TU Delft

korabin

The Maintenance Wheel

Creating a Maintenance Management Framework

Photo: (Hansen, 2006)

A Master Thesis by

Henrik Talleraas

Page intentionally left blank.

THE MAINTENANCE WHEEL

CREATING A MAINTENANCE MANAGEMENT FRAMEWORK

BY

HENRIK TALLERAAS

SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF:

MASTER OF SCIENCE

IN

MANAGEMENT OF TECHNOLOGY

FACULTY OF TECHNOLOGY, POLICY, AND MANAGEMENT

DELFT UNIVERSITY OF TECHNOLOGY

GRADUATION COMMITTEE:

CHAIR	: PROF.DR.IR. Z. LUKSZO	TU DELFT	GROUP E & I
FIRST SUPERVISOR	: IR. M. W. LUDEMA	TU DELFT	GROUP T & I
SECOND SUPERVISOR	: DR.IR. Z. ROOSENBOOM-KWEE	TU DELFT	SECTION ETI
EXTERNAL SUPERVISOR	: PARTNER ARE JAASTAD	KARABIN AS	

Page intentionally left blank.

PREFACE

Dear Reader,

The following thesis is the product of six of the most challenging months of my life, both on an academical and personal level. The thesis does not only represent the final challenge of my two years as an M.Sc. student in the Management of Technology program at TU Delft. It also marks the end of 18 years behind a school desk for me. In the following section, I want to thank some of those that have supported me along the way.

First, I want to thank Karabin and Equinor for presenting me with this highly interesting and educational thesis project. Particularly, I want to thank A. Jaastad and K. Gjellestad from these companies. I want to thank them for providing me with a thesis that has helped increase my knowledge of maintenance management, BPM, and performance management more than I could have ever expected. I also want to thank them for taking the time to meet with me during a highly challenging period.

Second, I would like to thank the members of my thesis committee from TU Delft. To my thesis' Chair and Second Supervisor, Prof.dr.ir. Z. Lukszo and Dr.ir. Z. Roosenboom-Kwee, I want to thank both for the quality of feedback and willingness to support me throughout the thesis project. Their insights and support improved my thesis' quality significantly. I also want to extend my greatest gratitude to my first supervisor, Ir. M. Ludema. His guidance and continuous support through regular meetings have been invaluable. Not only did he provide me with useful insights on maintenance management, designing, and research, he helped guide me when I was stuck.

Third, I want to thank my friends. First, I want to thank my friends in Norway who supported me once I decided to move abroad to pursue this M.Sc. degree. Second, I want to thank my friends from The Netherlands and Iceland that I got to know at TU Delft, who made my time in The Netherlands more joyous than I could have ever expected.

Fourth, and most importantly, I want to thank my family and girlfriend. The support you have given me has been extraordinary, and I am not able to thank you enough for your support over the years. For example, in my decision to move abroad. However, I want to focus on the duration of this thesis project. The thesis' kick-off meeting was held one week before Covid-19 resulted in the lockdown of Europe. I had no clue of the effect it would have on me personally. Luckily, the lockdown was initiated while I was at home in Norway. Throughout the thesis, I have been put in mandatory quarantine, had to sit in 9 different (home) office spaces, had three computer crashes, and worked longer days than I could have ever imagined. The list goes on. I think and hope everyone can understand that I would not have been able to complete this thesis without their help and support. Therefore, I dedicate this thesis to them.

Henrik Talleraas
Farsund, Norway
September 2020

Page intentionally left blank.

SUMMARY

Keywords: Maintenance management; maintenance management frameworks; business process management; performance management, diffusion of innovations; design science research.

In a world where companies rely increasingly on machines and automated production lines to deliver customer value, asset availability is a becoming a larger driver of companies' productivity and thus performance. In effect, where maintenance was historically perceived as a cost-centre, it is generally treated as a value-adding business element that must be effectively managed today. However, the increased use of machines and automation has also resulted in an increasing portfolio of assets, often with a highly complex nature. Coupling the growing portfolio of complex assets with factors such as maintenance being a cross-functional activity, stricter HSE requirements, a stochastic maintenance demand, maintenance management complexity has also increased drastically. The result is a reality where maintenance is, on the one hand, becoming more critical to companies' performance. Simultaneously, it is also a large and growing source of operational issues and costs that is highly challenging to improve.

This thesis project is conducted for a consulting firm, Karabin, which is specialised in helping customers realise benefits. Prior to this thesis, they had access to a highly successful way of managing maintenance developed and applied in the industry by a second company, Equinor. This maintenance management approach is called The Maintenance Wheel. It has realised benefits in the magnitude of roughly 10 M EUR per year in combined savings from two of Equinor's facilities. Moreover, it contributed to a significant increase in maintenance quality. In effect, this maintenance management approach provides a way to cope with the increased maintenance complexity, with massive empirical benefits.

Seeing this, Karabin has attempted to help customers with ineffective and inefficient maintenance operations realise benefits through The Maintenance Wheel. However, they have struggled to convince their customers to implement it due to customers struggling to understand the management approach. As senior managers considering The Maintenance Wheel will perceive it as an innovation, Karabin is struggling with an innovation diffusion barrier, caused by a failure to transfer knowledge on how The Maintenance Wheel works effectively.

The management approach was developed internally by Equinor without considering diffusion. Consequently, there existed no conceptual description of the management approach. Seeing this, the thesis project research objective was to ***design an MMF aimed at supporting Karabin in communicating how The Maintenance Wheel works to help cope with the knowledge-based diffusion barrier.*** Note that an MMF is a theoretical framework explaining an approach to managing maintenance. This MMF effectively provides knowledge on how The Maintenance Wheel works. To deliver it, the thesis answered the following research question:

> How can The Maintenance Wheel be effectively communicated through an MMF to help solve the knowledge-based diffusion barrier?

The MMF was developed using a design science research methodology. First, information on The Maintenance Wheel and how to solve its diffusion problem was gathered. This started with a review of literature, to identify applicable knowledge to solve the problem at hand. Thereafter, through in-depth semi-structured interviews with three experts on The Maintenance Wheel, the problem was analysed. Subsequently, the thesis ventured into the design phase, first converting the gathered information into design requirements. Then, using a morphological chart, the design space was constructed, and a satisfactory design identified. To conclude the thesis, the constructed MMF's efficacy was evaluated in a naturalistic setting in an illustrative scenario, with three external senior managers from the oil and gas industry.

The research found that to overcome the knowledge-based diffusion barrier, three main attributes had to be considered when designing, namely the MMF's transferability, complexity, compatibility. This refers to how informative, easy to understand, and relevant it is for a customer, respectively. While a balance between transferability and complexity was stricken by creating a design based on reductionism, compatibility is heavily influenced by the customer context. Thus, while evaluating, the framework was adapted to reflect maintenance in the oil and gas industry.

It was found that maintenance management is a highly fragmented field of literature, resulting in there being no standardised style or specification of what elements to include in an MMF. Despite the different styles of MMFs identified, a list of reoccurring elements was identified. This list helped identify what elements to focus on while creating the MMF based on The Maintenance Wheel. These elements include strategic maintenance activities, the control function (e.g. performance measurements), maintenance planning, maintenance execution, and some form of way to continuously improve. Additionally, the relationship between all of these elements is explicit, usually through a visualisation.

The thesis found that The Maintenance Wheel is an approach to maintenance management where BPM and performance management is used to manage the entire end-to-end processing of both corrective and preventive work orders. Note that the process used to process work orders is referred to as the maintenance process, and covers tasks from when a maintenance notification is created until a work order has been processed. By standardising the maintenance process and tracking the progress of each work order through the process in metrics related to the quality of the work and the time used, companies can generate easily actionable process performance data, in particular for the operational level of the maintenance process. Effectively, the goal is to ensure process flow. Essential to this are four concepts. The process is standardised by (1) defining best-practice standards specifying how to execute each task and defining corresponding performance indicators related to estimated time and expected quality, (2) standardising the task sequences by how work orders are processed, and (3) the standardisation of interfaces between sub-processes in the overarching maintenance process through customer-supplier agreements. Subsequently, by comparing the actual work performance of each task executed against the best-practice standard, on performance indicators related to quality and time, waste is easily identified enabled, and quality of the maintenance work ensured. Through this, (4) continuous improvements based on performance management are realised.

In terms of practical contributions for Karabin, the evaluation indicated that the constructed MMF sufficiently communicates how The Maintenance Wheel works. After a brief presentation with senior managers with no prior knowledge of how The Maintenance Wheel worked, it was possible to have in-depth discussions. Thus, the knowledge-based diffusion barrier caused by customers' senior managers not understanding the management approach should be solved. Nevertheless, the evaluation also showed that one particular area of future development is required. The senior managers interviewed requested examples of how the framework works in practice. In effect, to help more effectively transfer knowledge on how The Maintenance Wheel works, Karabin should provide more relevant examples of how the different elements of the framework works that are relatable for their customers.

In terms of practical contributions for companies in general, the thesis project addresses a pressing managerial issue. As explained, maintenance is rapidly becoming more critical to companies' performance. Simultaneously, it is also a large and growing source of operational issues and costs that is highly challenging to improve. While the thesis found that many solutions have been developed by academia to cope with the growing problem, few of them are adopted by real-world organisations. The thesis project found that the gap is generally caused by deficiencies lowering the practical relevance of the academic solutions, such as the lack of empirical benefits or a focus on complex mathematical modelling that is challenging for practitioners to understand. The designed MMF, on the other hand, communicates a way to manage a maintenance process which has massive empirical benefits from two large, real facilities. Thus, it provides practitioners with a proven way to deal with the many challenges of maintenance management. This being said, the MMF was designed for Karabin. External practitioners are, therefore, advised to take a proactive approach while examining the designed MMF, to interpret and make the necessary changes in order to make the MMF reflect maintenance in their particular business context.

The thesis project delivers a significant academic contribution to the body of knowledge on maintenance management. First of all, maintenance encompasses activities from a broad array of functional departments. Seeing that maintenance is perceived as a strategic, value-adding activity today, it is important to facilitate for continuous improvements in all of these activities. However, while publications discussing the application of BPM to manage maintenance activities were identified, which in itself appears to be an underexplored topic, none of them discusses how to effectively manage maintenance as an end-to-end business process with BPM and performance management. In other words, prior research on maintenance management has primarily focused on improvements for one and one maintenance activity, and not on collective process-improvements. For example, none of the publications reviewed for this thesis provides a way to measure the process performance of the end-to-end maintenance value-chain based on time. Thus, by creating the MMF which communicates how The Maintenance Wheel works, a new way of managing maintenance is introduced to the literature. Effectively, the thesis opens up a for how to effectively manage maintenance as an end-to-end process, e.g., by the elimination of waste between activities in the maintenance process.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

"If you want something new, you have to stop doing something old."

Peter Drucker

1. INTRODUCTION

1.1 The increasing importance of maintenance management

The historical perception of maintenance, especially within manufacturing firms, has been to view it as a necessary evil to keep production facilities running (Fraser, 2014). However, with its increasing importance to companies performance, this perception started to change towards the end of the 20th century (Simões et al., 2011). Today, maintenance is generally perceived as a value-adding set of activities that must be effectively managed (Van Horenbeek & Pintelon, 2014).

The change in perception stems from the rising importance of maintenance to companies' performance (Garg & Deshmukh, 2006). The third industrial revolution, associated with the introduction of ICT and electronics to ensure process and manufacturing automation, has played a big part in this (Fordal et al., 2019). Fordal et al. explains that, historically, a firm's productivity was determined by how quickly its operators could operate the machines of the production line. Today, on the other hand, as tasks are being increasingly automated, productivity is driven increasingly by equipment availability, i.e., by effective maintenance. In turn with this development, maintenance has today been directly linked to companies' productivity and profitability (Alsyouf, 2007; Swanson, 2001), and is also becoming more critical to product quality and compliance with safety regulations (Al-Najjar & Alsyouf, 2003).

However, due to asset automation, maintenance costs and complexity is also rising (Han & Yang, 2006). Today, there are large amounts of capital locked in maintenance budgets, with estimates ranging from roughly 15-70 % of companies' total operating costs (Bevilacqua & Braglia, 2000; Parida & Kumar, 2006). Several factors cause this massive spread, but typically, the more capital intensive a firm is, the larger the maintenance expenses will be (Maverick, 2018). Because of maintenance making up such a large part of operational budgets, even smaller changes in maintenance efficiency can have a tremendous effect on companies' bottom line. An estimate of maintenance projects returns on investment found that saving one million euros in maintenance expenditures is equivalent to increasing sales by three million euros (Wireman, 1997).

However, despite the immense and continuously increasing importance of maintenance to companies' performance, current maintenance operations are generally characterised by several issues. In an extensive literature review, Phogat and Gupta (2017) identified several of these issues, namely the (1) lack of benchmarking, (2) lack of communication and information, (3) lack of empowerment, (4) lack of teamwork, (5) lack of commitment of employees towards maintenance, (6) lack of training, (7) lack of strategic planning and implementation, (8) lack of top management support, (9) lack of awareness about safety and health, (10) lack of effective performance measurements, and (11) lack of OEE measurements (pp. 229–233). From the list of issues, it is observed that all the problems are connected to faulty maintenance management.

The European Committee for Standardisation defines maintenance management as all activities "[…] that determine the maintenance requirements, objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics" (2017, p. 9). In Figure 1, adapted from The Norwegian Petroleum Directorate (NPD, 1998), the connection between the core maintenance management activities is illustrated.

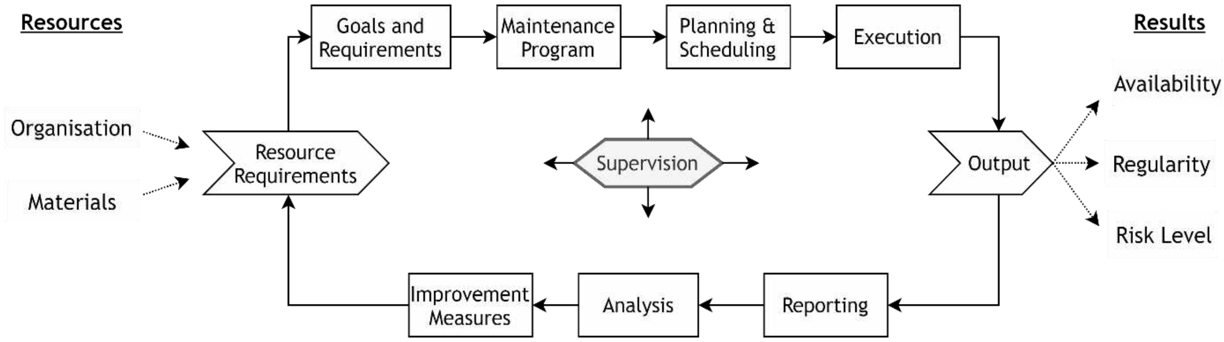

Figure 1: Maintenance management activities. Adapted from NPD (1998, p. 9).

Why do companies struggle to manage maintenance? While it is necessary to understand that barriers may also be identified per activity, the focus is on overarching issues due to relevance. In a literature review of such barriers, Crespo Márquez (2007, pp. 11–13) identified several barriers: (1) a lack of models to improve the underlying understanding of maintenance, (2) a lack of plant and process knowledge and data to help staff make suitable improvements, (3) a lack of time to analyse the data available, (4) a lack of top management support, (5) increased safety and environmental requirements have increased maintenance management complexity, (6) the broad span of maintenance activities makes it difficult to create a system to facilitate for continuous improvements, and (7) the increased use of advanced manufacturing technologies has increased maintenance complexity. Overall, Crespo Márquez (2007) state that the barriers have a negative influence on maintenance managers work schedule, resulting in the situation visualised in Figure 2. The figure shows how maintenance managers lack time to optimise their maintenance schedules to avoid unnecessary breakdowns, as well as to analyse data to identify possible improvements. Resultingly, they are faced with an abundance of short-term issues that must be prioritised.

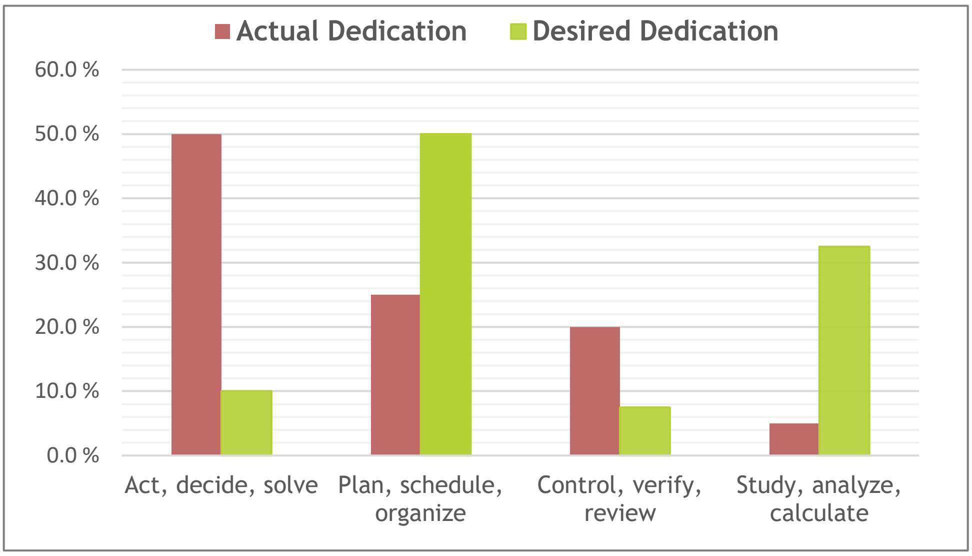

Figure 2: Maintenance managers time dedicated to each task versus their desired allocation. Adapted from Márquez (2007, p. 12).

Because of the many challenges associated with maintenance and maintenance management, several attempts have been made by academia to optimise maintenance management. As will be explained in-depth in Chapter 3.2, these attempts range from being focused on smaller parts or activities of maintenance management, to combinations of various optimisation techniques to provide complete frameworks for how to manage maintenance for organisations. The latter is often referred to as a maintenance management framework (MMF). While there is no standardised definition, MMFs generally describe the entire system and activities used to manage a maintenance process (Crespo Márquez, 2007). However, there is a problem with these academic solutions. Both Van Horenbeek et al. (2010) and Fraser et al. (2015) found that there is a clear gap between academic attempts to optimise maintenance and their adoption by real-world organizations. It is further examined in Chapter 3.2 why this is the case.

To summarise, the importance of maintenance has increased significantly over the last decades. However, the maintenance complexity has also increased significantly, resulting in maintenance by characterised by several operational issues today caused by faulty maintenance management. In connection to this, multiple attempts have been made to optimise maintenance management by academia, e.g., through MMFs. However, these attempts have not been successful, as few academic optimisation efforts are applied in practice.

This thesis aims to design an MMF that may solve this. Instead of attempting to push a solution developed in academia to real-life, an MMF will be developed based on the maintenance management practices of a company that has saved tens of millions from their maintenance budget since developing and implementing a new maintenance management approach in 2014. The background of this new maintenance management approach is now explained.

1.2 Background

1.2.1 Developing a new way to manage maintenance

Equinor ASA (formerly known as Statoil) is a large, Norwegian energy company. Besides a growing portfolio of renewable energy projects, Equinor is mainly engaged in the exploration, development, and production of petroleum, and are the leading actor on the Norwegian continental shelf (Equinor, n.d.-a).

On the western side of Norway lays two oil and gas facilities owned by Equinor: the Sture crude oil terminal and Kollsnes processing plant, which are commonly referred to as Sture and Kollsnes. These facilities share several of the highest-ranking managers due to their geographical proximity, e.g., the head of maintenance.

As stated by Kjell Gjellestad, who was the head of maintenance at the time, these facilities were struggling in 2013. In the years before 2013, optimism in the market space had decreased drastically, resulting in a reduction in profit margins for Sture and Kollsnes (K. Gjellestad, personal communication, 11.11.2019). This was further complicated by internal issues such as a considerable silo mentality among workers, improvement projects not resulting in lasting benefits, and managers being forced to fire-fight short-term instead of pursuing lasting improvements. These issues affected the profitability of both facilities severely, resulting in a situation summarised through the words of a manager as one where "business as usual is [was] not an option" (K. Gjellestad, personal communication, 11.11.2019). In other words, radical changes were needed to become competitive.

In a bid to increase Sture and Kollsnes' profit margins, the management team started looking for possible areas of improvement. Since the oil and gas industry is a capital intensive industry (Trefis, 2014), and that the industry is generally imposed strict regulations to prevent potential catastrophic HSE incidents (DNV GL, n.d.), a substantial maintenance budget is expected. However, the combined maintenance expenditures of Sture and Kollsnes were in the region of 400 million NOK per year in 2013 (roughly 51.2 million EUR at the time), and these expenditures were rapidly increasing (K. Gjellestad, personal communication, 11.11.2019). Therefore, improving maintenance activities efficiency was highlighted as a possible area of improvement.

The solution for Sture and Kollsnes was to develop a new way of managing maintenance developed internally. This solution is commonly referred to as "The Maintenance Wheel" today, albeit this nickname is somewhat unprecise, as is explained on the next page. This new way of managing maintenance utilises business process management (BPM) and performance management to manage the maintenance activities. Simply put, the idea is that by setting up the set of activities required to complete a maintenance work order into a process and focusing on increasing the flow of work-orders through BPM and performance management, benefits are realised. The sequence of activities required to process a work order is visualised in Figure 3 on the next page.

The decision to implement The Maintenance Wheel in Sture and Kollsnes was taken late in 2013. Since its implementation, the average yearly savings of both facilities (combined) has been approximately 10 million euros, equalling a cost reduction of roughly 25% of all maintenance costs per year (K. Gjellestad, personal communication, 11.11.2019). Other benefits include increased maintenance quality, increased competency among technicians, a reduced backlog of maintenance tasks, and a reduction in injuries of employees (K. Gjellestad, personal communication, 11.11.2019).

Today, Equinor both refer to the new approach to maintenance management, and the model in Figure 3, as "The Maintenance Wheel". In this paragraph, it is explained why these concepts are different and why it is vital to separate them from each other. Figure 3 visualises the sequence of activities required to process a maintenance work order, and who that is responsible for them. However, while the task sequence is an essential part of the solution developed by Equinor, as is explained in-depth in Chapter 4.2.4, it does not tell the full story of how Equinor manages its maintenance process. This is fundamental to this thesis project problem, as described further in

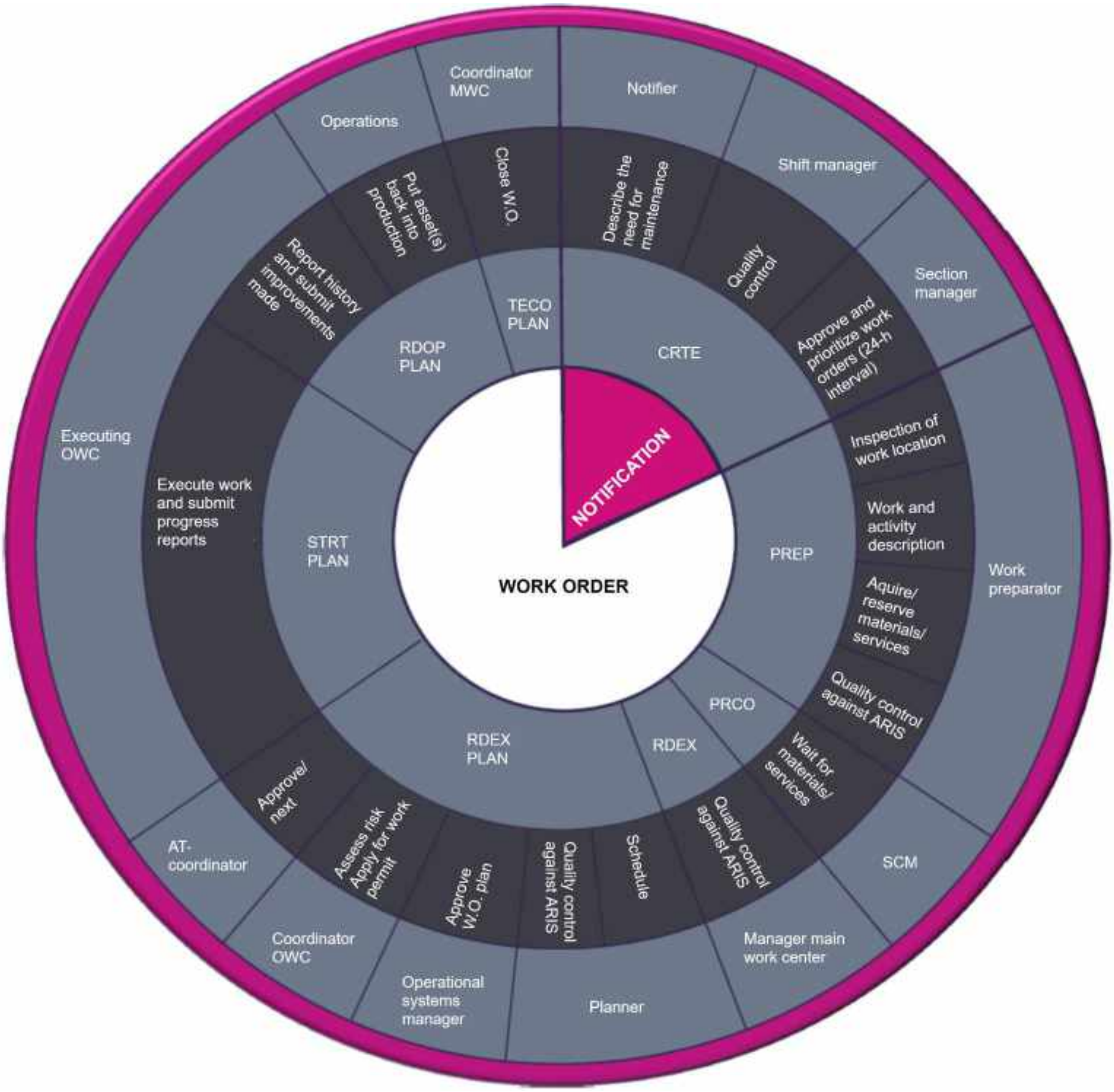

Figure 3: The Maintenance Wheel value-chain © 2020 Equinor ASA (K. Gjellestad, personal communication, 11.11.2019). Note that the figure has been translated from Norwegian to English by the author.

