed predictive maintenance knowledge improvement process using the predictive maintenance flow process. This PdM process is currently only applicable for the maintenance department of the RNLN, and a detailed description could help with the usage in the maintenance organization. The feedback from the participants in the input sessions was that the action blocks in the PdM process were very general. The interpretation of these actions is of great importance, however the tasks can look differently for every technical group within the maintenance department. The PdM process and the PdM KIP should be tested in the future for applicability and validity within the maintenance organization of the RNLN. These tests will help to understand the practical limitations of the PdM process and the PdM KIP. The demonstrations in this thesis were based on a case study of a the CSS which is not in operation yet, so when this ship is in operation the use of predictive maintenance and the knowledge improvement should be tested.

The biggest challenges of the RNLN are data entry and quality and data literacy to stimulate knowledge creation, the data quality and entry should increase with the use of predictive maintenance and can be stimulated with the use of the PdM KIP. It is important that the use of the PdM KIP is stimulated to generate knowledge improvement by, for example, feedback. The data literacy could be improved by the training of employees, however the training of people is currently a challenge. There is not enough capacity to train people. The training and education of people is necessary to increase the use and success of predictive maintenance. A way to do this is to hire more people to train and educate on predictive maintenance, also there should be more people available to process information and knowledge in the PdM KIP and the algorithm improvement process. Another recommendation is to embed the use of the PdM KIP in the organizational structure, in this way it's use should be stimulated.

In future research it would be valuable to give insights in the ”algorithm improvement process” and the ”maintenance planning process”, which were defined in the PdM process for the RNLN. The maintenance planning process is not an undefined process, it represents the overarching maintenance process where maintenance is planned on the long term. It would be beneficial for the RNLN to investigate the coherence between the maintenance planning process and the PdM process, and embed work procedures for this in the organizational structure. The algorithm improvement process is a new and undefined process, this process will help to improve the PdM algorithm such that better predictions on maintenance can be done. Because this process is undefined there is no responsible group or person to take on this process. It could be likely that project DfM is going to execute this tasks, but options should be explored. The algorithm improvement process is crucial for the improvement of data, information and knowledge in the PdM process, and could increase the data analysis.

Another recommendation for future research at the RNLN is the design of a social-organizational roadmap. This roadmap would show the steps needed to implement knowledge creation and improvement in the predictive maintenance organization of the RNLN. This roadmap could be based on the 8-step model of Kotter (1995), which could give practical insights in change implementations. The social-organizational roadmap could advance smooth implementation of PdM and knowledge creation within the RNLN.

The last recommendation for the RNLN is to create a space or context where knowledge can be created and improved. This context is important for the success of knowledge creation. As Nonaka et al. (2006) said: ”The organization might be a well-designed engine for information processing, but more importantly, it assiduously becomes a context in which knowledge — the engine’s fuel — is created”. Meaning that every organization, so also the predictive maintenance organization, needs a context where knowledge can be created. In this space for knowledge activism can be encouraged to create, transfer and improve knowledge as well as to communicate future prospects.

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Appendix A

Evaluation survey of the PdM KIP by participants of the input session

This chapter of the appendix is a transcript of the evaluation survey conducted by the participants of input session 3. An overview of the participants can be found in table 1.1.

Is the PdM process applicable in the organization? Are there parts missing, and does it cover the whole process?

- Senior maintenance engineer, RNLN (11/2022*d*): Yes, but it should be applied on specific installation numbers and the data-system aboard should be well implemented and easy to use.
- Maritime support, RNLN (11/2022): Yes, it is well applicable for the organization. Especially for critical systems.
- Engineer, RNLN (11/2022): I think that the process is generally well applicable. Which actions are behind each part will have big influence on the succes.
- Manager DMO, RNLN (11/2022):Yes, I don't think that there is anything missing. The execution will tell how it really works.
- Head engineering, RNLN (11/2022): The process is well applicable. With what we discussed I don't see any parts that we are missing.

Does the implementation of the PdM process influence the intensity of work on the ship without influencing the decision making or responsibility?

- Senior maintenance engineer, RNLN (11/2022*d*): You can focus more on maintenance, so less unnecessary tasks.
- Maritime support, RNLN (11/2022): It has a positive effect, unnecessary maintenance is reduced but only if the data-model is working.
- Engineer, RNLN (11/2022): The work intensity should decrease, no unnecessary work, less physical checks needed. You get better insights in the current status of the system.
- Manager DMO, RNLN (11/2022): It should be positive. It could prevent breakdowns by earlier detection and it could also make maintenance more planable. Besides that, the preventive tasks will only be performed when really necessary.

- Head engineering, RNLN (11/2022): I think the work pressure will eventually decrease, because you can have better insights in the maintenance.