Chapter 1.3. As explained above, Equinor's management approach applied BPM and performance management on the maintenance process. It should be clear from a visual inspection that how they manage the value-chain of work order processing activities is not explained in Figure 3. Therefore, even though the name "The Maintenance Wheel" comes from the way Figure 3 is set up, this thesis uses the "The Maintenance Wheel" to refer to the entire solution developed by Equinor. The reason for doing so is simply that in subsequent chapters, it is the whole solution developed by Equinor that is in focus. Figure 3, on the other hand, will be referred to as "The Maintenance Wheel value-chain" when it is discussed. The Maintenance Wheel, and Figure 3, is explained in-depth in Chapter 4.

1.2.2 Documenting benefits

While implementing The Maintenance Wheel in Sture and Kollsnes, Equinor hired **Karabin AS** in 2016 to aid in two jobs: to assist in the implementation and to document the realised benefits since the project's its initiation in 2013. This thesis is written for Karabin. Karabin is a consultancy firm, also based in Norway, who specialises in corporate process improvements and change management. Their analysis found that The Maintenance Wheel provided a cutting-edge and largely successful way of managing maintenance activities (see Appendix C). From this, Karabin understood that they could use this in their other projects. As Karabin works with realising benefits for organisations, The Maintenance Wheel could provide a novel way of improving their other customers' maintenance processes.

Fast forward to early 2020. Karabin has attempted to convince several of its customers, who could have used The Maintenance Wheel to improve their maintenance performance, to implement it. However, Karabin has struggled in doing so. In practice, The Maintenance Wheel is a large and complex system. Today, there is no in-depth description of what its main elements are and how they combine to realise benefits. Resultingly, Karabin has struggled to describe how this system works sufficiently. To explain this issue further, it is necessary to explore how Karabin realises benefits for their customers. The development leading up to this point has been summarised in Figure 4.

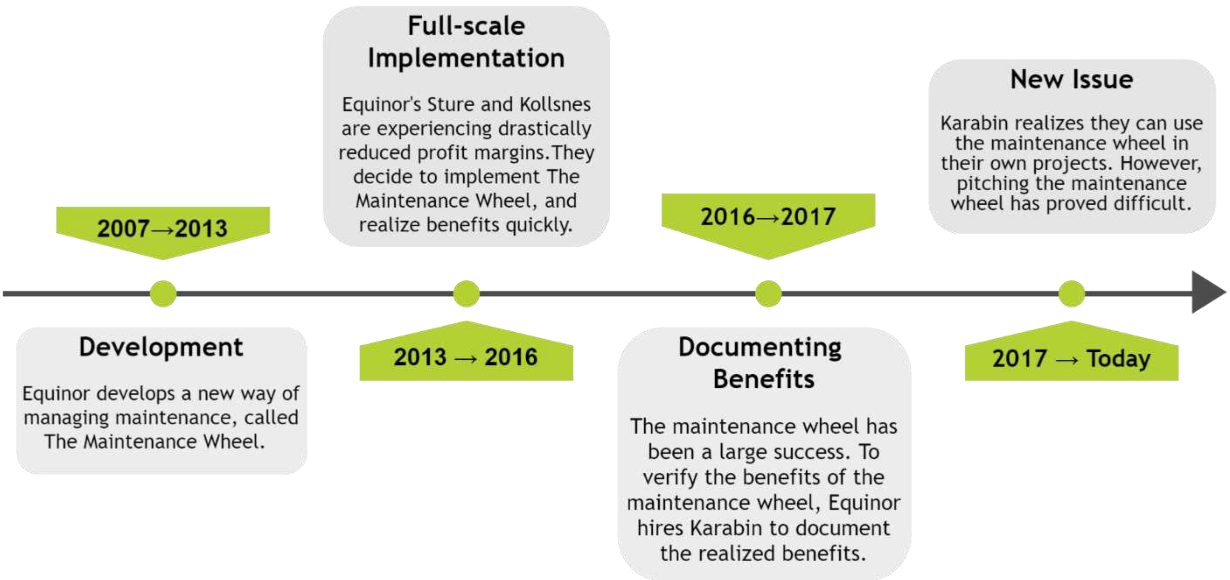

Figure 4: Milestones in The Maintenance Wheel's history. Illustration by author.

1.2.3 Karabin's benefits realisation process

To deliver value to its customers, Karabin uses what they refer to as the "benefits realisation process", visualised in Figure 5 below. While the process itself does not pose a problem to Karabin, it must be described to understand how Karabin has struggled. As visualised in Figure 5, it is made up of three sub-processes, which are discussed next.

The purpose of the first subprocess, the sales process, is simply to come to an agreement with and thus to acquire a potential customer, i.e., it is mostly commercial. Here, Karabin engages in high-level business scoping together with the potential customer, and scope and define, in broad terms, *what* and *where* the customer needs improvements. Subsequently, Karabin makes an offer, estimates the required hours and necessary resources, details contracts, and so on, culminating in an agreement with the customer. When this is done, the project ventures into the next phase, the delivery process.

In the delivery process, Karabin helps the customer realise the benefits agreed upon in the sales process. This is done over three subsequent phases. During the first phase, the customer's current situation is analysed. The goal of this phase is to scope in further on what particular part of the organisation to improve. To end the first phase, the scope of the project is clearly defined based on the situation analysis, culminating in a project mandate being signed.

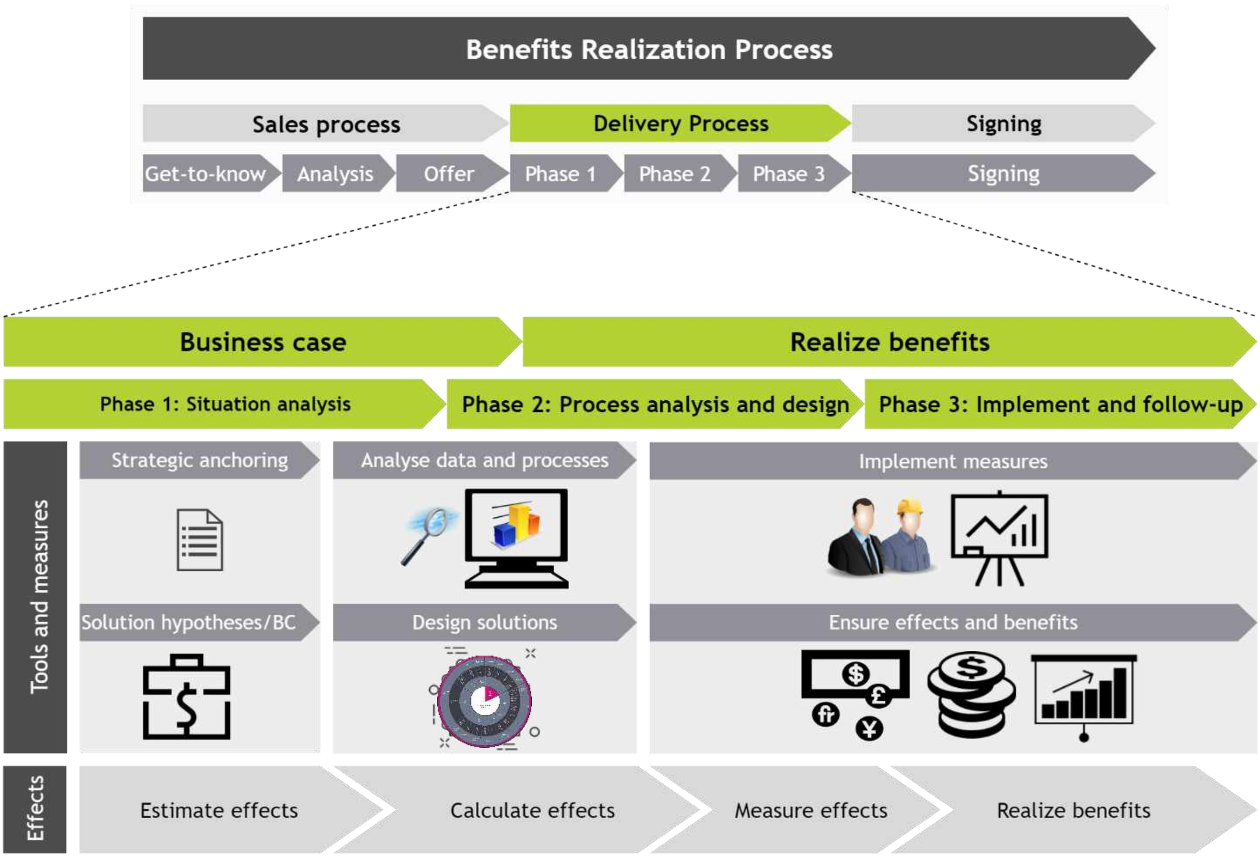

Figure 5: The benefits realization process, adapted from internal documents of Karabin (A. Jaastad, personal communication, 23.05.2020). Notice The Maintenance Wheel's location, showing where it is introduced to Karabin's customers.

Phase 2 is called "process analysis and design". During this phase, relevant processes are mapped and analysed in detail, to identify specific issues. Karabin does also establish a set of hypotheses about the cause of these issues before conducting root-cause analyses. In parallel to this, Karabin drafts up potential solutions. After identifying the root causes, a series of business cases are drafted, which in turn are presented for the customer's management team. This phase is highly important, as the customer essentially decides which solution to implement. In other words, this is where The Maintenance Wheel is presented to the customer.

Phase 3 is referred to as the "implement and follow-up" phase. The first step of this phase is to plan in detail how to implement measures before subsequently implementing them. After that, the effects of the measures are calculated. Corrections may be needed, pending on these results. However, assuming it goes smoothly, Karabin works out and present a report of their effects.

To end their benefits realisation process, Karabin has a practice of having their customer provide a signed letter to validate the value delivered by Karabin. This process is illustrated as "signing" in Figure 5.

1.3 Problem statement

The issue of Karabin covered in this thesis emerges during Phase 2 of the delivery process when pitching business cases. This means after having acquired a customer, analysed its processes, and having identified issues and their root-causes. As explained, Karabin then drafts a set of business cases based on their findings, which are pitched to the customer's senior management. Here, Karabin's customer effectively decides which solution to implement. If it is a relevant solution, this is where The Maintenance Wheel is introduced.

Karabin's experience is that it is difficult to convince the senior managers to implement The Maintenance Wheel, regardless of its immense empirical potential. While discussing with Karabin why this is the case, Karabin state that they have struggled to make senior managers understand how The Maintenance Wheel works. The problem is in effect related to the transfer of knowledge.

Why is the lack of understanding a problem? The Maintenance Wheel is perceived as an organisational innovation by Karabin's customers. This means that research on the diffusion on innovations, concerned with how and why innovations spread differently, is applicable to describe the behaviour of The Maintenance Wheel. Note that an innovation is not defined by its invention date, but as "[…] an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (Rogers, 2003, p. 11). Potential adopters not understanding an innovation pitched to them is a significant barrier to diffusion (Ortt et al., 2013). Effectively, since Karabin is not able to communicate sufficiently how The Maintenance Wheel works, they also struggle to make their customers implement it.

Karabin has struggled because there is currently no description, or illustration, of how the <u>entire</u> solution developed by Equinor works. The only tool available is Figure 3, which only visualises the maintenance process that is managed, not <u>how</u> it is managed. Karabin reiterated this in this thesis' kick-off meeting, where they stated that they lacked a conceptual description of the maintenance management approach developed by Equinor (see Appendix A). Effectively, this has resulted in Karabin having to use an ad hoc approach to communicate The Maintenance Wheel. However, seeing that The Maintenance Wheel is complex, developing a good explanation of the main elements has been challenging.

To summarise, the following problem statement has been defined:

> Karabin struggles to effectively explain how The Maintenance Wheel works to their customers' senior managers when pitching it, and in turn, to convince them to implement it. In effect, Karabin struggles with a knowledge-based diffusion barrier.

1.4 Designing a solution

The thesis uses a design science research (DSR) methodology to solve the problem formulated in Chapter 1.3. The reason is that Karabin's problem is well suited to the purpose of DSR: to design an artefact to solve a real problem (Hevner et al., 2004). In the following subchapter, the research objective and main research question are introduced, before Chapter 2 explains the methodology used in-depth.

1.4.1 Research objective

Recognising the diffusion barrier faced by Karabin, this thesis aims to design an MMF to help Karabin communicate how The Maintenance Wheel works. Before explaining this further, recall that an MMF is a theoretical framework explaining an approach to maintenance management, as described in Chapter 1.1. And again, note that "The Maintenance Wheel" refers to the entire maintenance management approach developed by Equinor, not Figure 3, as explained on page 5-6.

Implementing a new way to manage an end-to-end maintenance process (e.g. The Maintenance Wheel) requires organisational changes. Galbraith (1977) found that three factors commonly affect an organisation's ability to go through changes, namely resources, skills, and knowledge (as cited in Iden, 2018). Applying Galbraith's findings to this thesis' case, the customer considering implementing The Maintenance Wheel needs to provide the resources. Karabin will then help them get the required skills and knowledge through a transfer of competence. It is knowledge which has served as a bottleneck for Karabin. However, the problem does not reside in the knowledge

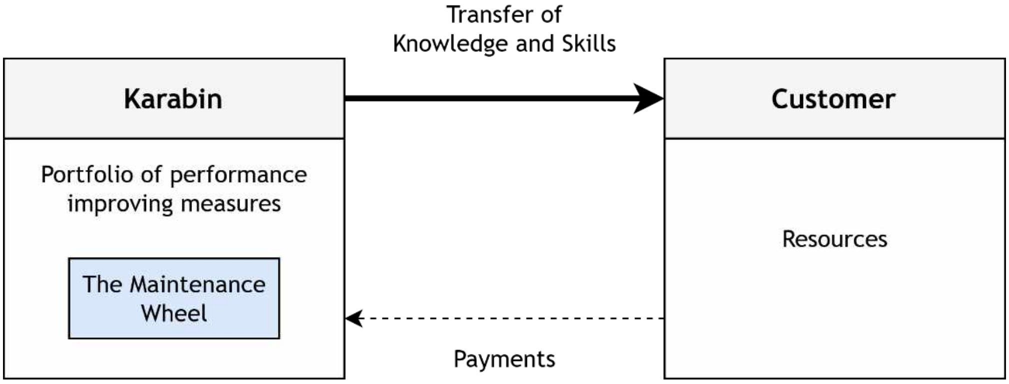

Figure 6: The transfer between Karabin and a customer.

transfer itself. The problem resides in *what* knowledge to transfer, as illustrated in blue in Figure 6. By creating an MMF, a prescriptive solution is developed, providing a comprehensive and conceptual description of how The Maintenance Wheel. In effect, this thesis focuses on *what* knowledge to communicate to make Karabin's customers understand The Maintenance Wheel.

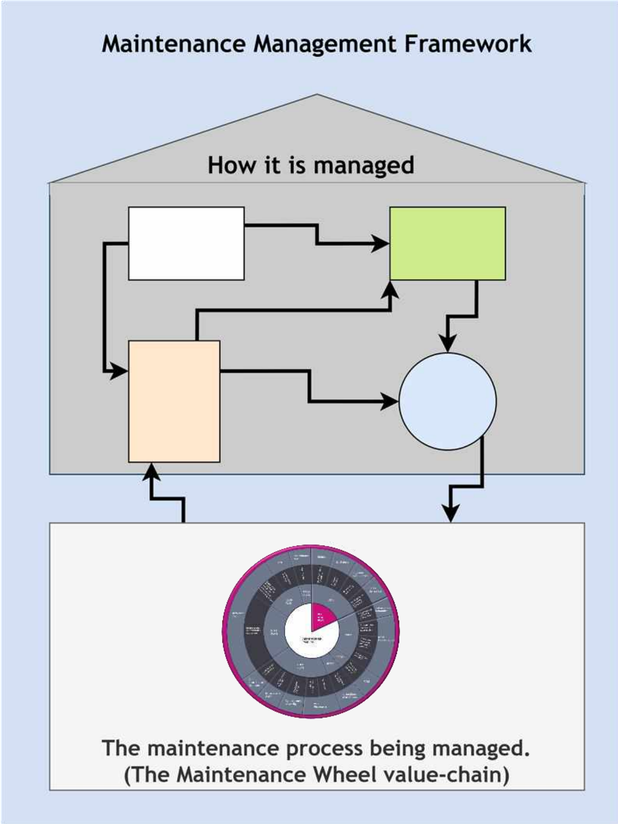

Figure 7: The research objective conceptualized.

To make this objective clearer, recognising that it might be challenging to understand, a metaphor is provided, as conceptualised in Figure 7. If the maintenance management approach developed by Equinor is a house, then Figure 3 only visualises the house' foundation, i.e., the process that is managed. This thesis aims to build a complete house. To construct the MMF, the other building-stones of the management approach must be identified, such as its walls, doors, windows, and roof. Additionally, these elements interconnections and connection to the process being managed must be made explicit, to create the MMF.

Ultimately, the following research objective has been formulated:

> Design an MMF aimed at supporting Karabin in communicating how The Maintenance Wheel works to help cope with the knowledge-based diffusion barrier.

1.4.2 Main research question

To achieve the research objective, the thesis must effectively answer the following research question:

> How can The Maintenance Wheel be effectively communicated through an MMF to help solve the knowledge-based diffusion barrier?

To answer the main research question, a set of research subquestions has been formulated. The purpose of these is to guide the research project and collection of information needed to achieve the research objective. However, these are first introduced in Chapter 2.2. While it is recognised that some researchers would possibly introduce these questions here, it is considered purposeful to introduce them while explaining which methods are used in the thesis project.

1.5 Scope

In the following subchapter, the thesis scope is outlined. This subchapter further elaborates on what the focus of the thesis is, and what is not covered.

First, of all, the thesis project is conducted for Karabin. In effect, the resulting framework is designed to align with Karabin's benefits realisation process (see Chapter 1.2.3). Specifically, the MMF is created to help Karabin during phase 2 of the delivery subprocess. Up until this moment, Karabin does not require assistance, i.e., the acquisition of new customers is not within the thesis' scope. Additionally, from off-the-record meetings with Karabin, they have been able to implement The Maintenance Wheel in customers' maintenance processes once a decision to implement it was first made. Resultingly, implementation of The Maintenance Wheel is not focused on. However, note that interviews with three key experts with an in-depth understanding of The Maintenance Wheel shows that implementation is indeed a substantial challenge, as explained in Chapter 4 and Appendix C. Resultingly, it is a recommendation for future research to analyse the critical success factors of The Maintenance Wheel's implementation.

Chapter 1.3 explained that the failure to provide sufficient knowledge of how The Maintenance Wheel works is a barrier to innovation diffusion (Ortt et al., 2013). Rogers (2003) describes that four main factors influence the diffusion of an innovation, namely (1) the innovation, (2) the communication channels, (3) time, and (4) the social system. While this is not a complete picture for diffusion to companies, as is explained further in Chapter 3.1, it is sufficient with a simpler explanation here. This thesis focuses solely on the innovation, i.e., The Maintenance Wheel. The scope would otherwise be too broad. In effect, while finding out how to solve Karabin's diffusion barrier, only attributes related to the innovation is considered.

It is important to clarify that the MMF will not alter how The Maintenance Wheel works. The designed MMF is simply a tool to transfer knowledge on how The Maintenance Wheel works, which can be used by Karabin. This means that the thesis will not attempt to analyse or make any type of improvements to how The Maintenance Wheel works when implemented. But researching whether it is possible to improve the structure or elements in The Maintenance Wheel is a recommendation for future research.

While the thesis is written for Karabin, generalisability of the designed MMF to a broader set of companies is a priority. The motivation for this was clarified in Chapter 1.1, where it was illustrated that the importance of conducting high quality and efficient maintenance is increasing, while current maintenance operations are in general characterised by several management-related issues. This being said, the MMF was still designed for Karabin. External practitioners are therefore advised to take a proactive approach while examining the designed MMF, to interpret and make the necessary changes in order to make the MMF reflect maintenance in their particular industry. In Chapter 7, an example of how this may be done is provided.

1.6 Thesis outline

Below, the thesis outline visualised in Figure 11 is explained. Note that the logic behind this structure stems from the design process explained in Chapter 2.1.

In Chapter 2, the thesis project methodology is explained. This chapter explains what has been done to solve Karabin's problem and why it was done. This chapter has effectively been separated into three sections. First, the design methodology used is introduced. Second, the research subquestions defined are explained. Third, the methods to answer them are discussed.

Chapter 3 is dedicated to the review of relevant literature. First, attributes important to solve Karabin's diffusion problem is reviewed by researching attributes affecting the diffusion of innovations. Second, relevant fields of the broad maintenance management literature are reviewed, to identify how to best design an MMF. Third, the main sections of BPM literature are reviewed, so to be able to understand and deconstruct The Maintenance Wheel in Chapter 4.

In Chapter 4, The Maintenance Wheel is analysed in-depth, mainly based on five semi-structured interviews with three subjects considered to be key experts on The Maintenance Wheel. The purpose is to identify the management approach' core concepts and how they combine to realise benefits. In effect, this chapter deep-dives into The Maintenance Wheel, describing it on a detailed level.

Chapter 5, the first of two design steps, sees the definition of the design requirements. These requirements ultimately outline what the designed MMF has to do in order to achieve the research objective. Essential to doing so is the information gathered on what attributes that affects the diffusion problem of Karabin, the information on what an MMF should contain, and ultimately how The Maintenance Wheel works gathered in Chapter 3 and 4.

Chapter 6, the second of the two design steps, is devoted to ultimately creating and presenting the MMF based on The Maintenance Wheel. The framework is constructed using a morphological chart. This is a formal design procedure, where various propositions for how to achieve the design requirements formulated in Chapter 5 are used to establish the design space. Note that the design space is the space of satisfactory solutions, spanned by the design requirements (Dym et al., 2014). Subsequently, an MMF is created by selecting from these means and synthesising them into a final design.

In Chapter 7, the constructed MMF is tested and evaluated. This is done by first adapting the designed framework to the oil and gas industry. The reason for this adaptation is explained in-depth in Chapter 2.1.3 while explaining Stage 4 of the research framework. Thereafter, this adapted framework is presented to senior managers from the industry before using a semi-structured interview protocol to evaluate the designed framework's ability to solve Karabin's diffusion problem.

Last, in Chapter 8, the thesis is concluded. First, the research subquestions defined in Chapter 2 are answered. Thereafter, both the managerial and scientific implications are discussed. Then, the limitations of the thesis are addressed before discussing the research quality. Subsequently, the link between the thesis and the master programme it was written for is made explicit, before finally giving recommendations for future research.

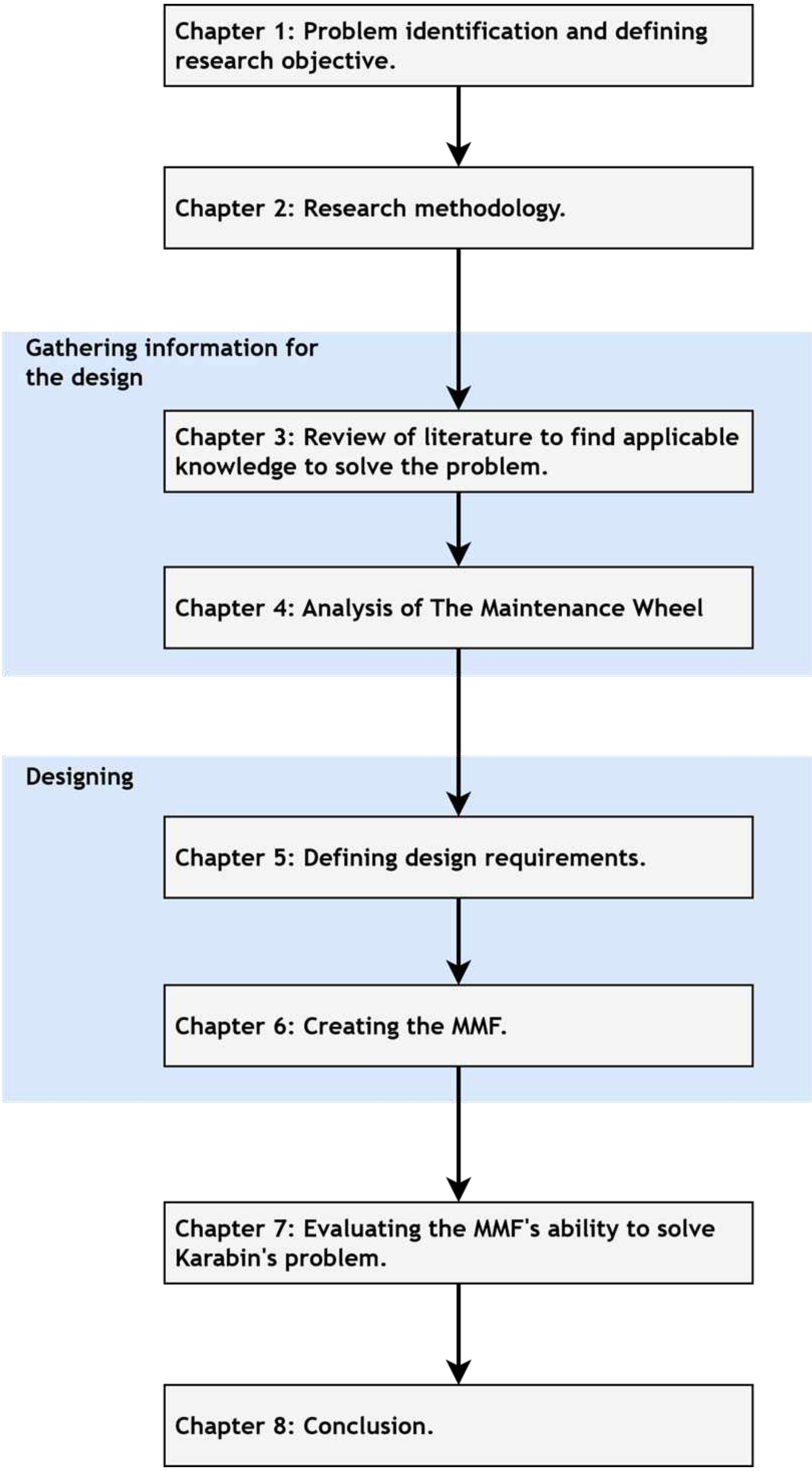

Figure 8: Thesis outline.

"A goal without a method is cruel."

W.E. Deming

2. THESIS PROJECT METHODOLOGY

This chapter describes and discusses the methodology used to design the MMF, aiming to provide rigour to the produced design. First, the methodological approach used, and the resulting research framework is explained in Chapter 2.1. Subsequently, the research subquestions are discussed in Chapter 2.2. Third, the research and design methods used to answer these questions are discussed in Chapter 2.3 and 2.4, respectively. Finally, to conclude what is an extensive chapter, an extended thesis outline is provided in Chapter 2.5.

2.1 Research framework

In this subchapter, the methodological approach used, and the resulting research framework is presented.

2.1.1 Introduction to design science research

The thesis uses a design science research (DSR) methodology to solve Karabin's problem (see Chapter 1.3), as the idealised solution was well suited to the purpose of DSR: to design an artefact to solve a real problem (Hevner et al., 2004). While there is no definition of DSR which is widely accepted, Hevner and Chatterjee's (2010) definition is one of the more cited ones. They define DSR as "[…] a research paradigm in which a design answers questions relevant to human problems via the creation of innovative artefacts, thereby contributing new knowledge to the body of scientific evidence" (Hevner & Chatterjee, 2010, p. 5).

Despite there being no shared definition of DSR, the literature is coherent on what DSR's main characteristics are, as found by van den Akker, Gravemeijer, McKenney, and Nieveen (2006, p. 5). By reviewing influential literature in the field, they found that there are five main characteristics. First, DSR aims to design a real-world intervention. Second, the research is iterative, cycling between design, evaluation, and revision. Third, the evaluation of the design process contributes to theory building. Fourth, the research is process-oriented, meaning that understanding the design process and interventions is essential. Last, the produced artefact's merit is measured partially on the practicality of real-life users.

DSR should result in a contribution generalisable to a broader class of similar problems (Hevner et al., 2004). According to Reubens (2016), this is done by capturing a theory either implicitly informing or that arises from the design process, and making it explicit. This generalisation can enable and aid other researchers and practitioners in similar situations (Dresch et al., 2015).

It is necessary to understand how DSR connects the problem area and the knowledge bases to understand how DSR influences and contributes to knowledge. "Problem area" is referring to the environment (context) where the problem is observed, i.e., the persons, organisations, and technology involved (Hevner et al., 2004). "Knowledge base", on the other hand, refers to the location of knowledge (e.g. theories, frameworks, instruments) used to solve the problem (Hevner et al., 2004). DSR takes the needs presented from the problem area, and relevant knowledge from the knowledge base, to create a satisfactory solution to the problem at hand. This happens through iteration, resulting in an artefact, which "[…] can be thought of as a meeting point […] between an "inner" environment, the substance and organisation of the artefact itself, and an "outer" environment, the surroundings in which it operates" (Simon, 1996, p. 6). The (new) knowledge which emerges from designing, justifying, and evaluating this artefact is then presented to make contributions in the knowledge base and to be applied in the problem environment. See Figure 9, adapted from Hevner et al. (2004, p. 80), for an overview.

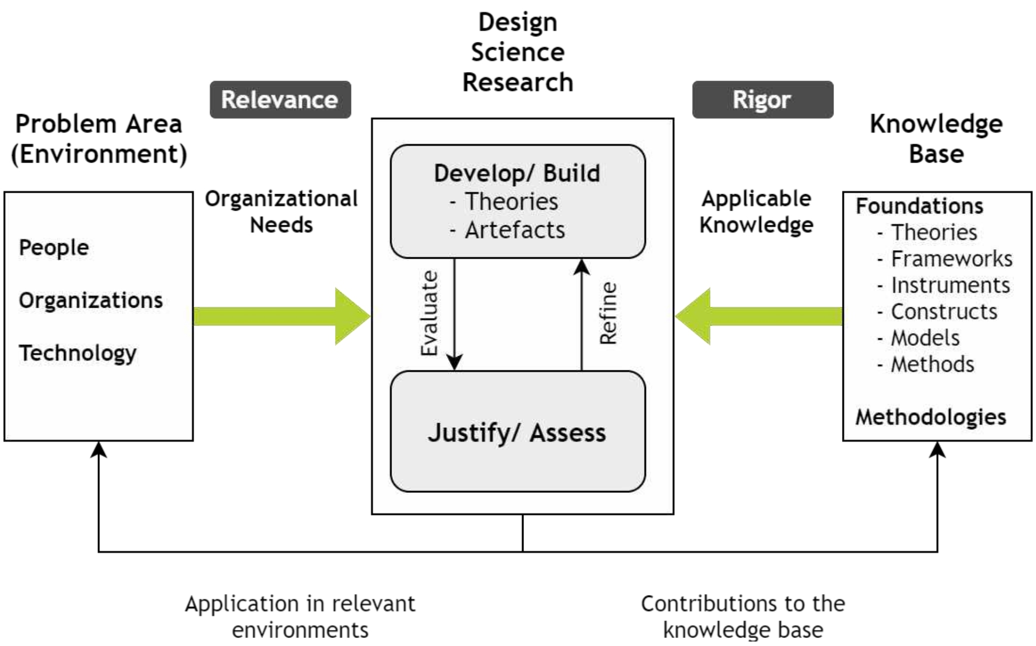

Figure 9: Contributions made in DSR. Adapted from Hevner et al. (2004, p. 80)

2.1.2 DSR frameworks

DSR processes are usually based around four design stages: research, analysis, synthesis, and evaluation, which are iterated continuously until a satisfactory solution balancing practicality versus the ideal outcome has been reached (Plomp & Nieveen, 2013; Reubens, 2016). However, different scholars have defined slightly different DSR frameworks, each with their own pros and cons. Prominent examples are provided by Dresch et al. (2014), Peffers et al. (2007), and Vaishnavi and Kuechler (2007).

This paper uses the highly acclaimed design science research methodology (DSRM) proposed by Peffers, Tuunanen, Rothenberger, and Chatterjee (2007), shown in Figure 10 below, as the basis of the research framework. This DSRM process was selected due to three reasons. First, it was used due to the emphasis on detailing and determining design objectives for a solution. This suits DSR projects with customers of the project (i.e. Karabin) since it is easy to include customer requirements in the design process. Second, as DSR is a relatively new research approach, it was considered purposeful to base the thesis on a popular DSR process. By doing so, it was believed it would be easier to obtain a methodological rigour. The DSRM of Peffers et al. is possibly the most cited DSR process, and most DSR publications reviewed discussed process somehow. This leads to the third point; the DSRM of Peffers et al. is often applied in literature or theses relevant for this thesis, such as engineering, information systems, and management. This made it easy to find relevant examples of how the DSRM could be applied in practice.

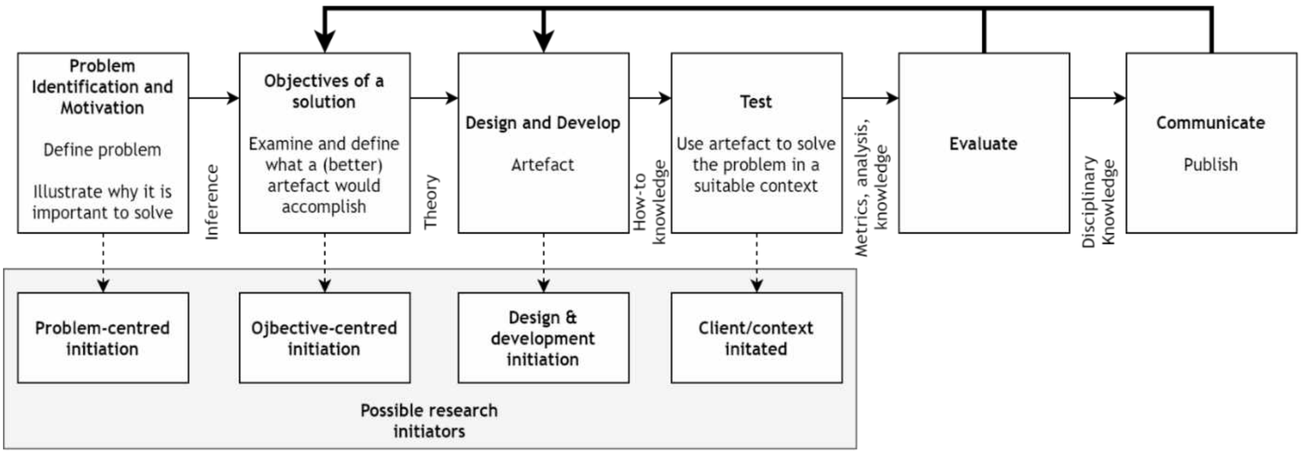

Figure 10: The DSRM process of Peffers et al. (2007, p. 54).

The DSRM of Peffers et al. (2007) was adapted to fit this thesis project better. First, based on arguments by Gleasure et al. (2012) and Reubens (2016), one additional stage was added to the DSRM process of Peffers et al. to increase procedural transparency, namely "gathering knowledge". This stage was inserted between stage 1 and 2 of the DSRM process of Peffers et al., with the goal of increasing the design process' reliability. Furthermore, since the selection of design objectives and requirements is a design activity, this stage was merged with the design stage. The same was done with the test and evaluation stages. The resulting 5-stage research framework is seen in Figure 11 on the next page. Note that while the research framework is illustrated as a linear, sequential process, a design process is iterative. To illustrate this iteration, dotted arrows have been added to the figure.

2.1.3 The research framework

In the following subchapter, the thesis research framework seen in Figure 11 is explained. A research framework is a schematic visualisation of the steps taken to achieve a thesis' research objective (Verschuren & Doorewaard, 2010, p. 19). Seeing that Stage 1 was explained in Chapter 1, it is not reiterated.

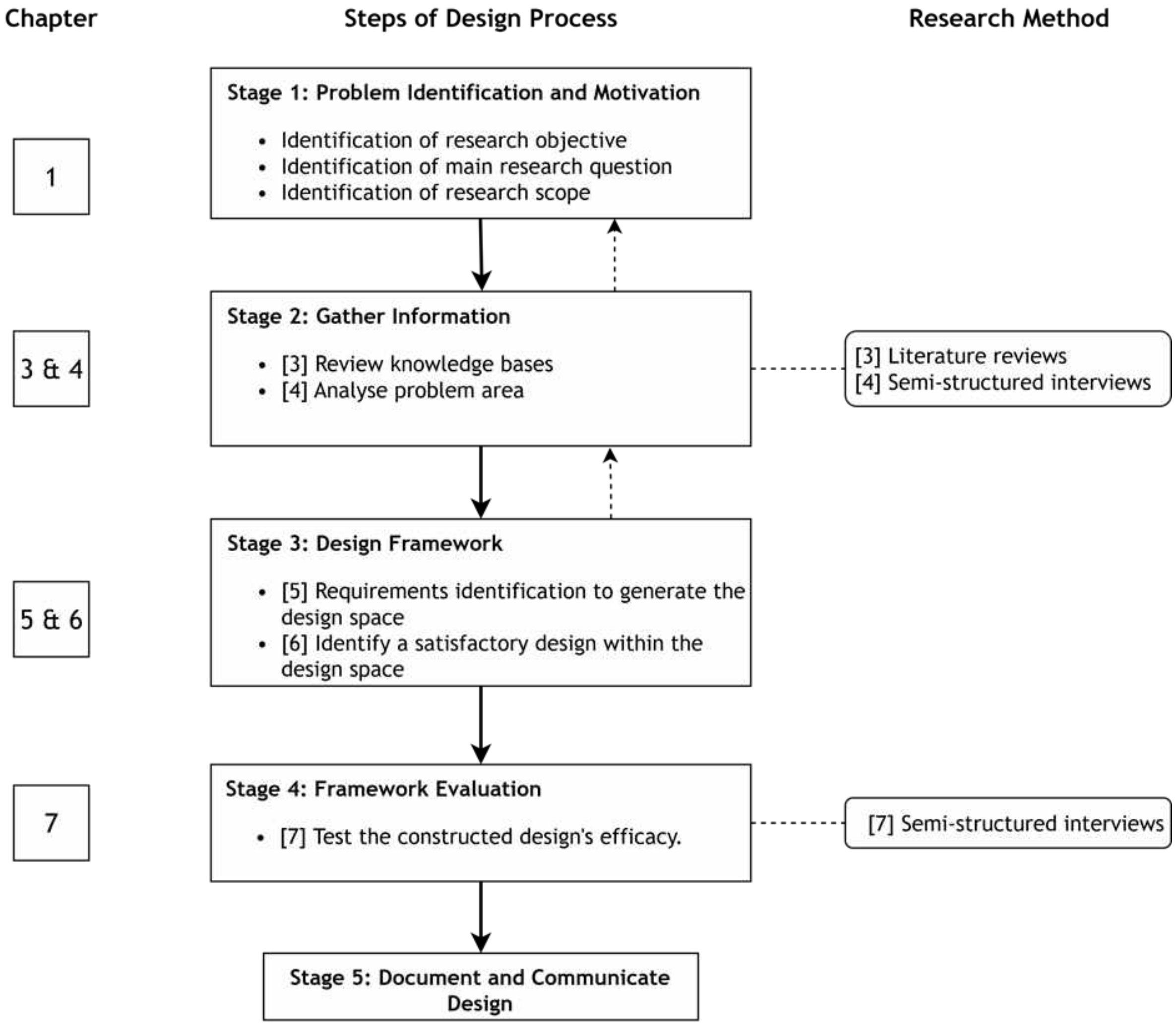

Figure 11: Research Framework.

Stage 2: Gather Information

In order to achieve the research objective, an extensive effort was put on gathering the necessary information to create a satisfactory design. This stems from the complex nature of the problem to be solved. Recalling Figure 9 on page 16, Hevner et al. (2004) described that the relevance of solving a problem comes from the so-called "environment", while the applicable knowledge to solve it comes from knowledge bases. While the two steps of Stage 2 have been named accordingly, it is not as simple in this thesis, as is explained next.

The first activity executed was to review knowledge bases, to identify applicable knowledge to solve Karabin's problem. In this, there were two main areas which needed to be addressed; how could the diffusion problem of The Maintenance Wheel be solved and how to create an MMF. Additionally, it provided the theoretical foundation necessary for the second activity, discussed next.

The second activity, the problem analysis, focused on The Maintenance Wheel. Note that when referring to this as "problem analysis", it is signalled that the knowledge-based diffusion barrier Karabin struggles with comes from the unsatisfactory design of The Maintenance Wheel and not Karabin. To create an MMF based on The Maintenance Wheel, it was necessary to identify The Maintenance Wheel's main elements and the relationships between them. Unfortunately, little had been written about The Maintenance Wheel prior to this thesis, meaning that desk research of existing documents would not be sufficient. Resultingly, an in-depth analysis of The Maintenance Wheel was required. However, Chapter 4 will show how The Maintenance Wheel is based on concepts from the literature, while the knowledge on how to combine these concepts comes from the environment. Effectively, a complex iteration between the review of knowledge bases in Chapter 3 and the problem area was required to analyse The Maintenance Wheel.

Stage 3: Design Framework

After analysing the problem at hand and identifying applicable knowledge for how to solve it, the design is created in Stage 3. This stage consists of two steps: (1) design requirements identification (Chapter 5) and (2) creating the design (Chapter 6).

The first step sees the identification of design requirements, i.e., the requirements needed to achieve the research objective. In combination with the research objective, scope, and the information gathered during Stage 2, a list of high-level design objectives is first defined. While some projects would possibly derive design requirements directly from the research objective, an intermediary step was considered useful to increase the thesis' procedural transparency.

After this, design requirements are derived from the design objectives. Ultimately, two kinds of design requirements are defined: functional and contextual requirements. The types of design requirements used are derived from Verschuren and Doorewaard (2010), who propose three types of requirements for design-oriented research projects: functional, contextual, and user requirements. Functional requirements are what an artefact should do to solve the problem at hand. Contextual requirements are requirements posed by the environment in which the artefact will be used. Last, user requirements are the demands of those who will use the artefact.

Considering the problem that the to-be-designed framework should solve, both contextual and user requirements are combined under the term contextual requirements. The reason for this is simply that the separation between these two requirements is not clear cut in this thesis. The designed MMF is created for Karabin's benefits realisation process (the context), and Karabin and their customer's senior managers (the users). As the rationale of each requirement is discussed in Chapter 5, combining the categories under one term did not significantly affect procedural transparency.

Step 2, where the design was constructed, took the design requirements as inputs. Dym et al. (2014), state that the first step of generating a final design is to establish a design space. They define this as an imaginary intellectual region of design alternatives that contains all of the potential solutions to the design problem at hand, based on the design requirements (Dym et al., 2014, p. 92). Ultimately, this step saw the construction of the design space before a satisfactory design was identified within it. This is explained further in-depth in Chapter 2.4 while discussing the design method used.

Stage 4: Framework Evaluation

Taking the design constructed in Stage 3, Stage 4 of the design process evaluated it. The explanation of this stage is lengthy as evaluating the framework was highly challenging. Thus, it was considered particularly important to explain the decisions made during the evaluation. However, it is first later in this chapter (Chapter 2.3.2), that it is explained which research method that has been used in the evaluation. For a complete overview of the resulting evaluation procedure, see Chapter 7.1, where it is executed.

First of all, the evaluation was summative due to time constraints, meaning that the results were not fed back into the design process to improve the design (Venable et al., 2012). Resultingly, the research framework does not illustrate any arrows are feeding back from Stage 4 to earlier research stages. This stands in contrast to a formative, ex-ante evaluation, where feedback is used to improve the design (Peffers et al., 2012).

According to Johannesson and Perjons (2014) and Peffers et al. (2007), the main purpose of evaluation in a DSR project is to assess the designed artefact's ability to solve the problem it was designed for, i.e., to determine the possible solution's efficacy. However, authors such as Venable et al. (2012) and Sonnenberg and vom Brocke (2012) propose alternative evaluation types. Prat et al. (2014) argue that five main forms of evaluation exist. First, an artefact may be evaluated based on the environment it will be applied in, e.g., on its consistency with people who will use it. Second, the robustness of an artefact's design process may be evaluated. Third, it is possible to evaluate the designed artefact's build quality. Fourth, for artefacts that are designed to do a certain activity, evaluation may focus on activity-centred measures such as consistency and efficiency. However, the last and most common approach remains to evaluate artefacts based on their efficacy (Prat et al., 2014).

The MMF designed in this thesis is evaluated based on efficacy. While it is recognised that the designed framework could have been evaluated on another criterion, Karabin's primary motivation for providing this thesis project was to solve their problem explicated in Chapter 1.3. Resultingly, evaluating whether this was indeed achieved was prioritised. However, evaluating other aspects of the constructed MMF remains a recommendation for future research.

Evaluation of efficacy is a two-step activity (Peffers et al., 2007). First, the artefact must be applied in a suitable context. Thereafter, the artefact's ability to solve the problem can be evaluated. Since the designed MMF is a socio-technical artefact, meaning that it requires human interaction to prove its utility, a naturalistic test was required (Venable et al., 2012). This meant that the framework had to be evaluated in a context with real people in a real environment.

The best way to measure efficacy would have been to use the framework in its intended setting, and to perform a case study. This would have meant to use it in a real pitch for a real customer of Karabin. After that, once could have evaluated whether the design had indeed been able to solve the knowledge-based diffusion barrier. However, this form of an evaluation required Karabin to have an ongoing contract with a customer with maintenance issues. Additionally, no decision should have been made as to what business case to pursue. This was not the case. But do note that this type of evaluation is a recommendation for further research.

Since it was not possible to apply the framework in its intended setting, the framework was evaluated using an illustrative scenario, which is the "application of an artefact to a synthetic or real-world situation aimed at illustrating suitability or utility" (Peffers et al., 2012, p. 402). An illustrative scenario is a weaker form of evaluation, as it is not possible to replicate the same conditions that would have been in the actual setting which the MMF was designed for.

Karabin's issue has been that senior managers have struggled to understand how The Maintenance Wheel works, and in turn, resulted in a knowledge-based diffusion barrier. Thus, in the illustrative scenario, it will be evaluated whether senior managers indeed are able to understand the constructed framework. While it is possible to evaluate whether the senior managers understand the designed MMF removed from the pitching process but measuring if it convinces is not. Being able to convince is dependent on the senior managers examining the designed MMF having an underlying desire to improve their maintenance performance. Identifying such subjects was not feasible, at least not within the time constraints. Resultingly, a compromise was made. The evaluation focuses on the frameworks ability to communicate how it works to senior managers and a set of measures affecting the framework's ability to convince.