How can engineers, using the PdM process, focus their work better on the future maintenance tasks? And will this improve the maintenance plans?

- Senior maintenance engineer, RNLN (11/2022*d*): Better data means better information and knowledge, right now we have incomplete data.
- Maritime support, RNLN (11/2022): Yes, but operational importance can cause maintenance tasks to not be executed.
- Engineer, RNLN (11/2022): Only doing what is necessary will give more time. If you don't measure anything then you never know the status of an installation, in the future you will have less surprises.
- Manager DMO, RNLN (11/2022): It's difficult to say. In the beginning they will not have more time, because they will still do corrective maintenance. Eventually it will help as a tool in a toolkit.
- Head engineering, RNLN (11/2022): Yes, but everything depends on the quality of data and reporting in the system.

How can the time between maintenance periods be increased using the PdM process?

- Senior maintenance engineer, RNLN (11/2022*d*): There is more data available, but the system should be user-friendly
- Maritime support, RNLN (11/2022): Not doing unnecessary maintenance saves time. If PdM is well processed, this can safe time, but it causes that all ships need maintenance at a different time. How will we do this?
- Engineer, RNLN (11/2022): The time between maintenance is not the main goal, it is a nice to have. The systems should be able to reach their maximum lifespan.
- Manager DMO, RNLN (11/2022): By having better insights in the current and future state of a system you can do a better prediction on maintenance. I don't expect that we will executed structural or periodic maintenance on a later time, this is not good for the planning.
- Head engineering, RNLN (11/2022): You will maintain based on condition, this could be a shorter or longer time period than expected.

How can the decision-speed of maintenance be increased using the PdM ?

- Senior maintenance engineer, RNLN (11/2022*d*): By giving the right priority to analysis.
- Maritime support, RNLN (11/2022): The more data you have, and how better the analysis, the better decisions can be made. This will help the decision speed.
- Engineer, RNLN (11/2022): —The decision speed will be one of the biggest challenges with implementing the model. Decisions should take place according to data and analysis, this will take time. But unless the predictive warning-time is long enough, and the data/analysis is easy accessable, there is no problem.

- Manager DMO, RNLN (11/2022): By using data, the root-cause analysis of a problem can be done faster, which increases the decision speed on maintenance.
- Head engineering, RNLN (11/2022): By creating insights on the installation using data you can know how long an installation will last.

How does the availability of information and knowledge improve using the predictive maintenance model?

- Senior maintenance engineer, RNLN (11/2022*d*): Better registration and the correct feedback, also good training.
- Maritime support, RNLN (11/2022): Enough and well trained personnel.
- Engineer, RNLN (11/2022): By providing the systems with the right information, such that everyone gets good insights.
- Manager DMO, RNLN (11/2022): Unless you immediately process changes in SAP, there will not be a lare change in comparison to the current situation. Now you are reliable on human input, this will stay for the new situation with CSS, with the exception of the first part of the PdM .
- Head engineering, RNLN (11/2022): Because a lot of people will see that reporting will eventually lead to improvements.

How can the Knowledge Improvement Process help embed availability of information and registration for the organization?

- Senior maintenance engineer, RNLN (11/2022*d*): The feedback in the system to the responsible maintenance engineer. This way the system will work for you.
- Maritime support, RNLN (11/2022): The correct usage of SAP.
- Engineer, RNLN (11/2022):It is important that SAP is filled in correctly and this Knowledge Improvement Process should be a part of the standard organizational ashore. It can be a part of quality management of asset management in the organization.
- Manager DMO, RNLN (11/2022): Make sure that there is good registration in SAP, and make the PdM KIP a part of the organizational ashore.
- Head engineering, RNLN (11/2022): It is important that people get good training, such that everyone understands what the system is meant to do.

Is the PdM Knowledge Improvement Process applicable in the organization of the RNLN? How can this process help with the creation of knowledge within the organization?

- Senior maintenance engineer, RNLN (11/2022*d*): Yes it can help, by correctly reporting in SAP
- Maritime support, RNLN (11/2022): Yes, it is already party applied by complex failures and expensive installations. People should learn how to let SAP work for them, instead of against it or with it.

- Engineer, RNLN (11/2022): The applicability will depend on the will and knowledge of users on all levels in the organization.
- Manager DMO, RNLN (11/2022): I think it is applicable, but it depends on the people who need to execute this process. If everyone applies this process, there will be knowledge created.
- Head engineering, RNLN (11/2022): Yes, it is applicable. A good training program is necessary, such that everyone understands it. Also, make sure all the data is correctly in the system.

Any other notes:

- Maritime support, RNLN (11/2022): I think this process is well applicable in the current organization, and will benefit the RNLN.