Stage 5: Documents and Communicate Design

The last stage of the design process was to process and diffuse the knowledge from the design project. The outcome of this process is the finalised document you are now reading. It was communicated to the research project's customer, Karabin. Furthermore, the thesis is published online and is freely accessible through TU Delft's educational repository. Additionally, the thesis was defended in public on October 5. 2020.

2.1.4 Justifying the methodology

Having explained how DSR works in brief, and how it will be used in this thesis, the reasons for selecting this research methodology is presented below.

First, a design-based research approach was selected due to its focus on solving real-world problems by designing an artefact (Hevner et al., 2004). As explained in the problem statement (see Chapter 1.3), Karabin struggles to communicate The Maintenance Wheel due to the lack of a conceptual framework explaining how to manage maintenance. The methodology did, therefore, suit the problem to be solved.

Second, DSR was chosen over traditional research methodologies since it can solve wicked problems. A wicked problem is, according to Hevner et al. (2004), characterised by (1) varying and changing requirements due to ill-defined problem area, (2) complex interactions between the root-causes of a problem and the solution, (3) malleable design processes and artefact, and (4) dependence on human creativity and social abilities to produce effective solutions. Commonly, design-based research is applied in areas where traditional research approaches struggle (Gleasure et al., 2012; March & Smith, 1995). The issues usually stem from dynamic and poorly defined environments, which renders isolation and measurement of variables to validate theoretical models challenging. Due to the iterative nature of a DSR project, a wicked problem is possible to solve. In retrospect, as Karabin's problem suffered from the same characteristics as those defined by Hevner et al. above, this ability to iterate and adapt the project proved useful on many occasions.

The third reason for choosing DSR is that the methodology not only aims at providing a practical solution to a practical problem; it also seeks to generalise these findings to a broader class of similar problems. This separates the DSR from other change-focused research methodologies, such as action research (Reubens, 2016). Chapter 3 will show that designing an MMF based on The Maintenance Wheel closes a knowledge gap in academia related to time-based performance measurements in a maintenance process. It is believed that the findings of this thesis can provide useful insights to both academia and industry. By examining this thesis, those facing the same types of problems as The Maintenance Wheel solve may see a novel way of managing maintenance activities with proven benefits.

Last, it was long planned to use another design-based approach in this thesis, namely the engineering design methodology of Dym et al. (2014). However, it was difficult to identify relevant literature to provide methodological rigour for this design methodology. Consequently, DSR was selected instead. Researchers have worked to grow DSR as a research approach in its own right for over 25 years (Cloutier & Renard, 2018; March & Smith, 1995; Van Aken & Romme, 2009). This is not meant to say that it has the same methodological rigour as more traditional methodologies, but it appeared as the best choice among design-based methodologies.

2.1.5 Drawbacks of using DSR

Having discussed why DSR was selected, it is also necessary to discuss some of the drawbacks of this methodology.

No Empirical Proof

While it is possible to debate whether this is an issue, it is important to be aware that no "proof" may be found in prescription-based design projects. Instead, supporting evidence is accumulated through the application and evaluation of artefacts in different contexts (Van Aken, 2004). By applying the designed artefact in enough and different contexts, enough supporting evidence may be built to reach "saturation" (Eisenhardt, 1989). Thus, no definite proof may be found that the to-be-designed framework does solve Karabin's problem. However, by applying it in enough and different contexts, a state of saturated evidence may be achieved. As this thesis only evaluates the designed MMFs efficacy in a single industry, applying it in other sectors is a suggestion for future research.

Inherent Subjectivity

It is important to acknowledge the subjectivity is inherent in DSR (Reubens, 2016). The designed MMF is the result of the author's perception of how to best solve Karabin's problem. Different researchers approach the same problem contexts differently, particularly in problem contexts with poorly defined problem areas, ultimately resulting in different artefacts being made (Drechsler, 2015). While a large source of subjectivity was avoided, as the contents of the designed MMF was to a certain degree pre-determined, since the framework had to be based on The Maintenance Wheel, other large sources of subjectivity remained. An example is the relative attention paid to different concepts in the framework or the thoughts on how to best illustrate them.

Measures have been taken to remain as objective as possible. For example, regular meetings with the first supervisor of this thesis have provided another, more experienced and neutral view on the best way to proceed throughout the DSR process. Despite this, subjectivity is unavoidable in DSR (Stahl, 2009). Based on this, it was considered important to provide the highest possible procedural transparency, resulting in the DSR process of Peffers et al. (2007) applied in this thesis being modified in Chapter 2.1.2.

Lack of Coherent Literature

To conclude this section, it is worth mentioning the practical difficulties of reviewing literature related to DSR. There is a lack of coherent literature and standardised definitions. For example, terms such as "design science" are not necessarily referring to DSR but to research of the subject design. Furthermore, articles not mentioning "DSR" may be discussing DSR. This confusion can affect a DSR project negatively, e.g. by citing misleading sources or missing out on influential papers.

To avoid the risk of the fragmented literature affecting the thesis, influential papers were used as starting points. Furthermore, several PhDs using DSR were examined, to identify more sources and to study how researchers using the same methodology structured their research, e.g. Reubens (2016), Östlund (2017), Linnéusson (2018), and Simonofski (2019). Last, note that the author of this thesis had experience with DSR from a course in the ICT specialisation of the master programme, which this thesis was written for (SEN1622 – I&C Service Design).

2.1.6 DSR compliance

The goal of this subchapter is to illustrate that the thesis complies with the DSR methodology, while also potentially clarifying how DSR works in practice for readers unfamiliar with the research methodology. For readers familiar with the methodology, it should not be necessary to read this subchapter.

In the renowned article "Design science in information systems research", written by Hevner et al. (2004), a list of seven guidelines for DSR projects is listed. The goal of these guidelines is to assist researchers and readers in understanding what DSR is and how it should be performed. In this subchapter, these guidelines are discussed in connection with what has been done in this thesis, as listed in Table 1.

Table 1: DSR guidelines connection to this thesis. The two columns in the middle are adapted from Hevner et al. (2004, p. 83).

#	Guideline	Description	Connection to thesis
1	Design as an artefact	DSR must result in an artefact, e.g. a framework, a model, or a method.	This thesis focuses on creating an MMF based on The Maintenance Wheel.
2	Problem relevance	The purpose of DSR is to produce artefacts which act as solutions to important and relevant business problems.	**Karabin's problem:** The MMF was designed to help Karabin communicate how to manage a maintenance process based on The Maintenance Wheel. Karabin has seen that The Maintenance Wheel has immense potential for its customers. However, because they have struggled to communicate how The Maintenance Wheel works, Karabin has struggled to convince their customers to adopt what is considered a solution with high potential. **Companies in general:** The importance of maintenance is increasing (see Chapter 1.1), but there are currently several issues with

			maintenance caused by faulty maintenance management. The designed MMF provides companies with a management approach, directly addressing many of the barriers to efficient maintenance management discussed in Chapter 1.1.
3	Design Evaluation	Artefacts value (e.g. utility, quality, and efficiency) must be rigorously demonstrated through properly conducted evaluation methods.	The efficacy of the designed MMF is tested by presenting the framework to senior managers from different companies in the oil and gas industry. There, the MMF's ability to meet the research objective is evaluated based on qualitative data gathered using a semi-structured interview protocol.
4	Contributions from the research project	DSR must (either) result in verifiable contributions in the artefact's application area, the disciplines which the artefact is based on, and/or of the used design methodology.	**Problem area:** The evaluation shows that the interviewed senior managers understand the MMF, i.e., it can likely be used by Karabin to communicate how The Maintenance Wheel works to their customers. Additionally, it scored positively in attributes influencing the framework's ability to convince senior managers. **Knowledge base:** Initially, the plan was to review the application of BPM on maintenance processes. However, there is a considerable knowledge gap here. The lack of time-based performance measurements in a review of different approaches to measuring maintenance performance illustrates this gap. In effect, the designed framework closes a knowledge gap. The framework shows how to apply time-based process measurements and standardisation on the maintenance process, to realise process-based performance improvements.
5	Research Rigor	DSR must be conducted with rigorous methods, both to construct and evaluate an artefact.	Later in this chapter, the various research and design methods applied in the thesis are discussed in-depth. This is done to provide rigour to the design process.
6	Design as a Search Process	A satisfactory artefact is the result of a search process where the available means are used to solve an issue in a given problem environment.	To produce an MMF that could help solve Karabin's problem, much time went into researching which means were available. While the thesis reads like a linear design process, the reality was much iteration. This iteration was particularly prominent between the first two stages of the research framework (problem definition, literature reviews, and describing The Maintenance Wheel).

7	Communication of Research	The outcome of the DSR project must be effectively communicated.	The thesis is published online in TU Delft's online repository, where it is freely accessible. Additionally, it was shared with Karabin and defended in public.

2.2 Research subquestions

Recall the main research question formulated in Chapter 1.4.2:

> How can The Maintenance Wheel be effectively communicated through an MMF to help solve the knowledge-based diffusion problem?

To answer the main research question, a set of research subquestions has been defined. These subquestions guided the collection of information, thought to be either useful or necessary, to achieve the research objective (see Chapter 1.4.1). The distribution of the research subquestions over the different research stages is seen in Table 2. After explaining the formulated research subquestions rationale, the remaining subchapters of Chapter 2 explain the methods used to answer them.

The first four subquestions are answered in the second design stage, explained in the previous subchapter. Of these, [RQ1] and [RQ2] provide insights on what attributes that are important to overcome Karabin's diffusion problem. First of all, recall that The Maintenance Wheel, and thus also the designed MMF which communicates how it works, will be perceived by Karabin's customers as an innovation (Chapter 1.3). Given this, the first subquestion provided insights on which attributes of an innovation that would affect the designed MMF's ability to overcome Karabin's knowledge-based diffusion problem, narrowing down on a set of relevant attributes. The second subquestion investigates why there is a gap between academic attempts to optimize maintenance and their adoption by real-world organizations, as explained in Chapter 1.1, seeing that simply designing an MMF might not be enough to overcome Karabin's diffusion problem. Third, [RQ3] identifies how to construct an MMF, i.e., a theoretical framework of an approach to maintenance management. Furthermore, it investigates what elements to avoid, considering the gap between academic solutions to maintenance issues investigated in [RQ2]. Last, [RQ4] investigates how The Maintenance Wheel works.

In the third research stage, the gathered information is converted into an MMF. This is done by answering [RQ5] and [RQ6]. First, considering the information gathered in the previous design stage, a list of design requirements is identified by answering the fifth subquestion. These requirements essentially specify the boundaries of what a satisfactory MMF, capable of solving Karabin's diffusion problem, has to do. Second, a satisfactory MMF is constructed by answering the sixth subquestion, i.e., to identify a satisfactory solution from the design space. For those unfamiliar with design terminology, note that the design space is an imaginary intellectual region of design alternatives that contains all of the potential solutions to the problem at hand, based on the design requirements (Dym et al., 2014, p. 92).

In the last stage, [RQ7] was answered. By answering this subquestion, it was assessed whether the constructed framework indeed achieved the research objective of helping to solve Karabin's knowledge-based diffusion problem.

Table 2: Research subquestions.

Design Stage	RQ #	Research Subquestions
Gathering Information	1	Which attributes of an organizational innovation can be influenced to solve a knowledge-based diffusion barrier?
	2	Why is there a gap between academic attempts to optimize maintenance and the application of these solutions in real-world organizations?
	3	What functions or elements should be in an MMF, and do the reviewed MFFs experience the same deficiencies identified in [RQ2]?
	4	What are the main elements of The Maintenance Wheel, and how do they combine to realize benefits?
Design Framework	5	What requirements does the MMF have to satisfy to provide a satisfactory solution, considering the research objective and gathered information?
	6	What does a satisfactory MMF from the design space look like?
Framework Evaluation	7	Can the constructed MMF help Karabin overcome the knowledge-based diffusion barrier of The Maintenance Wheel?

2.3 Research methods and data processing

Research methods have been used to answer [RQ1]-[RQ4] and [RQ7]. This subchapter first explains the two research methods used, "literature review" and "semi-structured interviewing", in Chapter 2.3.1 and 2.3.2. To conclude the subchapter, the procedure used to process the qualitative interview data gathered is explained in Chapter 2.3.3.

2.3.1 Literature review

[RQ1]-[RQ3] was answered by a review of literature. Additionally, reviewing literature was essential to answering [RQ4]. The following subchapter first explains the employed literature review techniques. After that, it is explained how each of the research subquestions was addressed.

Employed Literature Review Techniques

While many types of literature reviews exist, the traditional literature review's purpose may be defined as "the selection of available documents […] on the topic, which contains information, ideas, data, and evidence written from a particular standpoint to fulfil certain aims or express certain views on the nature of the topic […], and the effective evaluation of these documents in relation to the research" (Hart, 1998, p. 13).

Four main fields of literature are reviewed: MMFs, maintenance performance measurements, BPM, and diffusion of innovations. Two types of literature reviews have been used: traditional and conceptual reviews (Jesson et al., 2011). The review of the first two fields aligns with the definition of Hart (1998) above, i.e., to identify, examine, and critically compare prior work in the fields. The reviews of BPM and diffusion research, on the other hand, are conceptual.

Traditional reviews are characterized by rigorous search procedures to be able to critically compare publications within a given literature field of interest, for example, to identify common or diverging perceptions (Jesson et al., 2011). An explanation of the search procedure is found in Appendix B. There, aspects such as the search strings, the various databases, and the selection criteria used are discussed.

Conceptual reviews do not follow as strict review procedures as traditional literature reviews. The main criterion for these reviews is that the included literature is cross-checked for accuracy. Resultingly, they are quicker than traditional reviews which utilize stringent search processes, but with the caveat that they are not suited when different publications within a field of interest have to be critically compared (Jesson et al., 2011).

Next, it is explained how the respective research subquestions were answered through the reviews.

[RQ1] - Which attributes of an organizational innovation can be influenced to solve a knowledge-based diffusion barrier?

Research on the diffusion of innovations was reviewed to answer [RQ1] in Chapter 3.1. It was not considered necessary to critically compare different publications to answer this research subquestion, i.e., it was answered with a conceptual review. This was done by reviewing popular literature reviews in peer-reviewed journals, and cross-checking that the findings aligned. However, note that it is first addressed in connection to the design requirements identification in Chapter 5.1 which of these attributes that may be used to solve the diffusion barrier.

[RQ2]: Why is there a gap between academic attempts to optimize maintenance and the application of these solutions in real-world organizations?

This question is answered in the introduction to the traditional review of MMFs in Chapter 3.2.3. MMFs are based on concepts from the broader maintenance management literature. Thus, since it was not expected that the audience of this thesis had an in-depth understanding of maintenance and maintenance management, an introduction to these fields is given before reviewing MMFs. It is in connection to this introduction that [RQ2] was answered. To answer [RQ2], previous, journal-published studies of why the gap existed and their findings were reviewed.

[RQ3]: What functions or elements should be in an MMF, and do the reviewed MFFs experience the same deficiencies identified in [RQ2]?

This question is answered in Chapter 3.2 by critically comparing different MMFs in a traditional review, and using the information gathered when answering [RQ2].

[RQ4]: What are the main elements of The Maintenance Wheel, and how do they combine to realize benefits?

The Maintenance Wheel is based on concepts from academia. Resultingly, to answer [RQ4], it was necessary to review literature covering these concepts. The mentioned review of different MMFs contributed, but the most important theoretical foundation came from a traditional review of maintenance performance measurement approaches (Chapter 3.3) and a conceptual review of BPM (Chapter 3.4). But do note that the literature reviewed did not directly answer [RQ4]; this was done with the semi-structured interviews discussed below.

2.3.2 Semi-structured interview

Two sets of interviews have been conducted: to analyse The Maintenance Wheel (Chapter 4) and to evaluate the designed MMF (Chapter 7). The purpose of these interviews was to answer [RQ4] and [RQ7], respectively. This chapter explains how these interviews were conducted, i.e., the various aspects summarised in Table 3. Note that "Set 1" refers to the interviews used to analyse The Maintenance Wheel, while "Set 2" refers to the evaluation interviews.

Table 3: Summary of the semi-structured interviews conducted.

	Interview Set 1 – Chapter 4		Interview Set 2 – Chapter 7	
Purpose	Get an in-depth understanding of The Maintenance Wheel to answer [RQ4].		Answer [RQ7] to evaluate the designed MMF's efficacy.	
Interview Length	60-90 min		45-50 min	
Sampling Technique	Judgement sampling		Opportunity sampling	
Subjects	Three key experts on The Maintenance Wheel		Three senior managers from the oil and gas industry	
Data type	Qualitative		Qualitative	
Data analysis	Deductive and inductive		Inductive	
Interview Procedure				
Introduction	Introduce the purpose of the interview. Establish ground rules.	5 min	Introduce the purpose of the interview. Establish ground rules.	5 min
Presentation	-	-	Present the designed MMF.	20 min
Interview	In-depth interview on the maintenance Wheel	50-80 min	Interview to assess the framework's efficacy.	20 min
Conclusion	Conclude interview, alternatively set up a new interview.	1 min	Conclude interview.	1 min

Introduction to interviewing

An interview is a purposeful and guided conversation between two or more people (Sekaran & Bougie, 2016, p. 113). Three categories of interviews are commonly distinguished, pending on the level of structure in the interviews, namely unstructured, semi-structured, and structured interviews (Harrell & Bradley, 2009). In unstructured interviews, there are no prepared questions. Structured interviews are the opposite, using strictly defined lists of questions(Sekaran & Bougie, 2016). This thesis uses the third option, semi-structured interviews. This form of interviewing lay in-between unstructured and structured interviews, on the one hand allowing the probing and flexibility of unstructured interviews, while also imposing part of the structure of structured interviews.

Why were semi-structured interviews used? [Set 1 and 2]

Semi-structured interviews were used while researching The Maintenance Wheel as it provided the depth of information required to answer [RQ3]. Additionally, it was considered useful to be able to ask questions to clarify seemingly conflicting information when something was unclear. The ability to not follow a strict protocol was therefore desirable. According to Harrell and Bradley (2009), semi-structured interviews provides both of these features. While Harrell and Bradley also argue that focus groups provide the same features, it was not a feasible to schedule video conferences with multiple subjects as the interviews were conducted in April-May 2020, at the height of the Covid-19 pandemic.

Regarding the evaluation interviews, semi-structured interviews were partly because of the nature of the designed framework, and partly because of the explicated problem and research objective. First of all, the framework is a socio-technical artefact. As explained earlier, this means that the designed MMF requires human interaction to prove its utility (Venable et al., 2012). Thus, it was necessary to evaluate it in a real setting with real people. Based on this, primarily, three research methods were considered: surveys, interviews, and focus groups. First, it was necessary to research in-depth about whether senior managers understood the framework. Thus, a decision to not use surveys was made, as focus groups and interviews are more prone to provide the depth of information required (Harrell & Bradley, 2009). To decide between focus groups or interviews, it is necessary to understand that the evaluation had to assess whether the interviewed managers understood the framework. Due to this, it was considered beneficial to understand how individual subjects perceived different parts of the framework. According to Harrell and Bradley (2009), focus groups are less suited to obtain this type of information, e.g., due to the participants moderating themselves because of the other participants in the group. Additionally, focus groups are less qualified to determine what issues individual managers had with different parts of the framework, as members of focus groups do not necessarily share the same perception (Harrell & Bradley, 2009). Resultingly, semi-structured interviews were used.

Sampling and Interview Subjects [Set 1]

Due to the type of data required to answer [RQ4], judgement sampling was used to select interview subjects for Set 1. Recall that [RQ4] aimed to identify the main elements of The Maintenance Wheel and their interconnections. Characteristic of this form of sampling is that interviewees are selected based on their knowledge and expected contributions to the research (Harrell & Bradley, 2009). In other words, since the goal of the interviews was to explore and describe The Maintenance Wheel in-depth, subjects with an in-depth understanding of the maintenance management approach were interviewed.

The dominant type of data gathered to analyse The Maintenance Wheel is objective background information, i.e., information such as facts and descriptions of contemporary phenomena (Harrell & Bradley, 2009). The largest risk of bias in this type of data was considered to be interview subjects forgetting crucial information. Based on this, a smaller sample size, with in-depth interviews with subjects having different perceptions of The Maintenance Wheel, was deemed sufficient. In total, three subjects were interviewed, with more than 6 hours of recorded interviews. Their profiles are introduced in Chapter 4.1.2, in connection to the analysis of The Maintenance Wheel.

Sampling and Interview Subjects [Set 2]

It is necessary to understand that there were some attributes required or desirable when selecting suitable subjects for the evaluation interviews. First, it was necessary with senior managers. This is because the framework was designed to help communicate The Maintenance Wheel to the senior managers of Karabin's customers, as it is with them that the knowledge-based diffusion barrier has been experienced (see Chapter 1.3). Second, it was critical to interview subjects who did not know of The Maintenance Wheel prior to the interviews, as the interviews' purpose was to assess whether the designed framework was indeed able to communicate how The Maintenance Wheel works. This was an absolute requirement, as the evaluation would have no purpose otherwise. Third, it was necessary with subjects from the oil and gas industry, as the evaluation would take place in this industry (explained in Chapter 2.1.3 under Stage 4). Last, it was considered necessary to have subjects with maintenance experience. Without an understanding of maintenance and the challenges of managing it, there would be little use in interviewing subjects on whether they believed it was a useful approach to maintenance management.

Since it was not a goal to generalize the findings, but to test efficacy, a smaller sample was used given time constraints. Additionally, since it was not an objective to generalize the findings, opportunity sampling was used (Harrell & Bradley, 2009). This is a sampling technique where subjects not necessarily planned to be interviewed are interviewed. Specifically, respondents were selected using an intermediary with connections in the senior management of several oil and gas companies, and have him, based on a list of requirements to, propose subjects which were then contacted and asked to participate in this evaluation. Resultingly, three interviews of roughly 45 minutes were conducted with senior managers from different companies in the oil and gas industry to evaluate the designed MMF. Their profiles are discussed in connection to the evaluation, in Chapter 7.3.1.

Interview procedure [Set 1 and 2]

All interviews were conducted according to a RAND manual on how to conduct semi-structured interviews presented by Harrell and Bradley (2009). RAND Corporation is a non-profit research organisation offering research and analysis guidance on how to improve decision-making and policy, funded by the US Government (RAND, n.d.). The benefits of using a RAND manual is that they provide peer-reviewed, in-depth explanations. In other words, they provide a middle way between a journal-published article and a book, combining the peer-review characteristic of articles while also allowing the in-depth explanations of books. Also, a book on different research methods by Sekaran and Bougie (2016) was consulted to complement the RAND manual.

As mentioned, the interviews' procedure was adapted from Harrel and Bradley (2009). First, the interviews' purpose was introduced. Then, more importantly, the ground rules of the interviews were established. This means that it was clarified how to deal with anonymity and confidentiality prior to the interviews, in addition to obtaining permission to record the interview. It was also asked for permission to translate findings, and for permission to transcribe interviews. In the evaluation interviews, it was after this permission that the framework was presented.

After covering the fundamentals of the interviews, the questioning started. Generally, prior to each interview, a list of questions had been prepared and organized according to the topic it was performed for. The interviews generally employed a funnelling questioning technique, meaning that broad questions were asked first before moving on to more specific questions (Harrell & Bradley, 2009). However, note that a characteristic of semi-structured interviews is that interview protocols are not strictly followed. Thus, they do not necessarily provide an accurate understanding of the interviews.

The reason for using a funnelling technique, instead of, e.g., an inverted questioning technique which does the opposite, is that starting broad makes it possible to narrow in on specific areas as the interviews progressed. This was considered particularly purposeful when interviewing subjects to describe The Maintenance Wheel in-depth, as it was possible to narrow in on unclear topics.

To conclude the interviews, each subject was thanked before agreeing on the way forward. For example, if it was not possible to complete the full list of questions in the time available (which happened during two of the interviews on The Maintenance Wheel), a new meeting was scheduled here.

Drawbacks of semi-structured interviews and bias-mitigating actions [Set 1 and 2]

There are several drawbacks of using semi-structured interviews. For example, Harrel and Bradley (2009) describe that they can be time-consuming, that they generally consume more of respondents' time than surveys, and most importantly, they are exposed to bias. Regarding the two first drawbacks mentioned, these are features of the research method that was known while selecting the research method. Based on interviewing being considered the best research method to answer the research subquestions, these issues were therefore considered as necessary evils. However, bias can and should be controlled. Below, various sources of bias, and the actions taken to minimize their influence, is discussed.

Sekaran and Bougie (2016) state that bias in interviews is either introduced by the interviewer, the interview setting, or the interview subject. First, to reduce interviewer bias, Harrell and Bradley's (2009) manual on semi-structured interviews was used to reduce bias in questions. However, not all questions are prepared in semi-structured interviews, making it difficult to guarantee unproblematic questions. The only method to improve this aspect is through training. Therefore, leading up to the interviews, several publications on how to successfully conduct interviews were reviewed, such as Harrell and Bradley's (2009), Sekaran and Bougie's (2016), and Adams' (2015). Second, each interview was recorded (both video and audio) to avoid loss of information, referred to as note-taking bias (Sekaran & Bougie, 2016). However, Sekaran and Bougie (2016) further state that recording of interviews may induce another bias, as subjects may moderate themselves in interviews on sensitive topics when respondent's worry about their anonymity. The interviews in this thesis are not considered to be on topics where this behaviour would be a problem. Recording the interviews was, therefore, perceived as the best option.

Regarding situational and interviewee bias, measures were also taken. Sekaran and Bougie (2016) argue that the physical location can induce a bias, which is relevant for this thesis, as all interviews had to be conducted remotely. For example, they argue that telephone interviews may induce bias, as non-verbal cues cannot be picked up on. On the other hand, they describe that face-to-face interviews can cause concerns of anonymity and may create a bias due to the interviewer's presence. By interviewing with video and since the topics examined are not sensitive, it is believed that these forms of bias have been minimised.

2.3.3 Qualitative data processing

After conducting the semi-structured interviews, the resulting qualitative data had to be processed to help answer [RQ4] and [RQ7]. A thematic analysis method is used for this thesis, as it provides a way to process qualitative data to identify common themes in the collected data, for example, to identify important topics or patterns (Marshall & Rossman, 2014). This made it possible to answer the relevant research subquestions. The specific procedure used to analyse the data, adapted from Marshall and Rossman (2014), is seen below.

1. Translate, transcribe, and organize the data
2. Establish themes
3. Code data
4. Review codes and themes
5. Write up findings

Step 1 – Translate, transcribe and organize the qualitative data

First, the interviews were translated from Norwegian to English and transcribed. This helped get familiar with the gathered data, as each word was carefully considered while translating. Additionally, the transcripts were read several times. The main purpose of this step is to develop an understanding of the data to be analysed. Note that translating the interviews exposed the interviews to a translator bias. It is therefore relevant to point out that the author of this thesis has an IELTS test with a score of 8/9 from 2018. According to IELTS, a score of 8/9 means that the author should have a "fully operational command of the language, with only occasional unsystematic inaccuracies and inappropriacies" (n.d.). Norwegian, on the other hand, is the native tongue of the author. Resultingly, the risk of translation bias is considered low.

Step 2 – Code interviews

Coding means to identify interesting features in the data, assigning labels to them, referred to as "codes" (Caulfield, 2019). This was done by printing the transcripts and reading over them with a highlighter. Similar codes used the same colour codes.

Step 3 - Establish themes

After establishing codes, patterns between the codes were made explicit by grouping them under larger themes. Note that one theme contains several codes. Here, it has to be mentioned that there was a preconceived idea of the themes in both sets of qualitative data analysed.

Harrell and Bradley (2009) explain that there are primarily two ways to analyse qualitative data: deductive and inductive analysis. Deductive analysis confirms information for a researcher, while inductive analysis uncovers new information. As explained by Caulfield (2019), deductive analysis thus means that a researcher has an idea of what themes to find in the data prior to interviews, based on existing knowledge. In an inductive analysis, however, themes are identified as the analysis progresses. Knowing this, it is worth mentioning that Harrell and Bradley (2009) says that single research projects commonly employ both kinds of analysis. This was also the case in this thesis.

The first set of interviews, on The Maintenance Wheel, were executed to analyse The Maintenance Wheel in-depth. This was done to answer [RQ4], i.e., what the main elements of the maintenance Wheel were and how they combined to realise benefits. Both deductive and inductive analysis was used to answer this. Prior to the interviews, several preliminary meetings had been held with both Karabin and the creator of The Maintenance Wheel (Equinor). Additionally, two internal documents of Equinor had been reviewed. Resultingly, there was an understanding of the main elements in The Maintenance Wheel prior to the interviewing. This made it possible to set up themes prior to the analysis. However, the relative importance of these themes and their connections was identified by inductive analysis.

Regarding the evaluative interviews, conducted to answer [RQ7], the analysis was inductive. The qualitative data gathered from the interviews were analysed to look for common trends between the interview subjects, resulting in the final evaluation seen in Chapter 7.

Step 4 – Review codes and themes

After finalising the analysis, the resulting codes and themes were reviewed. This was done to ensure that the actual findings of the analysis aligned with the data. The procedure used for this step was to read over the transcripts again and cross-checking the findings with resulting codes and themes.

Step 5 – Write up findings

The last step was to write up the findings of the analysis. To avoid issues with anonymity or confidentiality, as all of the interview subjects are senior managers, summaries of the interviews are included in the appendixes instead of the full transcripts. However, due to the importance of the interviews with The Maintenance Wheel's creator, the interview transcripts from the meeting with him are included in full in Appendix D. He was asked for permission, which was granted.

The result of the analysis of The Maintenance Wheel is seen in Chapter 4, which answers [RQ4]. The summaries and transcripts from these interviews are found in Appendix C and D, respectively.

The results of the analysis of the evaluation data are seen in Chapter 7, which answers [RQ7]. The summaries of these interviews are found in Appendix G.

2.4 Design method

Recall [RQ6]: "What does a satisfactory MMF from the design space look like?" After answering [RQ5], a set of design requirements were defined. However, moving from these requirements to a satisfactory design was not straightforward, due to the complex nature of the design required. Ultimately, a design technique called a "morphological chart" was applied to help answer [RQ6] (Dym et al., 2014).

According to Dym et al. (2014), the first step towards producing a final design is to establish the design space. The design space is an imaginary intellectual region of design alternatives that contains all of the potential solutions to the design problem at hand, based on the design requirements (Dym et al., 2014, p. 92). Subsequently, when the design space has been established, a satisfactory solution could be produced from it.

The way with which a morphological chart works is that it is a matrix listing design requirements on the vertical axis and propositions for how to realise each of these requirements on the horizontal axis (Dym et al., 2014). Through this, the design space is created. Finally, a satisfactory design is created by selecting one or more of the proposed means per row and synthesizing them into a design, thereby answering [RQ6].

Note that morphological charts are useful when approaching a design project with a goal to produce a "satisfactory" design. However, if a design optimization approach was taken, such as axiomatic design developed by Suh (1998), it would not have been ideal.

2.5 Extended thesis outline

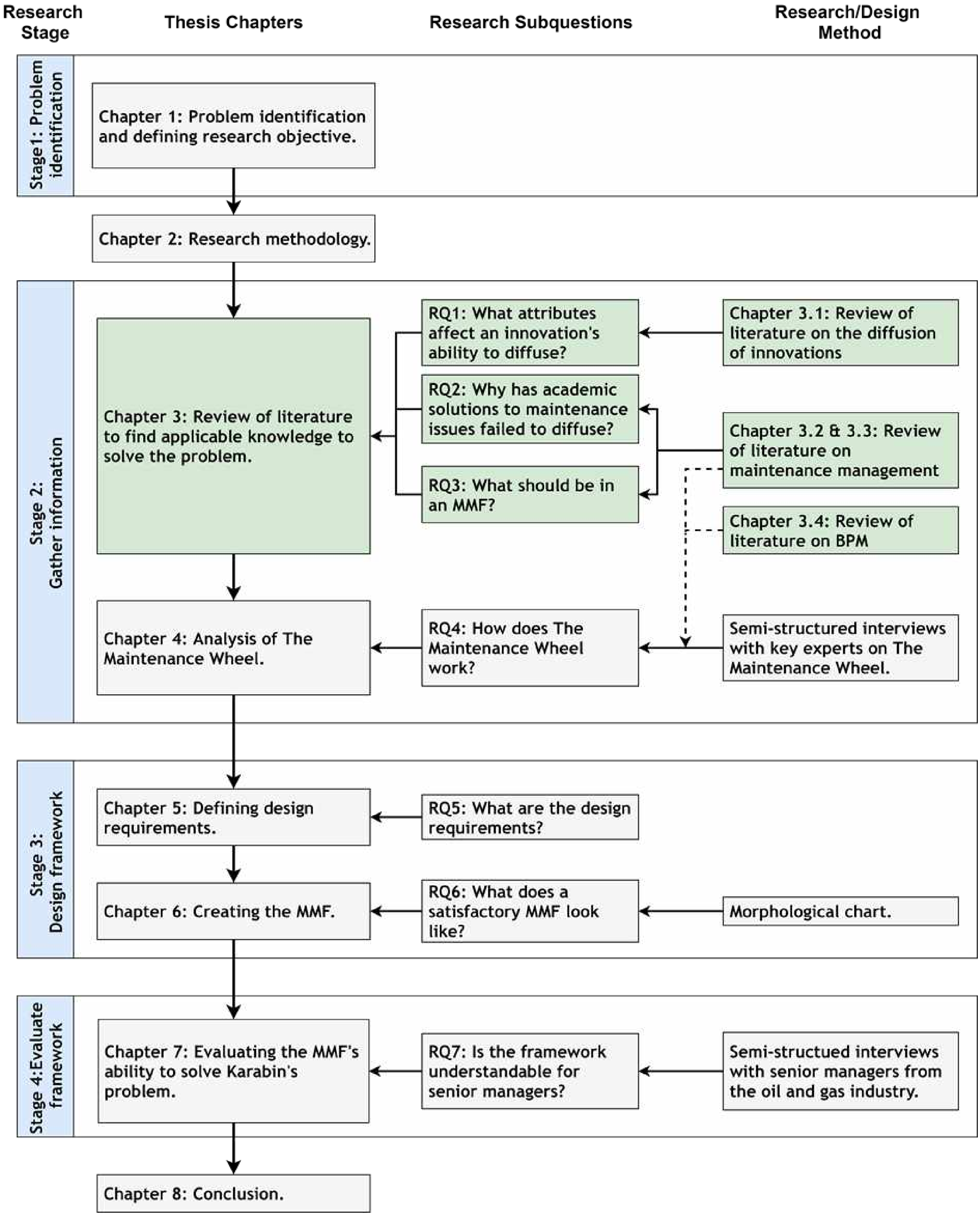

Figure 12: Extended thesis outline. Notice that Chapter 3 is colour coded to clearly separate it from Chapter 4 and that the research subquestions have been simplified to fit them in the image.

"Knowledge has to be improved, challenged, and increased constantly, or it vanishes."

Peter Drucker

3. LITERATURE REVIEW

In the following chapter, applicable knowledge to solve Karabin's problem is gathered. This is done through literature reviews on the diffusion of innovations, MMFs, maintenance performance measurement, and BPM. This is the first of two steps in Stage 2 of the design process, as visualized in green in Figure 13.

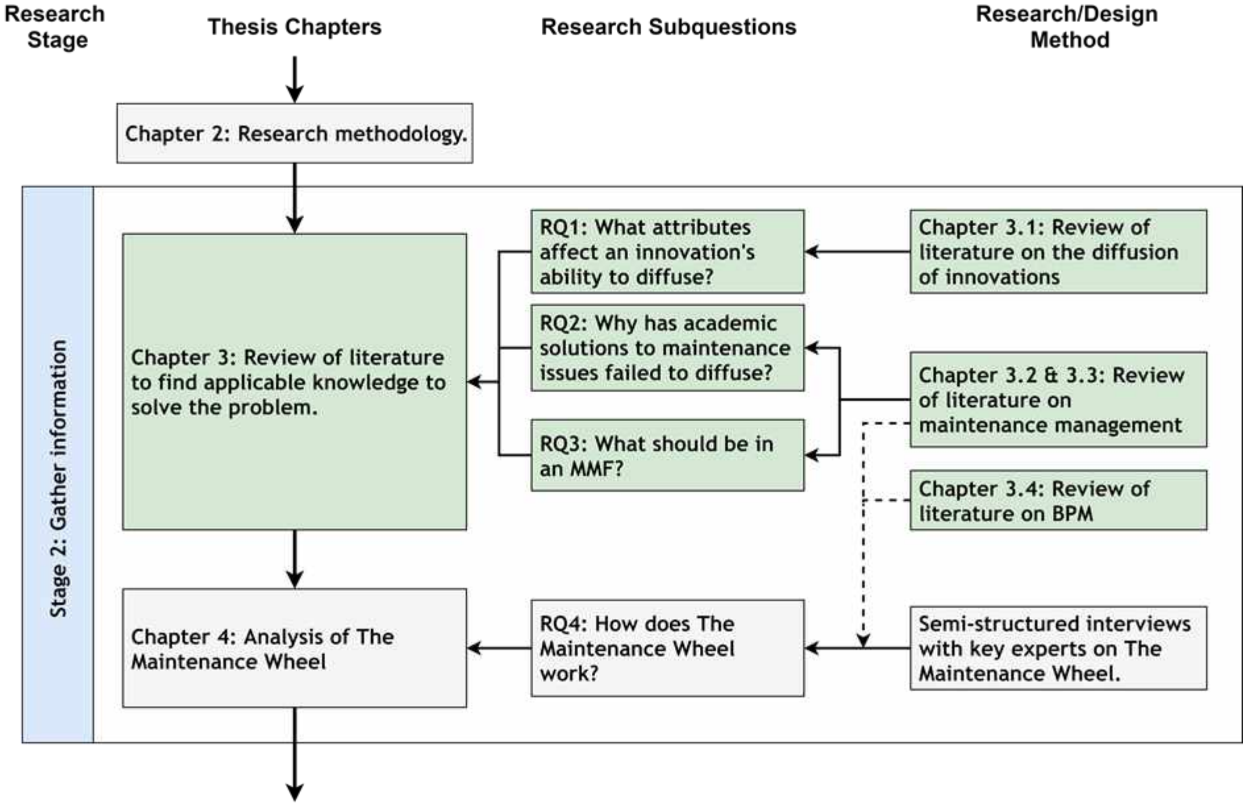

Figure 13: Overview of Chapter 3 in the design process.

First, research on the diffusion of innovations is reviewed. This field of research is concerned with how and why innovations spread differently. The review focuses on a narrow section of this field, namely attributes of innovations that diffuse easily. This is done to provide a theoretical understanding of how to-be-designed MMF can be designed to improve its ability to convince, in effect, answering [RQ1].

Second, different MMFs is reviewed. MMFs are theoretical frameworks of different approaches to managing maintenance. These frameworks are based on different concepts from maintenance management literature. Thus, the review first introduces maintenance and maintenance management. In this introduction, [RQ2] is answered, i.e., why there is a gap between academic solutions to maintenance issues and their application in real-world organizations. Thereafter, [RQ3] is answered by reviewing various MMFs, i.e., what functions or elements should be in an MMF. Note that this review provides part of the theoretical understanding necessary to understand The Maintenance Wheel.

In the third review, different approaches to maintenance performance measurements are reviewed. This field is concerned with different techniques, or strategies, to measure the performance of maintenance work. This review provides part of the theoretical understanding necessary to understand The Maintenance Wheel. As performance measures play a large role in The Maintenance Wheel, it was necessary to review this in addition to the MMFs, as most of the reviewed MMFs did not go in-depth on the topic.

The fourth review focuses on BPM. BPM, or business process management, is a discipline focused on how companies can manage their activities as end-to-end business processes effectively (Iden, 2018). This review provides a large part of the theoretical foundation necessary to understand and analyse The Maintenance Wheel in Chapter 4.

3.1 Diffusion of innovations

Spreading a new idea, regardless of it having self-explanatory advantages, may be difficult. The field of diffusion research is concerned with the mechanisms determining why and how different innovations spread (Rogers, 2003). Based on this research, one can influence the attributes influencing the probability of an innovation being adopted by an organization, i.e., its ability to convince.

The goal of this review is not to review all aspects of diffusion research. To understand the review's focus, it is useful to examine Figure 14 adapted from Greenhalgh et al. (2004), visualising the spread of innovations to companies. Based on the thesis' scope, as defined in Chapter 1.5, the focus is solely on the innovation itself. Therefore, while aspects such as system antecedents and system readiness are clearly essential to diffusion, these are not within the scope. Nevertheless, a brief introduction is given first to contextualize what is actually reviewed for a reader unfamiliar with this field of research.

3.1.1 Introduction

Diffusion research emerged during the 1940s, as different disciplines attempted to describe how innovations in the respective disciplines spread, e.g. agricultural innovations to farmers and new teaching techniques to teachers (Rogers, 2003). Although the different disciplines emerged separately, Rogers (2003) describes that by the mid-1960s, the different branches had started to merge into the cross-disciplinary field of diffusion research known today.

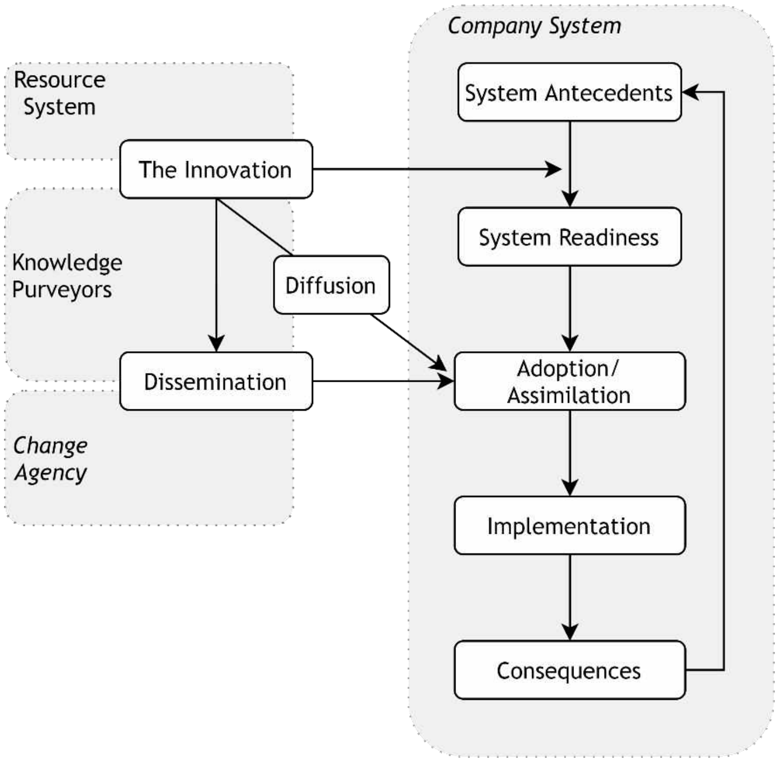

Figure 14: Model to describe the diffusion and dissemination of innovations for companies. Adapted from Greenhalgh et al. (2004, p. 595).

The person who popularized the modern school of diffusion research, Everett M. Rogers, described that there are four main factors influencing diffusion, namely (1) the innovation, (2) the communication channels, (3) time, and (4) the social system (Rogers, 2003). Innovations are the item being spread. Communication channels spread information about this innovation spread and are a prerequisite for diffusion. Time concerns the passage of time required for an innovation to diffuse. Last, Rogers defines a social system as "[…] a set of interrelated units that are engaged in joint problem solving to accomplish a common goal" (Rogers, 2003, p. 23).

3.1.2 Attributes of innovations affecting diffusion

The innovation is an idea, practice, or an object perceived as new by potential adopters (Rogers, 2003, p. 12). According to Rogers, innovations can be made up of two components: hardware and software. While hardware is physical items, software is the non-physical information base which the innovation is based on. He further describes that while most only consider hardware-based items as innovations, innovations may also be purely information-based, where he uses the metric system as an example.

Rogers described six attributes of an innovation that affects how it diffuses: relative advantage, compatibility, complexity, trialability, observability, and reinvention (Rogers, 2003, pp. 15–16). Relative advantage is the perceived advantage of one innovation, in comparison to its alternatives. This advantage may be measured in several ways, e.g., through economic advantage or convenience. Compatibility refers to whether a potential adopter believes the innovation aligns with its values, experiences, and needs. Complexity refers to how difficult an invention is to use and understand. If an invention is difficult to use or understand, potential adopters are less likely to adopt it as it requires them to learn. Trialability refers to whether potential adopters may experiment and try out an innovation before adopting it. Rogers describes that trials reduces uncertainty, and also allows implementers to learn. Observability refers to whether the benefits of a given innovation are visible to others. Last, reinvention refers to whether potential adopters may adapt the innovation to suit their own business context. The importance of these attributes has since been validated by multiple studies (Greenhalgh et al., 2007).

Besides the list of characteristics identified by Rogers (2003), which are often referred to as standard attributes of innovations that diffuse easily, Greenhalgh et al. (2007) identified some operational attributes particularly important for organizations in a systematic literature review: task relevance and usefulness, the complexity of implementation, and risk. In addition to these, Greenhalgh mention transferability. First, task relevance and usefulness refer to whether the innovation is relevant to and will help increase the performance of tasks in the organization. Second, the more complex an innovation is to implement, the less likely it is that organizations will adopt it. Third, risk relates to the uncertainty and undesired consequences associated with the implementation of an innovation. The higher the risk, the more difficult it will be to convince a company to adopt it. Last, transferability refers to whether it is possible to communicate how the innovation works, both regarding aspects related to the innovation in-use and whether the innovation's underlying principles may be communicated.

While all of these attributes are important for the diffusion of innovations, the relative importance of them vary. In a study, Vagnani and Volpe (2017) conducted a meta-analysis to assess how innovations' attributes affected managers likeliness to adopt innovations. They found that for innovations not targeted for specific companies, or where the adopter's characteristics were not known, particularly the relative advantage over available alternatives, compatibility, ease of use/understanding (complexity and transferability), and observability was important.

3.2 Maintenance management frameworks

In the following review, different maintenance management frameworks are reviewed. In order to review this topic, it is first necessary with an elaborate introduction into assets, maintenance, and maintenance management. Subsequently, the reason why this gap exists is reviewed before reviewing different frameworks for how companies may manage their maintenance activities.

3.2.1 Introduction to assets and maintenance

The meaning of the term maintenance differs, depending on what context it is applied in. In the context of a person's day-to-day life, the term usually refers to an activity needed to fix an item, say a bike. In an organization, the term maintenance is associated with higher complexity and risk than in a household. In this thesis, the focus is solely on maintenance for organizations.

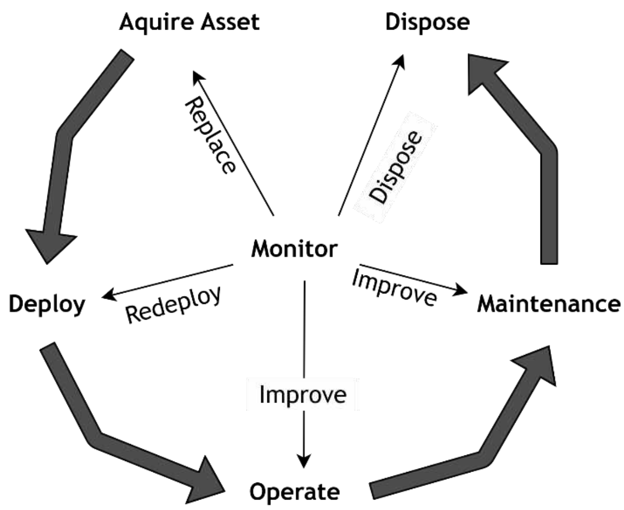

Figure 15: The asset lifecycle. Adapted from Ouertani et al. (2008, p. 31).

Maintenance is a subsidiary activity of what is referred to as asset management. There are many definitions of what an asset is. The one used for this master thesis is the general definition that an asset is "[…] anything of economic value that is owned by an organisation" (Baskarada et al., 2006, p. 7). Subsequently, asset management may be defined as the "[…] coordinated activity of an organisation to realise value from assets" (International Organization for Standardization, 2014, p. 14). These activities are structured around the asset's life cycle, with the number of stages and specified activities depending on contextual factors (International Organization for Standardization, 2014). However, in a generic asset life-cycle is illustrated, as adapted from Ouertani et al. (2008, p. 31). Ouertani et al. see an asset life cycle as made up by five sequential stages: 1) being acquired, 2) being deployed, 3) operating, 4) being serviced and maintained, and 5) to be retired. In this thesis, the focus is on step 4, namely maintaining companies' assets.

In short, maintenance is the combined set of activities performed to ensure the desired availability and performance from an asset over its life-cycle (European Committee for Standardization, 2017, p. 8). The historical view of maintenance, especially within manufacturing firms, has been to treat it as a necessary evil to keep the production facilities running (Fraser, 2014). However, after a shift in the view of maintenance towards the end of the 20th century, this view is no longer acceptable (Garg & Deshmukh, 2006). However, this perception changed towards the end of the 20th century, as maintenance is today considered as a value-adding business process (Garg & Deshmukh, 2006). To exemplify its importance, maintenance has been linked to companies' productivity and profitability (Alsyouf, 2007; Swanson, 2001).

3.2.2 Introduction to maintenance management

As maintenance is crucial to companies' performance, it is essential to manage it. In Chapter 1.1, maintenance management was defined as "[…] all activities that determine the maintenance requirements, objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics" (European Committee for Standardization, 2017, p. 9). Other scholars, such as Campbell and Reyes-Picknell (2015) provide similar definitions, defining maintenance management as "the tactical planning, organising, directing and use of the resources necessary to keep your physical assets running well and contributing to your customers' as well as your own business success" (p. 35). However, not all scholars share the same perception. For example, Duffuaa and Haroun (2009, p. 93) perceive maintenance management as an input/output system. In their perspective, inputs are the resources necessary to conduct maintenance, whereas the output is operational machines and equipment. Maintenance management's role is then to plan, schedule and execute maintenance the usage of these inputs. Additionally, it should control these activities to ensure that the outputs are met according to objectives related to availability, costs, and quality. Another example, and possibly the easiest way of interpreting and understanding maintenance management, is given by Wireman (2005). Wireman views it as "the management of all assets owned by a company, based on maximising the return on investment in the asset" (2005, p. 38).

The different definitions of maintenance management act as a signal of the complexity maintenance management is characterized by. Maintenance management is a broad concept, encompassing several different activities (e.g. maintenance scheduling and performance measurement), with different people have different conceptions of what is most important when attempting to manage a maintenance process. Before explaining the main areas of research in this field, it is thus useful to revisit Figure 15, first shown in Chapter 1.1. This figure, adapted from The Norwegian Petroleum Directorate (NPD, 1998, p. 9), explains the connection between the essential maintenance management activities.

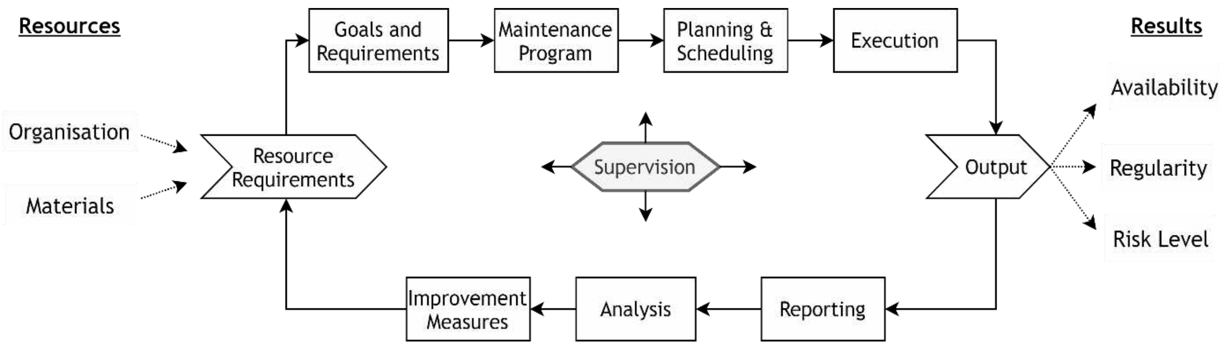

Figure 16: Maintenance management activities. Adapted from NPD (1998, p. 9).

As illustrated in Figure 15, maintenance management encompasses several activities. Therefore, it is necessary to focus on the most important activities. Based on a literature review of maintenance management literature, Garg and Deshmukh (2006) identified six main areas of literature: (1) maintenance optimization models, (2) maintenance techniques, (3) maintenance scheduling, (4) maintenance performance measurement, (5) maintenance information systems, and (6) maintenance policies. Each of these is now explained, before reviewing different MMFs. Do note that the areas of research are not clearly separated, i.e., a maintenance technique may also be an attempt to optimize maintenance. These types of blurred lines is a characteristic of maintenance management literature, which is bound to complicate any review of maintenance management literature.

Maintenance optimization models refer both to qualitative and quantitative attempts to optimize maintenance (Garg & Deshmukh, 2006). However, due to an overlap between qualitative optimization models and maintenance techniques, which is discussed next, only quantitative techniques are explained. Garg and Deshmukh state that these types of quantitative models typically describe a technical system that deteriorates or is faced by different scenarios, with specific types of information and actions available, where the authors have either developed an optimization technique or function (2006, p. 208). Notice that there is a large span in what objective these models try to optimize. No quantitative optimization models are found in the reviewed MMFs, and they are not used in The Maintenance Wheel. Resultingly, they are not discussed further.

Maintenace techniques is a broad field of research, and it generally refers to how companies decide which assets to fix (Garg & Deshmukh, 2006). In other words, it may be considered as the strategic approach chosen by companies to service assets in the way best suited to their business context. The simplest way to categorise different maintenance types is as corrective or preventive maintenance (Shafiee et al., 2011). Corrective maintenance is maintenance where companies first service assets when something is wrong. Preventive maintenance is maintenance done to prevent assets from breaking down. There are several sub-categories of preventive maintenance, such as maintenance done based on time-intervals, condition-based maintenance, or predictive maintenance. Another simple type of maintenance strategy is design-out maintenance, which is a one-off activity (PCMS ENG Group, 2016), meaning that it differs from the previously mentioned maintenance activities. This form of maintenance is usually triggered by a desire to reduce the maintenance needs of an asset that is consuming higher maintenance efforts than desired. By redesigning some of the asset's parts, or even the entire asset, the goal is to avoid future maintenance expenditures on this asset. Besides these maintenance strategies, Garg and Deshmukh (2006) describe reliability-centred maintenance (RCM), risk-based maintenance (RBM), total productive maintenance (TPM), and maintenance outsourcing. First, RCM is solely concerned with keeping production facilities running by maximising the uptime of a corporation's assets. It is not concerned with the ideal operation of these assets, however. Second, RBM allocates maintenance efforts (money, time, and personnel) based on the associated risk of an asset breaking down; the higher the risk, the higher the effort invested. By doing so, unnecessary expenditures on low-risk assets are saved. Third, the goal of TPM is to keep all assets in good condition without influencing daily processes. Last, maintenance outsourcing differs from the previously mentioned strategies in that the maintenance is conducted by another company. This strategy has experienced an upswing in recent years (Shafiee, 2015), enabling companies to attain expert knowledge resulting in better, and often cheaper, maintenance. For example, if a company purchases a highly specialised machine with a complicated maintenance routine, the manufacturer of the machine may provide the service themselves, possibly even annulling any warranty if the purchasing company tries to fix the machine themselves.

The third research area described by Garg and Deshmukh (2006) is maintenance scheduling. Garg and Deshmukh describe maintenance scheduling as bringing together the right mechanics, materials, information, permissions, tools, and access to the asset in need of maintenance at the right time (2006, p. 219). It is an area of much research since maintenance demand varies stochastically (i.e. assets break stochastically), resulting in maintenance scheduling generally being an area performing worse than for example production planning (Al-Turki, 2009).

The fourth research area described by Garg and Deshmukh (2006) is maintenance performance measurements. This is the subject of its own review later in this chapter, as the reviewed frameworks do not go in-depth. Resultingly, it is not explained in depth here. However, do note that it is a problem that maintenance managers often have access to much data, but does not receive information that can be used to easily manage and improve the maintenance performance (Garg & Deshmukh, 2006). Additionally, note that there are different types of performance measurement techniques that may be used in a maintenance process, such as data envelopment analysis (DEA), system audits, or the balanced scorecard, which have different strengths when measuring performance for different stakeholders (Tsang et al., 1999). This is explored further in the subsequent review.

The fifth area of research in maintenance management is the use of information systems (Garg & Deshmukh, 2006). According to Garg and Deshmukh, the use of such information systems has opened several opportunities for maintenance management. One prominent example is e-maintenance, which is the wireless and real-time monitoring and management of plants and machinery using items such as intelligent sensors, the internet, online GUIs, and databases (Kumar et al., 2013). For this thesis, however, it will not be necessary to review the various ICT systems that may be used in-depth, such as enterprise resource planning (ERP) systems or computerized maintenance management systems (CMMS). This stems from interviews conducted in Chapter 4, where The Maintenance Wheel's creator stated that all types of ICT systems might be used to make The Maintenance Wheel work in different companies, as no advanced ICT-based features are required (see Appendix D).

The research area described by Garg and Deshmukh (2006) is maintenance policies. Maintenance policies describe various policies for how to deal with deteriorating systems. For example, Garg and Deshmukh (2006) discuss age replacement and random age replacement policies. While these types of policies are likely to be found in companies, it not as relevant for this thesis. None of the reviewed MMFs discusses maintenance policies in-depth, and it will be seen in Chapter 4 that neither does The Maintenance Wheel.

Maintenance Management Frameworks

The separate fields of research mentioned above are concerned with smaller parts of the maintenance management process. In a bid to communicate their perceptions of the best-practice approach to maintenance management, scholars and practitioners have proposed different MMFs combining different elements from, but not limited to, the fields of research in maintenance management discussed above. Through this, various researchers and practitioners have set up different frameworks illustrating their proposed systems for how to manage maintenance best. Note that these MMFs affect all of companies' maintenance management activities. However, before examining various MMFs, it will be assessed why the gap between academic attempts to optimize maintenance and their real-world application exists.

3.2.3 A gap between models to optimize maintenance and their application in organizations

In this thesis introduction, in Chapter 1.1, it was explained that while the importance of maintenance to companies' performance has increased drastically in turn with increased automation and increased investments into production equipment, the maintenance processes of companies is still characterised by several issues. The various areas of research mentioned above aim to optimize maintenance, i.e., they aim to solve these issues. However, it was also discussed in Chapter 1.1 that these attempts had failed to diffuse into organisations.

In this section, a set of studies discussing the reason behind this gap has been identified. None of these studies includes the MMFs reviewed later, which is why this is discussed here. This way, it is possible to judge whether the reviewed MMFs suffer from the same issues as other academic attempts to optimize maintenance.

The first study, by Dekker (1996), points to several reasons why the gap exists: (1) academic attempts to optimize maintenance being difficult to understand and interpret for practitioners, (2) many attempts to optimize focus only on mathematical optimization and not real problems, (3) companies with successful approaches to maintenance management are not interested in publication, (4) maintenance is a very broad concept affected by many aspects meaning there is no automatic reason that a framework working in one context is applicable in another, and (5) older attempts to optimize maintenance relies on maintenance techniques which have since fallen out of favour (pp. 235–236). The second study, by Van Horenbeek et al. (2010), points to similar reasons, pointing to that academic solutions fail to recognize and discuss how they will be applied in practice. The last study examined, by Fraser et al. (2015), points to two main reasons: a lack of empirical proof from real-world applications and a lack of practical focus.

The studies point to the same category of issues. Generally, academic attempts to optimize maintenance fails to recognize or consider that they must be applied in practice. Revisiting the review of diffusion research earlier in this chapter, the issues mentioned by the various studies show that several attributes important to diffusion are missing. By having no empirical proof, it will likely be difficult for practitioners to understand the relative advantage. By being difficult to understand or interpret, the academic constructs likely suffer from being too complex. By failing to provide demonstrations or consider the practical application of the frameworks, it likely becomes difficult for senior managers to understand how to make the frameworks suit their business contexts. Knowing this, various maintenance management frameworks are now assessed. There, this information will be used to identify areas of improvements to consider in the design process.

3.2.4 Selection criteria

In a review of MMFs, two types of MMFs were identified: declarative and process-oriented frameworks (Campos & Crespo Márquez, 2009). A declarative framework is an MMF which specifies the components of a maintenance management system, but not the links between these components. The frameworks may be highly informative, but each company looking to use the framework ultimately needs to interpret how to implement it in their respective companies. Process-oriented frameworks, on the other hand, do connect the components and explain their interrelationships. Since The Maintenance Wheel is based on BPM, meaning that it will be necessary to illustrate the process flow, only process-oriented MMFs are relevant to the design process, and only process-oriented MMFs are therefore reviewed.

In this paragraph, other selection criteria are explained. First, only frameworks considering maintenance as a value-adding activity was considered. If the MMFs do not consider maintenance as a value-adding activity, it will not attempt to manage it actively either. Additionally, due to the importance of ICT-based solutions in contemporary maintenance management, frameworks accounting for the integration of ICT-systems such as ERP and computerized maintenance management systems (CMMS) were prioritized. Based on these two criteria, the search procedure was limited to publications published after 1985. Furthermore, an attempt to only review frameworks from peer-reviewed journals was made. However, note that an exception was made to include two frameworks published in books, namely, frameworks [2] and [9] in Table 4. Last, inspired by the review of Campos and Crespo Márquez (2009), only global maintenance management frameworks, meaning that the frameworks cover all maintenance management activities are reviewed. Resulting from this, the nine frameworks listed in Table 4 were reviewed.

Table 4: List of reviewed MMFs.

#	Author	Name of publication
1	(Hassanain et al., 2003)	Framework model for asset maintenance management
2	(Wireman, 2005)	Developing Performance Indicators for Managing Maintenance
3	(Crespo Márquez & Gupta, 2006)	Contemporary maintenance management: Process, framework and supporting pillars
4	(Pramod et al., 2006)	Integrating TPM and QFD for improving quality in maintenance engineering
5	(Söderholm et al., 2007)	A process view of maintenance and its stakeholders
6	(Crespo Márquez et al., 2009)	The maintenance management framework: A practical view to maintenance management
7	(Campos & Crespo Márquez, 2011)	Modelling a maintenance management framework based on PAS 55 standard
8	(Barberá et al., 2012)	Advanced model for maintenance management in a continuous improvement cycle: integration into the business strategy
9	(Campbell & Reyes-Picknell, 2015)	Uptime: Strategies for Excellence in Maintenance Management

3.2.5 Framework 1 - Hassanain, Froese, & Vanier (2003)

In this article, Hassanain et al. (2003) develop a process-based framework for maintenance management. The framework is illustrated with the $IDEF_0$ modelling approach, an approach which describes a given business process' activities and their sequence, how these activities should be performed, and how and what information that should be shared between these activities (Hassanain et al., 2003). In total, the constructed framework consists of five sequential processes, namely (1) identify assets, (2) identify performance requirements, (3) assess performance, (4) plan maintenance, and (5) manage maintenance. For each of these processes, sub-activities are also modelled. A brief summary of these processes and their sub-activities is now given.

The first process's purpose is to decide on which assets to include in the framework. The second and third process then identifies performance indicators for these assets and assesses whether the assets perform according to their set performance requirements. After that, the process first continues when an anomaly is identified. When this happens, a signal is sent, after which an assessment of the anomaly's cause is examined. This results in a report, on which the management decides the appropriate actions to bring the asset back to its desired condition. Based on this decision, a plan for the work is constructed. This plan constitutes estimating the required maintenance costs and resources and creating a schedule for the work to be done. The last step is then to follow this plan to fix the asset and create an operational facility.

The framework has one main benefit. It provides an example of how a maintenance process may be standardised. Benefits of this include a reduction of variability in the maintenance process, as boundaries, the sequence of activities, responsibilities, and more are defined. As Mapes (2000) found, low process variability is one of the critical variables separating a high-performing plant from the rest.

However, there are some issues with the framework. First of all, the framework focuses on individual assets. This is not an issue in itself. However, in the modern view of maintenance, where maintenance is seen as a value-adding business element, it is essential to understand that value is not only generated within the maintenance department. It is generated for the entire organisation, which is usually the maintenance process' primary customer. Hassanain et al. (2003) do not account for this. For example, Hassanain et al. discuss the maximisation of assets' performance, not the organisation's value generated from the maintenance. Little consideration is given to how the assets' performance, and the maintenance activities themselves, affect other parts of the organisation. Due to this, the framework can not be seen as compatible with the modern view of maintenance.

The highly standardised sequence of activities causes a second issue, namely that it is inflexible. Related to this, a third issue is that no guidance on how to adapt the framework to different contexts is given. Last, the article provides no proof of concept, which will make it hard to convince managers to adopt the framework.

3.2.6 Framework 2 - Wireman (2005)

The second MMF was developed by Wireman (2005). As described in the introduction, Wireman sees maintenance management as the activities related to the maximisation of return on investment in an organisation's assets. However, in contrast to the framework of Hassanain et al. (2003), where each task of the maintenance management process is described in-depth, Wireman creates a framework focusing on the "broader-strokes" of maintenance management. To do so, Wireman lists that there are 11 main elements to manage maintenance successfully. These are preventive maintenance, stores and procurement, workflow systems, computerised maintenance management systems (CMMS), interpersonal training, operational involvement, predictive maintenance, RCM, TPM, statistical, financial optimisation, and continuous improvement. Then, he argues that these elements should be implemented sequentially. To illustrate this, Wireman uses a pyramid-shape wherein each layer of the pyramid corresponds to one of the elements. Also, any given layer of the pyramid is dependent on the support of the lower levels of the pyramid. Note that this means that the elements should be implemented sequentially.

As with any pyramid, a foundation is first needed. Wireman (2005) argues that for any part in the maintenance management process to work, a preventive maintenance program must be operational. The reason behind this is to ensure that the levels of reactive maintenance are at a low enough level so that the other elements of the pyramid can be effective. After this is functional, he argues that the next elements to implement are procurement, workflow systems, CMMS, and interpersonal training. These are also seen as crucial for the other elements to work. Then, when these five elements are operational, the organisation should implement predictive maintenance, operations involvement, and RCM. These activities focus on equipment availability. The next level, made up of TPM and financial optimisation, uses data captured by the previously implemented tools to increase equipment effectiveness. Last, the top of the pyramid is to self-evaluate and benchmark to ensure continuous improvement.

3.2.7 Framework 3 - Crespo Márquez & Gupta (2006)

The third maintenance management approach was created by Crespo Márquez and Gupta (2006). Their motivation was to create a framework for maintenance management, based on the argument that the myriad of practices, tools, prescriptions and trappings at the time inundated maintenance managers. More specifically, they argue that this overwhelming set of tools resulted in maintenance managers starting to confuse maintenance actions and the tools created for these tasks. To create the framework, they first define what they consider to be an effective maintenance management process, i.e., actions needed to manage maintenance. After that, they develop a supporting structure to help manage this process. As explained in the introduction, both the process and the supporting structure is seen as one MMF in this review.

Crespo Márquez and Gupta (2006) consider maintenance management activities to take place at three different organisational levels, referred to as the operational, tactical, and strategic levels. More precisely, the overarching maintenance management process is seen as composed of three closed-loop processes. They use closed loops to signal that information from the process should become feedback to facilitate continuous improvements.

The *strategic* actions start by maintenance managers using the organisation's business plan to crafting a maintenance plan. This plan is then used to decide on mid-to-long-term strategies of how to manage the maintenance function to achieve the desired performance. To do so, performance targets are set, related to key aspects of maintenance. For example, the degree of unscheduled corrective maintenance versus the scheduled preventive maintenance is set. The *tactical* actions' purpose is to then decide on how to allocate resources to fulfil the maintenance plan set on the strategic level. This should result in a detailed schedule of work orders and the distribution of resources among them. Last, actions on the *operational* level are to ensure that technicians carry out the work orders according to the schedule, according to the set procedures and with the proper tools. This information is then logged in an information system and fed back to the tactical and strategic level.

To support this maintenance management process, Crespo Márquez and Gupta (2006) create a support structure made up of what they refer to as three "pillars". These pillars are in practice the three categories of tools to aid managers in maintenance management and are referred to as the IT pillar, the maintenance engineering pillar, and the organisational techniques pillar. The IT pillar concerns the ICT-based tools CMMS, condition monitoring technologies, and e-maintenance. The purpose of these technologies is, in simple terms to make increase data availability and to process data to make decision-making easier. The maintenance engineering pillar is made up of a set of different techniques, such as RCM, TPM, maintenance policy optimisation models, reliability data analysis, and more, which has primarily three purposes. These are to optimise the maintenance plan design and to ensure the continuous improvement of it, the optimisation of the maintenance policy, and the measurement of maintenance engineering performance to ensure control of maintenance engineering activities. The last pillar, organisational techniques, consists of techniques to build competency and relationships to improve the interface between different activities. Under this pillar, the three main functions described is providing flexibility to the maintenance organisation, to improve external relationships (OEMs and customers), and to support the communication internally within different functional departments.

3.2.8 Framework 4 - Pramod et al. (2006)

The fourth framework reviewed was created by Pramod et al. (2006), in which they develop a framework to integrate TPM and quality function deployment (QFD) into maintenance. Although TPM was introduced briefly before, its large role in this framework means that it warrants a bit longer explanation.

TPM is a maintenance strategy based on achieving maximal production output by achieving zero breakdowns or delays in a company's production processes (Pramod et al., 2006). On its own, TPM is considered to be a declarative MMF. Simply put, TPM's foundation is a basic care system for maintenance, referred to as 5S (Ahuja & Khamba, 2008). Then, based on this basic care, TPM uses eight concepts called autonomous maintenance, planned maintenance, quality maintenance, focused maintenance, education and training, HSE, Office TPM, and development management as tools to eliminate asset breakdowns and assets operating at below maximal capacity in the pursuit of perfect production output (Pramod et al., 2006). The purpose of 5S is to provide an environment in which the eight concepts may be realistically be achieved by avoiding the firefighting of short-term issues. To briefly summarize the eight pillars, they are centred techniques aiming to have a preventive effect. QFD (often referred to as the house of quality), on the other hand, is a method for converting customer requirements into detailed objectives. Indicators do then measure whether these objectives are met. Note that the customer of maintenance is the facility in which the maintenance happens.

In the framework, Pramod et al. (2006) start by using QFD to convert customer requirements into specific objectives used while making strategic maintenance decisions. These strategic decisions are reflected on the organization in question through manipulation of the eight TPM concepts, which have direct effects on both the tactical and operational level on the organization. Subsequently, the effects of these strategic decisions on production and maintenance related variables measures are measured through a comparative analysis of observed performance and performance objectives. Ultimately, the outcome of this performance analysis is fed back to the strategic decision making and the customers, making a closed-loop. Notice that this is a simplified explanation, as the framework of Pramod et al. (2006) is based on a complex illustration

3.2.9 Framework 5 - Söderholm, Holmgren, & Klefsjö (2007)

The fifth framework reviewed, proposed by Söderholm, Holmgren, and Klefsjö (2007), is a framework focused on treating maintenance as a process. Additionally, they attempt to make the framework so that the maintenance process aligns with other processes in the company in order to satisfy the requirements of external stakeholders.

The framework is built on four maintenance activities: maintenance planning, maintenance execution, functional testing, and feedback. According to Söderholm et al. (2007), these activities are inspired by Deming's (1993) "Improvement Cycle" of plan, do, check, act. Söderholm et al. state this to signal that their framework is set up for continuous improvement, with the continuous reduction of risk as their motivation.

The first step of the process, maintenance planning, is based on setting up a plan for what maintenance to do based on stakeholder requirements, system health information, and information on the available resources. Based on this step, step 2 is initiated, which is about executing the maintenance planned. Thereafter, during the third step, assets are tested either periodically or continuously to determine the need for maintenance. Functional testing is also conducted post-maintenance execution, to aid in troubleshooting or to assess whether the maintenance was successful. Last, functional testing is about feeding the functional testing information back to step 1 and 2. Additionally, feedback should be provided to the maintenance objectives, strategy, and policy to continuously improve. Note that no flow-related process improvements nor the standardisation of tasks or information flow are discussed.

3.2.10 Framework 6 - Crespo Márquez, de León, Fernandez, Márquez, & Campos (2009)

The sixth framework reviewed, proposed by Crespo Márquez et al. (2009), is similar to the one proposed by Crespo Márquez and Gupta (2006). However, where Crespo Márquez and Gupta develops an elaborate and complex process maintenance management process and framework separately, Crespo Márquez et al. uses a more straightforward approach. By separating the maintenance management process and its supporting framework, Crespo Márquez and Gupta make it difficult to for readers to understand why and where to apply the tools of the supporting framework in the maintenance management process. Crespo Márquez et al., on the other hand, defines a simple 8 step maintenance management process and describes what maintenance management techniques that are applicable where in this process. Framework 6 may, therefore, be seen as an improved version Crespo Márquez and Gupta (2006) framework, at least in terms of interpretability.

As mentioned, the framework of Crespo Márquez et al. (2009) is made up of 8 steps. These steps are (1) "defining maintenance objectives and KPIs", (2) "determine asset priority", (3) "fix immediate high impact weak points", (4) "design PM plan", (5) "implement PM plan, schedule and optimise resource usage", (6) "maintenance execution assessment and control", (7) "asset lifecycle analysis and replacement optimisation", and (8) "continuous improvement and new techniques utilisation" (Crespo Márquez et al., 2009). For each of these steps, different techniques are then suggested. The techniques suggested are respectively (1) BSC, (2) criticality analysis, (3) failure root cause analysis, (4) RCM, (5) risk-cost optimisation, (6) reliability analysis and critical path method, (7) lifecycle cost analysis, and (8) TPM and e-maintenance. However, note that these tools are only suggestions. The key part of the framework is to follow the list of maintenance management activities and to choose fitting techniques to conduct these activities.

3.2.11 Framework 7 - Campos & Crespo Márquez (2011)

The seventh framework reviewed, developed by Campos and Crespo Márquez (2011), is a framework based on BPM which was created to meet the requirements of the discontinued asset management standard PAS 55 (replaced by ISO 55000). BPM is simply put about improving companies performance through the management of business processes, e.g. maintenance (Hammer, 2010). For an extensive explanation of BPM, see the next literature review.

The framework is illustrated with two business process modelling languages, UML 2.1. and BPMN 1.0. The authors argue that by using these modelling languages, the framework becomes easy to adapt, in addition to making it easy to implement into a company's information system. Generally, business processes may be modelled on four different levels (level 0 to 3), with increasing detail per level (Campos & Crespo Márquez, 2011). The authors' framework is illustrated on level 0, visualizing four macro-processes, with several subsequent illustrations to explain their framework on increasing levels of detail.

Overarchingly, Campos and Crespo Márquez's (2011) framework is composed of four sequential macro-processes: "System Planning", "Resources Management", "Implementation & Operation", and "Assessment & Continual Improvement". Each of these macro processes is made up of sub-processes and specific tasks. As the framework is extensive and illustrated over multiple pages, the purpose of the four processes is summarized instead. System planning is a process set up to generate maintenance policies, strategies, objectives, and plans. This process sets the direction of the maintenance process. After this process, the Resources Management process is set up of the various activities to support and facilitate for maintenance complying with the set direction, e.g. risk management, HRM, and spare parts management. Then, in the Implementation & Operation process, maintenance is performed, based on maintenance work orders created in the short-term planning of the System planning process. Last, the Assessment & Continual Improvement process sets up a process to process data from the executed maintenance process' completed, to identify ways to continuously improve.

3.2.12 Framework 8 - Barberá et al. (2012)

Framework 8, developed by Barberá et al. (2012), is a closed-loop maintenance management process focused on achieving continuous improvement through seven steps. They motivate their framework by arguing that other MMFs fail to consider how to operationalize the theoretical models into a real-life company. Besides this, they wish to develop a framework that can align maintenance objectives with the overarching business objectives.

The framework is centred around seven steps: (1) situational analysis and setting strategic direction, (2) prioritizing asset equipment, (3) risk analysis of potential failure mechanisms on high-risk assets, (4) design of preventive maintenance plan, (5) maintenance scheduling and optimizing resource allocation, (6) assessment of the implemented maintenance system, (7) life cycle analysis and assessing asset portfolio. Besides these steps, the framework covers how the balanced scorecard, software, enabling tools for the information system, and how spare parts may be applied to aid in the maintenance process.

3.2.13 Framework 9 - Campbell & Reyes-Picknell (2015)

The last framework reviewed is presented by Campbell and Reyes-Picknell (2015). Their framework assimilates the framework of Wireman (2005), as they also use a pyramid structure. But, in contrast to Wireman, Campbell and Reyes-Picknell argue that their framework is not a prescriptive "one-size-fits-all" approach. The pyramid-shaped framework is divided into three sections, listed down-up: *leadership*, *essentials*, and *choosing excellence*. Of these, Campbell and Reyes-Picknell argue that only the two lowest sections are prescriptive, whereas, on the uppermost level, the implementing company may decide how to realise their benefits.

In the lowest section, leadership, there are two key elements: to build a maintenance strategy based on the organisation's strategy and to manage human resources in such a way that they remain or become committed to achieving this strategy. The second section, essentials, is made up of the elements work management, basic care, materials management, performance management, and management and support systems for maintenance. Campbell and Reyes-Picknell (2015) see these five elements as essential for any company which want to be successful with its maintenance, while also preparing for high-performance maintenance. Work management is related to setting up a smoothly operating maintenance process for getting things done according to planning and budgets. Basic care is about conducting more maintenance than the regulatory compliance, e.g. through cleaning, inspections, and PM programs. Materials management is about having the right materials and parts for the work to be done, without stockpiling to avoid unnecessary storage costs. Performance management is about measuring the performance of the maintenance activities, to identify problems and to fix them to increase performance. Last, management and support systems for maintenance is about having computerised systems for assisting. The authors distinguish between two forms of programs, support systems and management information systems such as CMMS and ERP systems. The first category is specialised systems for gathering data, processing and analysing it, before aiding decision-making. The second category is about automating business processes and the flow of information, with work orders as the main document. Campbell and Reyes-Picknell argue that due to the complexity of maintenance, such electronic systems are key.

The last section, choosing excellence, is about companies selecting a method to bring their performance from good to great. There are three options discussed in the framework, namely RCM, continuous improvements, and evidence-based asset management. RCM and continuous improvements have been discussed in brief previously in this review. Evidence-based asset management is based on only servicing assets based on evidence instead of hunches. This is achieved through unbiased expert opinions and statistical data. Campbell and Reyes-Picknell (2015) provide several arguments for each of these approaches. However, possibly the most important thing to remember is their argument of the framework being adaptable pending on the implementing company.

3.2.14 Discussion and summary

It is difficult to compare the frameworks, as there is no standard form of MMFs. For example, Campbell and Reyes-Picknell (2015) and Wireman (2005) construct abstract frameworks and rely on in-depth explanations to describe how the framework works. On the other hand, Hassanain et al. (2003) and Campos and Crespo Márquez (2011) describe in-depth, descriptive maintenance processes with detailed task-sequences and information flows. For the remaining frameworks, they lay somewhere in-between these two types. This wide span of frameworks makes it challenging to compare the frameworks. However, given the scope of the thesis, this is not strictly necessary either. The goal of the review was to determine what functions or elements need to be in an MMF, and if these frameworks suffer from the same issues causing a gap between academic attempts to optimize maintenance and their real-world application. Thus, only these aspects are discussed below.

Common functions or elements that should be in an MMF is seemingly strategic maintenance activities, the control (e.g. performance measurements) of maintenance activities, maintenance planning, maintenance execution, and continuous improvements. However, the various approaches to these elements differ significantly. Additionally, the relationship between all of the elements is explained, which is a consequence of reviewing only process-oriented frameworks. Had also declarative frameworks been reviewed, this would not have been the case. Last, all of the frameworks except are generic, i.e., they are not adapted to any specific business contexts.

Whether the reviewed frameworks suffer from the same issues causing the gap between academic attempts to optimize maintenance, the answer is yes. Particularly the lack of demonstrations or empirical evidence from real-life applications is troubling. This will be considered when designing an MMF based on the reviewed MMFs. A summary of how the reviewed frameworks score in these variables is summarized in Table 5.

Only Pramod et al. (2006) provides empirical evidence that their framework works in practice. Söderholm et al. (2007) provide a demonstration of how their generic framework may be utilised in a paper mill, but without real benefits to show to and it is not illustrated how the framework adapts based on this specific business-context. However, the most common approach is that frameworks are built on the authors' experience and some literature reviews, without any demonstration or empirical evidence to show or prove that the frameworks work in practice.

Table 5: Comparison of the reviewed MMFs in two factors affecting their practical relevance.

#	Framework	Demonstration	Empirical Evidence
1	(Hassanain et al., 2003)	-	-
2	(Wireman, 2005)	-	-
3	(Crespo Márquez & Gupta, 2006)	-	-
4	(Pramod et al., 2006)	✓	✓
5	(Söderholm et al., 2007)	✓	-
6	(Crespo Márquez et al., 2009)	-	-
7	(Campos & Crespo Márquez, 2011)	-	-
8	(Barberá et al., 2012)	-	-
9	(Campbell & Reyes-Picknell, 2015)	-	-

3.3 Measuring maintenance performance

In the following review, different approaches to measure maintenance performance are reviewed. This field is reviewed because performance measurements are essential to The Maintenance Wheel, while the MMFs reviewed in Chapter 3.2 did not go in-depth on the topic. Measuring maintenance performance is an essential part of maintenance management as it supports the identification of performance gaps between the desired and current performance, in addition to indicating whether efforts to close these gaps are effective (Muchiri et al., 2011). The reviewed approaches act as benchmarks and provide part of the theoretical foundation necessary to understand how The Maintenance Wheel works.

The review starts by introducing performance measurements in general. The introduction also briefly touches upon the field of maintenance performance measurement. Second, in Chapter 3.3.2, it is explained how publications were selected for the reviewed. Then, in Chapter 3.3.3 to 3.3.5, different approaches to maintenance performance measurement are reviewed. Concludingly,

3.3.1 Introduction

The set of available approaches to measuring maintenance performance today are largely attributed to developments in performance measurement literature. Consequently, it is necessary with a brief review of this discipline's evolution to understand the different developments of maintenance performance measurement. The discipline has gone through two distinct phases (Ghalayini & Noble, 1996). Phase 1 had a focus of financial performance measures, and started around 1880, lasting until the mid-1980s. Performance measures of this phase were built on management accounting systems, using performance indicators such as return on investment, productivity, and profit per unit. These approaches were heavily criticised for only using financial measures, as critics claimed this emphasised short-term thinking (Hayes & Garvin, 1982; Kaplan, 1983). This argument can be explained by looking at the two, broadly recognized categories of performance indicators, namely lagging or leading indicators. A lagging indicator measures the performance of something which has already happened, whereas leading indicators measure whether tasks are performed in a way which will yield to the desired results (Muchiri et al., 2011). As financial reports are commonly closed monthly, meaning that they measure whether past decisions have achieved a set goal, financial performance indicators are lagging (Ghalayini & Noble, 1996). This is problematic, as relying solely on one of the indicator categories results in an askew view of a company's performance. A second argument raised against financially-based performance measurement is that they fail to measure all the factors critical to a company's success (Kaplan, 1984).

To understand how Phase 1, which had lasted close to 100 years, fell out of favour is to understand the drastic changes to management, technology and manufacturing leading up to (and succeeding) the 1980s. Phase 1 was initially made for textile mills, railroads, and retail stores where labour was the driving cost (Hayes et al., 1988, p. 135). However, as companies started implementing new technologies, such as increasingly automated machines, in addition to a change in manufacturing philosophies from a low-cost production focus to an emphasis on quality, flexibility and customer value (e.g. just-in-time), relying on solely financial metrics was no longer adequate (Ghalayini & Noble, 1996). A relevant example of this, given by Fisher (1992), is that setting targets to measures such as costs set a standard incompatible with the philosophy behind continuous improvement, as improvement efforts will slow down once targets are met. Consequently, Phase 2 was initiated in the mid-1980s. Here, a balanced set of financial and non-financial measures is emphasised (Gomes et al., 2004). In other words, Phase 2 measures performance both in the short and long run.

Having an understanding the different phases of performance measurement literature, maintenance performance measurement can be introduced. Parida, Kumar, Galar, and Stenström (2015) define it as "[…] the multidisciplinary process of measuring and justifying the value created by maintenance investment and taking care of the organisation's stockholders' requirements viewed strategically from the overall business perspective" (p. 15). Note that this definition is based on the second phase of performance measurement literature and sees maintenance as value-adding.

Generally, when academia presents different approaches to performance measurements, it is done through frameworks. These frameworks may be defined as a "[…] set of metrics used to quantify both the efficiency and effectiveness of actions" (Neely et al., 1995). Such frameworks are also used to present different approaches to maintenance performance measurement. However, note that not only the set of metrics used is essential; the measurement method is important too. For example, there is a significant difference in the performance measurements obtained from an audit versus an e-maintenance approach (explored later in this review). However, the indicators and measurement technique used are heavily interlinked, as the subsequent review will illustrate.

3.3.2 Selection criteria

Below, the selection criteria used to identify publications for the review are explained. Thereafter, the resulting publications reviewed are listed in Table 7. For a more in-depth overview of the search process, see Appendix B.

In a literature review, Parida, Kumar, Galar, and Stenström's (2015) identified five main approaches to measure performance. The categories are called "traditional accounting-based", "business-specific", "multi-criteria", "multi-criteria hierarchical", and "function-specific". Only literature related to the three latter categories is examined. First, accounting-based frameworks do only measure financial performance, using measuring indicators such as cost. Frameworks using these indicators belong to phase 1 performance measurement literature and are therefore built on a perception of maintenance being a cost-centre, not a strategic business element. Such frameworks are not relevant to this thesis, as one of the core principles of The Maintenance Wheel is to treat maintenance in a way to maximize customer value. Second, business-specific frameworks are not examined. These frameworks are based on indicators customized for specific industries, e.g. nuclear plants. These are not as relevant for this thesis, given that the framework is MMF is not designed for one particular industry (explained further when defining design requirements in Chapter 5.2). It would also probably be highly challenging to compare approaches from different industries.

Consequently, the different publications reviewed belong to the three remaining categories identified by Parida et al. (2015), namely multi-criteria frameworks, multi-criteria hierarchical frameworks, and function-specific frameworks. The frameworks have also been categorized according to these categories. However, note that the difference between articles is not always as evident in practice. In effect, the categorization of the articles reviewed is somewhat subjective.

Besides this, only publications from peer-reviewed journals were included, except for Parida's (2006) doctoral thesis. This thesis was included on the grounds of its influence on the body of knowledge reviewed. Second, influential articles were desired. Being influential increases credibility and shows that the examined frameworks have contributed to the field of knowledge. Therefore, a minimum amount of citations was initially specified, but as the field is relatively mature, it was not needed to identify the leading articles. Additionally, only articles considering maintenance as value-adding was desired. Therefore, the review was restricted to articles from 1995 forward. Otherwise, it would be difficult to compare the various approaches.

Table 6: List of the reviewed maintenance performance measurement publications.

	#	Author	Framework	Name of publication
Multi-criteria	1	Tsang (1998)	✓	A strategic approach to managing maintenance performance
	2	Tsang, Jardine, and Kolodny (1999)	✓	Measuring maintenance performance: a holistic approach
	3	Liyanage and Kumar (2003)	-	Towards a value-based view on operations and maintenance performance management
	4	Alsyouf (2006)	✓	Measuring maintenance performance using a balanced scorecard approach
	5	Muchiri, Pintelon, Martin, and De Meyer (2010)	-	Empirical analysis of maintenance performance measurement in Belgian industries
	6	Muchiri et al. (2011)	✓	Development of maintenance function performance measurement framework and indicators
Multi-criteria hierarchical	7	Kutucuoglu et al. (2001)	✓	A framework for managing maintenance using performance measurement systems
	8	Parida & Kumar (2006)	-	Maintenance performance measurement (MPM): Issues and challenges
	9	Parida (2006a)	✓	Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM)
	10	Parida & Chattopadhyay (2007)	✓	Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM)
	11	Van Horenbeek & Pintelon (2014)	✓	Development of a maintenance performance measurement framework-using the analytic network process (ANP) for maintenance performance indicator selection
Function specific	12	Al-Najjar & Alsyouf (2004)	✓	Enhancing a company's profitability and competitiveness using integrated vibration-based maintenance: A case study
	13	Parida (2006b)	✓	Maintenance performance measurement system: Application of ICT and e-Maintenance Concepts
	14	Stenström et al. (2013)	✓	Performance indicators and terminology for value driven maintenance

3.3.3 Multi-criteria maintenance performance measurements

Multi-criteria performance measurement approaches were the first alternative developed to the Phase 1 accounting-based performance measures and were based on the idea that a company's performance affects multiple stakeholders, each having individual demands (Parida et al., 2015). Consequently, a maintenance performance measurement framework would need to measure that each of these stakeholder's needs was indeed satisfied (Parida, 2006a, p. 50). From this, the name "multi-criteria" emerged, as a signal that multiple perspectives need to be accounted for when measuring maintenance performance.

Approach 1: Article 1 and 2 – Tsang (1998) and Tsang, Jardine, and Kolodny (1999)

The first approach to measure maintenance performance reviewed was developed by Tsang (1998). Tsang argues for the importance of treating maintenance as both a tactical and strategic matter. With the tactical aspect, he is referring to the traditional perception of maintenance, namely the activities concerned with maintaining, fixing, and servicing assets in a company. The strategic dimension, on the other hand, is referring to:

> "… issues such as [the] design of facilities and their maintenance programmes, upgrading the skills of the workforce, and deployment of tools and manpower to perform maintenance work" (Tsang, 1998, p. 87).

Based on this, activities concerning asset improvement, replacement and disposal are also regarded as maintenance activities. By taking this perspective, Tsang in effect viewed maintenance as an activity contributing to an organisation's long-term performance. Therefore, using the argument that only "what gets measured gets done" by Peters and Waterman (1982), Tsang (1998) developed a performance measurement framework incorporating performance measures for maintenance activities having both short-term and long-term effects.

To construct his framework, Tsang (1998) adapted the balanced scorecard (BSC) framework of Kaplan and Norton (1992). The BSC is built around four perspectives, namely (1) learning and growth, (2) customers, (3) internal processes, and (4) financial. Companies which implement this framework must derive long-run objectives in each perspective from the corporate strategy. From these objectives, the performance measures are subsequently derived. The purpose of using the corporate strategy to find performance measures is to force the company into long-term thinking.

There are a few points of criticism to be made about Tsang's framework. First, Tsang takes a top-down approach by using the BSC, meaning that performance indicators are derived from the top-management. A consequence of this is that metrics derived from the top-management's strategy is used to govern operational aspects, which could make it difficult to interpret for people lower in the organizational hierarchy, i.e., technicians (Alsyouf, 2006). This can be exemplified with the confusion technicians on the operational would likely experience if they were measured on terms such as return on investment. Secondly, some stakeholders' perceptions are excluded by excluding performance measures to the four categories ("perspectives") found in the BSC model. For example, employee satisfaction is not measured. Moreover, Tsang is solely focusing on the company in question and their customers, neglecting suppliers and competitors. Potential consequences of this is a lack of benchmarking against competitors, as well as possible improvements upstream not being capitalized on.

In 1999, Tsang et al. (1999) elaborated on the work of Tsang (1998). In the article, four approaches to (including Tsang's (1998) BSC framework) is reviewed and compared. The purpose of the paper is to illustrate the consequences of indiscriminately using MPIs. The other methods examined are (1) value-based performance measurement, (2) system audits, and (3) data envelopment analysis (DEA). Firstly, value-based performance measurements measure the possible impact of each maintenance task on the future value of the organization's assets, measured through future cash flows. Second, system audits to measure the performance of maintenance departments comprehensively, commonly through extensive surveys. Lastly, DEA is a tool to measure the relative performance of decision-making units, such as maintenance departments (Beasley, n.d.). Note that the approaches system audits and DEA are not within this thesis' scope but are included due to their role in the article.

Tsang et al. (1999) conclude that Tsang's (1998) framework is the best approach to maintenance performance measurements. First, value-based performance measures imply that all maintenance activities can be quantified in monetary values. This is difficult with aspects such as employee satisfaction. Additionally, it is a labour intensive and complicated way of measuring maintenance performance, according to Tsang et al. (1999). Second, system audits are found to provide extensive and detailed performance measures in dimensions such as employee satisfaction, which is not possible to measure with approaches like the value-based performance measurements. However, system audits are complicated to carry out and are thus only conducted on an ad hoc basis in specific key areas (Tsang et al., 1999). Consequently, system audits are ill-fit to measure the performance of day-to-day operations of the maintenance department. Lastly, DEA is presented as a complicated method useful for comparing the productivities of companies. It is undoubtedly useful when benchmarking against competitors, but it is ill-fit to run the day-to-day operation.

Article 3 - Liyanage and Kumar (2003)

The third article reviewed, written by Liyanage and Kumar (2003), is related to an extensive joint industry project conducted among oil and gas companies in Norway. This project was aimed at the development and implementation of BSC-based performance indicators. After the project concluded, Liyanage and Kumar conducted several interviews with key participants of the project to generalize the experiences from it for other implementation efforts of maintenance performance measurement frameworks.

One of the more interesting results is related to the difficulties faced while implementing such frameworks. In total, three issues are identified, all of which are interesting for this thesis. The first issue relates to the data available in ERP systems not being quality assured, in addition to low levels of data availability. The second issue relates to operational crews struggling to understand the measurements taken. Although Liyanage and Kumar (2003) conclude that this is due to a lack of training, another reason could be that that the project entered the same top-down pitfall as Tsang (1998) by applying the BSC. In other words, it is possibly not a lack of training which is a problem; it is the assumption that measures used by the top management should be understood on the operational level. Lastly, it was found that there was a resistance to adopting such a BSC-based approach to performance measurement. Liyanage and Kumar conclude that this likely stems from the second issue, in addition to a long history of failed projects within the companies.

Approach 2: Article 4 – Alsyouf (2006)

The last multi-criteria framework reviewed, which has been based on the BSC, was developed by Alsyouf (2006). But although Alsyouf base his framework on the BSC, he argues that the earlier BSC-based approaches (e.g. Tsang (1998)) were flawed. First, he argues indicators are difficult to understand for workers on the operational level when they are derived solely in a top-down process. Second, it does not allow benchmarking. Third, it leads to the neglect of important actors in the extended value-chain. Consequently, after visualizing the negative effect this neglect has on a company's value-chain, he expands the four original perspectives in the BSC framework into seven broader perspectives to incorporate the actors in the extended value-chain. These perspectives are (1) financial, (2) society, (3) production, (4) suppliers, (5) support functions, (6) consumers, and (7) human resources perspectives.

These perspectives are distributed according to their location in the value chain. After distributing them, adjacent perspectives are connected. To illustrate such a connection, take the two perspectives "production" and "support functions". If a machine breaks down uncontrolled, this failure may be measured by maintenance indicators such as "amount of uncontrolled failures per month", "hours of unplanned downtime", and "hours of unscheduled maintenance work". These support function indicators can then be traced to indicators in the production perspective, e.g. "availability". Such connections can be found among all of the framework's perspectives. Consequently, the change in a maintenance indicator can be tracked to the change in the company's strategic business objectives. This is what is referred to as cause-and-effect relationships. To achieve interconnected indicators, and perspectives, Alsyouf suggests deriving indicators using both a top-down and down-up process. The purpose of this additional down-up process, in comparison to the traditional BSC framework, is to avoid using solely indicators which have been derived top-down. He argues that this results in indicators becoming easier to understand for technicians.

The article is an attempt to create a framework for measuring strategic maintenance performance. This implies to not only measure the performance of the day-to-day operations but to predict potential maintenance projects influence a company to aid in their decision-making. In other words, the framework works as a tool to both measure the expected performance of a given improvement project, and to then track whether a company remains on track to achieve these objectives.

Article 5 - Muchiri, Pintelon, Martin, and De Meyer (2010)

This article, written by Muchiri et al. (2010), is based on a study conducted among Belgian companies to examine the various approaches to maintenance performance measurements used. The study examines the popularity of various KPI's, how KPI's were chosen or sourced, how manufacturing and maintenance objectives have influenced the used KPI's, and how effective the usage of KPI's in fact was.

The studies found a set of interesting results. First, most of the used indicators were lagging. This means that indicators such as maintenance costs and HSE issues dominated, with leading indicators of, e.g. maintenance work process being uncommon. Muchiri et al. warn against this development, arguing that the leading indicators are essential, as they measure whether the maintenance conducted will lead to the desired results. A second result was that there was no correlation found between the maintenance objectives and the KPI's used. This signals that the BSC-based frameworks mentioned previously had not gained traction, as linking strategy and indicators used is a key element in these frameworks. Third, it was found that these KPI's rarely led to a decision being made. Last, and according to Muchiri et al. their most important finding was that a correlation study indicated that when KPI's as processes were changed, and decisions were being made due to KPI's, the satisfaction with the performance measurement system increased.

Approach 3: Article 6 - Muchiri et al. (2011)

Based on the findings of Muchiri et al. (2010), Muchiri et al. (2011) create their own framework. Specifically, they aimed to fix the observed separation between maintenance objectives and maintenance KPI's, in addition to connecting maintenance KPI's to production-related objectives.

Their framework is divided into three sections: alignment with production, analysis of maintenance effort and process, and maintenance result analysis. The first part is about setting objectives for maintenance which are aligned with the manufacturing. Muchiri et al. (2011) argue that corporate strategy should first result in the definition of manufacturing's performance requirements. These requirements are then used to set maintenance objectives.

The remaining sections' purpose is to ensure that these maintenance objectives are met. First, the maintenance efforts and the process must be managed. This is done through measurements of the maintenance activities as they happen. Muchiri et al. (2011) use the following four steps to describe a maintenance process, listed in sequence: work identification, work planning, work schedules, and work execution. As these activities determine the outcomes of maintenance, indicators measuring these activities performance are referred to as leading. Muchiri et al. does also provide examples of indicators to be used for all of the activities, but stresses that indicators need to be selected individually for each company.

The last section, the maintenance results analysis, is concerned with assessing whether the performance targets set in the first section is actually met. Notice that this is a retroactive analysis, meaning that the performance indicators are lagging. Muchiri et al. suggest using equipment performance and maintenance cost in this analysis. This analysis is done according to set intervals, e.g. monthly. Muchiri et al. argue that this section is important as it is the driver of identifying performance gaps, which is crucial to ensure continuous improvements.

3.3.4 Multi-criteria hierarchical performance measurements

Multi-criteria hierarchical and multi-criteria performance measurement frameworks are similar, as given away by their names. For example, both types stress the importance of measuring performance for multiple stakeholders. However, multi-criteria hierarchical frameworks are generally based on the idea that important decisions are made by managers on each hierarchical level, resulting in them deriving performance indicators for each hierarchical level (Parida & Chattopadhyay, 2007). Resultingly, multi-criteria hierarchical frameworks appear to be more of a niche within the multi-criteria framework's category than a separate category.

Approach 4: Article 7 - Kutucuoglu, Hamali, Irani, and Sharp (2001)

In this article, Kutucuoglu et al. (2001) present the fourth performance measurement framework reviewed. The framework is based on the QFD method discussed previously, i.e., the house of quality. Simply put, the QFD method converts customer requirements into detailed objectives. Indicators do then measure whether these objectives are met. Note that the main customer of maintenance is the facility in which the maintenance happens (see Appendix C).

Kutucuoglu et al. (2001) conduct two literature reviews to find requirements for their framework, resulting in a list of requirements for an effective maintenance performance measurement system. They argue that since customers come from many different levels in the organisation, such as production and top management, it is necessary with a framework considering hierarchy. Additionally, measures should be linked to objectives and strategy, a balanced view of long term and short performance should be given, employees should be included, and cross-functional issues should be addressed.

Having identified this list, Kutucuolgu et al. (2001) argue that a performance measurement system based on the QFD is suitable. The resulting QFD framework developed by Kutucuolgu et al. consists of three stages. First, KPI's are identified and aligned. Notice that alignment is referring to connecting corporate strategy to maintenance indicators, which Kutucuoglu et al. provides in-depth guidance for how to do. During this step, objectives to maintenance performance are also set. Second, comes the identification of critical measures for ensuring high performance. Notice that KPI's are aggregated from several smaller indicators, which is what is identified here. Last, in step 3, performance is measured and recorded against performance targets set in the first step.

Article 8: Parida & Kumar (2006)

Following developments in the field of maintenance performance measurement, Parida and Kumar (2006) decided to examine the prevailing maintenance performance systems at the time to identify common issues and challenges. The main flaw identified in the article is that the most common systems (at the time) only measured internal maintenance performance. Parida and Kumar argue that this leads to the neglect of external performance measures, affecting measures such as customer satisfaction and market share growth (Parida & Kumar, 2006). These are performance indicators with a long-term effect on the company.

Approach 5: Article 9 and 10 - Parida (2006a) and Parida and Chattopadhyay (2007)

The fifth framework reviewed is presented by Parida and Chattopadhyay (2007). This article is based on the doctoral thesis of Parida (2006a), where Kumar from Article 8 was the supervisor, and Chattopadhyay was a co-supervisor.

As with many of the multi-criteria frameworks, Parida and Chattopadhyay present a framework which has been based on the BSC. However, as found in the review of Parida and Kumar in (2006), the most commonly used performance measurement systems failed to measure external maintenance performance. To solve this issue, Parida and Chattopadhyay (2007) expand the original BSC perspectives into the seven perspectives: (1) equipment and process-related, (2) cost and finance related, (3) maintenance task-related, (4) learning, growth and innovation, (5) customer satisfaction related, (6) HSE, and (7) employee satisfaction. Notice the similarity to Alsyouf's (2006) framework. Then, in each of these perspectives, indicators are defined for the various hierarchical levels of an organization. The amount of hierarchical levels within a company depends on the organisational structure and company size. Parida (2006) and Parida and Chattopadhyay (2007) uses one with three levels of hierarchy, listed top-down: senior management, middle management, and the operational level.

Approach 6: Article 11 - Van Horenbeek and Pintelon (2014)

The sixth approach reviewed is presented by Van Horenbeek and Pintelon (2014). Their framework is based on a review of other performance measurement frameworks, in which they identify a set of issues they want to fix. First, they argue that all of the performance measurement frameworks reviewed are too generic. Van Horenbeek and Pintelon see this in connection to the work of Muchiri et al. (2011, 2010), in particular, their findings of the link between corporate strategy and the MPIs used not being established properly. Van Horenbeek and Pintelon argue that this is caused by the generic nature of the reviewed performance measurement frameworks. However, they disagree with the framework designed by Muchiri et al. (2011) to solve this issue, as they neglect hierarchical levels. Van Horenbeek and Pintelon see organizational structures (i.e. hierarchical levels) as an example of how different organizations have different business contexts, which a performance measurement framework needs to be adaptable to. The second issue they mention is related to this, namely the lack of methodological approaches to derive or select MPIs, which are business-specific. Consequently, van Horenbeek and Pintelon develop their own framework to solve these issues.

The framework created by van Horenbeek and Pintelon (2014) is composed of five steps. In the first step, the authors define a generic set of maintenance objectives, based on a literature review and the authors' experience. Then, the second step is to use this generic set of objectives and prioritize them using an ANP model, for all of the organization's hierarchical levels. An ANP model is a multi-criteria decision-making tool, used to rank a set of alternatives. In this case, the alternatives are the various maintenance objectives. Note also that this prioritization is done by using the corporate strategy, which is how van Horenbeek and Pintelon establishes the link between corporate strategy and maintenance objectives. The third step is then to use the now business-specific maintenance objectives to derive performance indicators on all organizational levels. In step 4, these indicators are used to measure and control the performance based on these indicators. Last, in step 5, performance gaps are closed as they are identified, to ensure continuous improvement.

3.3.5 Function-specific performance measurements

Function-specific approaches to performance measurement are specialised for a specific functional department; in this case, the maintenance department. Examples of indicators used in such approaches can, for example, be the number of unplanned maintenance tasks or maintenance response time (Parida & Chattopadhyay, 2007). Note that, unlike two categories of multi-criteria performance measures, function-specific performance measures do not necessarily belong to the second phase of performance measurement literature, as explained in Chapter 3.3.1.

Approach 7: Article 12 - Al-Najjar and Alsyouf (2004)

Al Najjar and Alsyouf (2004) presents an approach to maintenance performance measurement based on condition-based maintenance. More specifically, a model to identify, monitor, and improve the financial impact of vibration-based maintenance is created. Note that vibration-based performance measures assets' vibrations, making it possible to receive indications of wear an early stage.

The article is built on the premise that the failure, unplanned-but-before-failure stops, and short stoppages of assets are the leading cause of economic losses in companies, i.e., potential savings not capitalized on. This is explained by such stoppages resulting in indirect costs, defined as all expenses indirectly related to maintenance, e.g. the loss of customers and lost production caused by delivery delays and reduced product quality. Furthermore, the authors state that these failures can be reduced to approximately zero by using a plant-wide condition monitoring system.

By using the information provided by the condition monitoring system, in conjunction with the life cycle costs of assets, cost-effective decisions can be made. Note that life cycle costs consist of both indirect costs and direct maintenance costs. Furthermore, the approach can be used in continuous improvement efforts. This is caused by the possibility of assessing the economic impact of a given decision retroactively to determine how cost-effective it was and to subsequently determine whether another decision would be better the next time.

Approach 8: Articles 13 – Parida (2006b)

Another approach to maintenance performance measurements is ICT-based and is referred to as e-maintenance. It can be defined as the wireless and real-time monitoring and management of plants and machinery using intelligent sensors, the internet, online GUIs, databases, and more (Kumar et al., 2013). A performance measurement system which is based on e-maintenance collect the data for its indicators real-time and can be used to assess the performance of maintenance when linked to other operational data (Parida, 2006b). Such data can also be used to benchmark the performance of equipment against competitors, in addition, to trigger preventive maintenance by predicting breakdowns (Kumar et al., 2013). Kumar et al. argue that the main problem for performance measurement, in general, was the lack of relevant data and information to make decisions, an issue which e-maintenance can fix.

Approach 9: Article 14 - Stenström, Parida, Kumar, and Galar (2013)

Value-driven maintenance is a maintenance management methodology developed by Haarman and Delahay (2004). The methodology is based on calculating the net present value for maintenance activities according to four value drivers, namely asset utilization, cost control, resource allocation, and health, safety and environment (HSE) (Stenström et al., 2013). However, as Stenström et al. find that for such a methodology to work, a maintenance performance measurement system is needed, they create a framework. The purpose of this framework is to build knowledge of the four value drivers so that the net present value can be estimated precisely.

Stenström et al. (2013) view maintenance as a process. It is the only article in the review which discuss and illustrate why both leading and lagging indicators are needed by using BPM terminology. Inputs into a process are measured by leading indicators, whereas the outputs of the process are measured by lagging indicators. Both aspects' performance is seen as necessary.

A set of indicators are given, categorized according to four value drivers. Of the four value drivers, asset utilisation is governing. This means that the required asset utilization is first defined, resulting in a set of objectives that needs to be met. After that, objectives related to resource allocation and costs are set. HSE is measured separately for the entire process.

3.3.6 Discussion and summary

All of the reviewed frameworks belong to three overarching approaches to maintenance performance measurement, i.e., multi-criteria, multi-criteria hierarchical, and function-specific performance measurements. In addition to this, each framework reviewed perceived maintenance as a strategic, value-adding part of a company, hoping to realise benefits by effectively measuring performance and manage accordingly. Resultingly, with the exception of Approach 8 by Parida (2006b), all of the articles focused on performance measures with both long term and short term effects. However, this is where the similarities end.

Initially, this review was conducted to identify benchmarks for The Maintenance Wheel. However, even though a broad search was conducted, by reading Chapter 4.2, it should be clear that no comparable performance measurement approaches were identified. Thus, since the approaches are not comparable to The Maintenance Wheel, the following discussion will be limited to what is indeed relevant. When researching why different solutions developed by academia to optimize maintenance has failed to spread to real-world organizations in Chapter 3.2.3, it was seen that a lack of practical relevance was to blame. This problem is also believed to affect the reviewed performance management solutions. Below, three main issues are discussed. This is then discussed further in Chapter 4.3.2, after explaining The Maintenance Wheel in depth in Chapter 4.2.

For the first issue, it is necessary to understand the concept of multi-criteria. Companies maintenance processes have different stakeholders with different needs. Additionally, there are variables such as industry type and government requirements separating companies from each other. This ultimately means that different companies have different needs for their maintenance department. Due to these different needs, companies should also use different categories of indicators to measure the performance required by each stakeholder. It is therefore hard to understand the logic of scholars who simply provide a list of prescriptive performance indicators, such as Parida and Chattopadhyay (2007) and Alsyouf (2006).

Second, the least of requirements to be perceived as practically relevant for real-world organizations is to have a demonstration or empirical evidence showing that the proposed way to measure performance works indeed works in practice. Of the reviewed frameworks, only three frameworks have any form of proof of concept, as seen in Table 7 under the category "Proof of Concept".

Third, on several occasions in this thesis, it has been explained that maintenance is generally perceived as a strategic, value-adding part of a company. Resultingly, it is important for performance measures today to contain both strategic and organizational measures to facilitate continuous improvements on all hierarchical levels, and in all maintenance activities (Simões et al., 2011). It is believed that the reviewed frameworks fail to do so sufficiently. Many of the frameworks discuss maintenance using process-related terms. However, none of the frameworks provides a way to measure the process performance of the maintenance process. Although Muchiri et al. (2011) do touch upon time-based performance measures, they only do so for the servicing of assets themselves, i.e., a smaller section of the maintenance process. Effectively, this means that prior research on how to measure maintenance performance has focused on performance measures for one and one activity. First, the concept of measuring flow in maintenance activities appears to be an underexplored topic, as the articles did not focus on time-based performance measures. Second, measuring the performance of and thus managing maintenance as an end-to-end process, where also wastes in-between activities identified, has not been researched. Consequently, prior research has overlooked a large range of potential continuous improvements.

To summarize the findings of the review, the following table has been made. For a more in-depth overview of the various publications, see Appendix E.

Table 7: Overview of attributes and features affecting the practical relevance.

#	Approach	Balanced Indicators	Multi-Criteria	Hierarchical	Process Performance	Proof of Concept
1	Tsang (1998)	+	-+	-	-	-
2	Alsyouf (2006)	+	+	-+	-	+
3	Muchiri et al. (2011)	+	-	-	-+	-
4	Kutucuoglu et al. (2001)	+	-+	+	-	+
5	Parida & Chattopadhyay (2007)	+	+	+	-	-
6	Van Horenbeek & Pintelon (2014)	+	+	+	-	-
7	Al-Najjar & Alsyouf (2004)	-	-	-	-	+
8	Parida (2006b)	-	-	-	-	-
9	Stenström et al. (2013)	+	-	-	-+	-

Meaning of signs: "+" = yes, "-+"= somewhat, "-" = no.

3.4 Business Process Management

In the following review, BPM is introduced. The reason for the review is that preliminary research of The Maintenance Wheel signalled that it was built on concepts from BPM. Resultingly, the purpose of this review was to explore and understand the theoretical context of The Maintenance Wheel. This was crucial to identify the main elements of The Maintenance Wheel in Chapter 4, to understand these elements interconnections, and to be able to describe both of these accurately. Thus, the review provides the theoretical foundation to properly analyse The Maintenance Wheel in the next chapter.

First, the antecedents to BPM are introduced. This introduction is important to understand the common view of BPM's history, as there are some underlying principles to this way of managing business activities. However, there are alternative perceptions of BPM, which are also discussed. After this, an in-depth explanation of BPM is given, starting with key concepts in BPM, before explaining how it (usually) works in practice. Subsequently, key motivations of why managers use BPM are explained, before explaining common approaches to BPM, such as lean. Note that the key motivations have been reviewed to strengthen the common approaches to BPM, by highlighting how even seemingly the same approach to BPM can be used to realise very different benefits.

3.4.1 Introduction

BPM is a continuously developing field, whose start is usually attributed merge of the quality movement and business process reengineering (BPR) towards the end of the 20th century (Hammer, 2010; Iden, 2018). Therefore, as these two antecedents are essential to understand the underlying principles of the common view of BPM, they are explained first.

According to Hammer (2010), the quality movement is based on the work of Deming (1953) and Shewhart (1986) on statistical process control. Deming and Shewhart's work sought to reduce process performance variation through careful performance measurements, upon which any deviations would spur the isolation and subsequent fixing of deviations root causes through improvement work (Iden, 2018). However, according to Hammer (2010), it is not a reduction of process performance variation which is the most important contribution of the quality movement to the field of BPM; it is the underlying assumptions of this work. Hammer states the work of Deming and Shewhart introduced the following principles: (1) operations are highly important for a company's success, (2) the companies operation require meticulous and considerate management, (3) the use of hard data instead of opinions to solve unwanted performance deviations, (4) the focus on using performance measurements to assess whether the company is producing (5) the focus on processes being the root-cause of deviations, not people, (6) and the concept of continuous improvement. Despite this, Hammer argues that the quality movement also suffered from two issues. First, the movement defined a process as "any sequence of work activities" (Hammer, 2010, p. 4). This resulted in organizations having up to thousands of small processes. Hammer argues that this results in many, small-scale projects which are difficult to manage. Second, Hammer argues that the quality movement's focus on eliminating all variation to achieve level performance outputs was detrimental, as consistency is not necessarily good. Because, a process could perform consistently on a level below the customer or organizations desired performance, which is not what a good process would achieve. It should deliver consistently on a level satisfactory for both the customer and the organization.

The second movement, which merged with the quality approach to become the BPM movement known today, is BPR. This antecedent was initiated in the early 1990s and is known as a radical approach to cost reduction and improvement work (Davenport & Short, 1990). This field introduced predominantly two new concepts to the field of process management (Hammer, 2010). First, it solved one of the issues of the quality movement, namely the small processes. BPR considered processes as end-to-end value chains stretching throughout organizations to create customer value. Second, BPR introduced the concept of thinking about improving process designs instead of solely process execution. In the quality movement, processes were considered as inherently good, meaning that increased performance needed to come from improved process execution. In BPR, this was not the case, as processes were subject to radical redesigns to improve performance. However, this brings us to the first of BPR's shortcomings, namely that most companies see such a radical change as challenging (Grover et al., 1995). A second issue is that BPR had a large emphasis on one-shot improvement projects, with little emphasis on day-to-day management (Iden, 2018). Last, BPR lacked the systematic performance measurement and follow-up which the various approaches to quality management is known for (Hammer, 2010).

These two performance improvement approaches have merged into BPM over the last two decades (Hammer, 2010). BPM may be defined as an "integrated system for managing business performance by managing end-to-end business processes" (Hammer, 2010, pp. 4–5). Iden explains, based on a similar definition of BPM provided by Smith and Fingar (2003), that BPM resultingly encompasses both the characteristic one-short improvement projects of BPR, as well as the management and continuous improvement of processes which the TQM movement is known for.

It is important to acknowledge that other authors have different views of the origin of BPM, e.g. Harmon (2010). Harmon's explanation is more pragmatic, arguing that BPM is simply part of a long tradition which aims to improve businesses. He argues that whether a particular manifestation of this tradition is referred to as BPR or total quality management is not as important. Instead, Harmon argues that what matters is understanding how these manifestations come from three

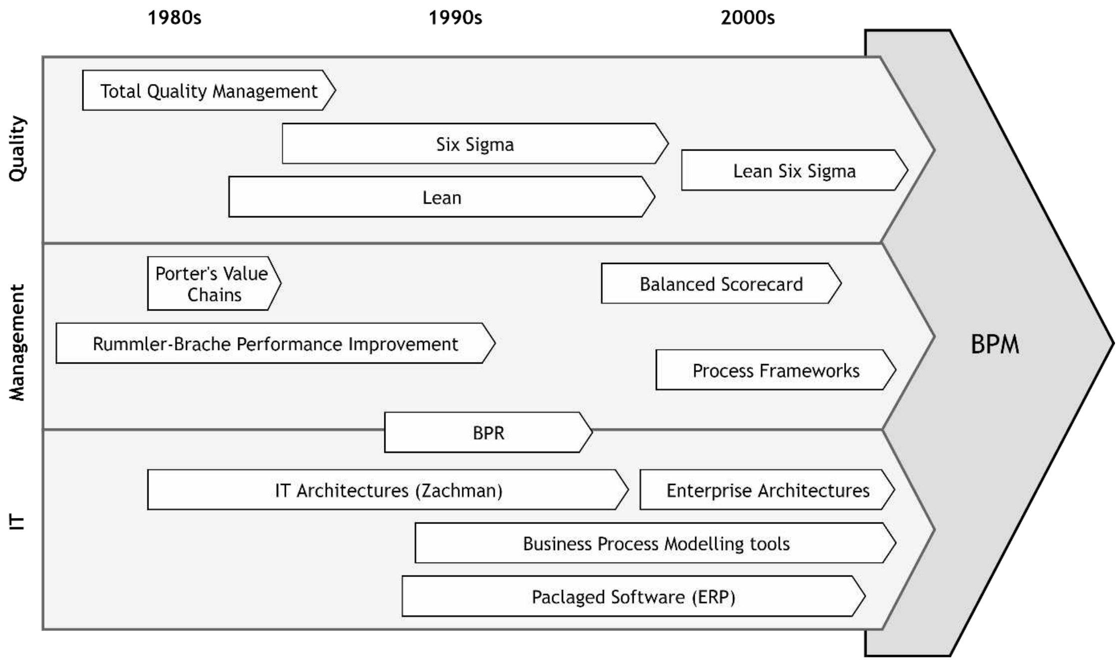

Figure 17: Overview of concepts which has resulted in BPM. Adapted from Harmon (2010, pp. 38, 41, 47, 50)

broader process traditions, namely the quality control tradition, the management tradition and the IT tradition. In this perspective, BPR is treated as a sub-concept within the management and IT tradition. Hammer (2010) points out that his own explanation of how the quality movement and BPR merged to form BPM only explains the main concepts of BPM. Harmon's explanation supplements this, allowing us to see the larger picture of BPM, e.g. how concepts such as lean, six sigma, BPR, Porter's value chain, and ERP systems are interconnected. To illustrate how a select few concepts of BPM have emerged, under the broader term BPM, see Figure 17, adapted from four figures of Harmon (2010, pp. 38, 41, 47, 50).

3.4.2 Key concepts in BPM

BPM has grown into an important research domain over the last two decades and has matured significantly (vom Brocke et al., 2014). However, Rosemann and vom Brocke (2010) found that the discipline has its challenges, e.g. fragmented adoption, a lack of standardized terminology, and disagreements on how to scope BPM. Despite this, vom Brocke et al. (2014) argue that the foundation of BPM itself is well-proven. Because, even though there are multiple definitions of BPM, there is a wide agreement among both scholars and practitioners that the core purpose of BPM is to improve companies' performance through the management of end-to-end processes (Hammer, 2010; Iden, 2018).

Since there are disagreements regarding definitions, it is necessary to specify what is considered a process. In a bid to identify dominant definitions, Palmberg (2009) examined 77 articles, and found that there are no definitions are more dominant than others. However, she did identify a set of commonalities between all definitions: (1) inputs initiate processes and are converted to outputs in the process, (2) processes have a purpose or create value for customers, (3) processes require resources, (4) activities of processes are connected, (5) processes are repeatable, and (6) processes are cross-functional and horizontal (Palmberg, 2009, p. 207). To summarize, processes span organizational boundaries, creating end-to-end value chains which systemize the flow of information, linking people and equipment to deliver customer value (Iden, 2018).

Iden (2018) argues that it is important to recognize business processes as lasting organizational phenomena in need of continuous management. He states that while managers know customer value is generated in processes, functional departments are still prioritized, which has negative effects. First, Iden argues that companies organized by functionality focus on departmental performance instead of value-chain performance, which could result in sub-optimization. The departmental performance is optimized, but this is not synonymous with the optimization of the organization's value creation (Iden, 2018). Second, Iden states that by focusing on functional departments instead of processes, cross-functional communication is difficult, hampering the creation of customer value.

Most companies who implement BPM adapt a matrix-like organizational structure, where processes and functional departments co-exist (Maddern et al., 2014; Palmberg, 2010). The result is an organization with vertical functional departments, where processes move horizontally between different functionalities. Very few companies adopt a solely process-based organizational structure (Iden, 2018). Based on an illustration from Palmberg (2010, p. 99), this is illustrated in Figure 18 on the next page.

Note that matrix structures, such as the one illustrated above, can cause internal conflicts (Iden, 2018). As Iden explains, conflicts may arise between a process owner (i.e. process manager) and line managers, as power remains with the line-managers. When process owners lack the power to

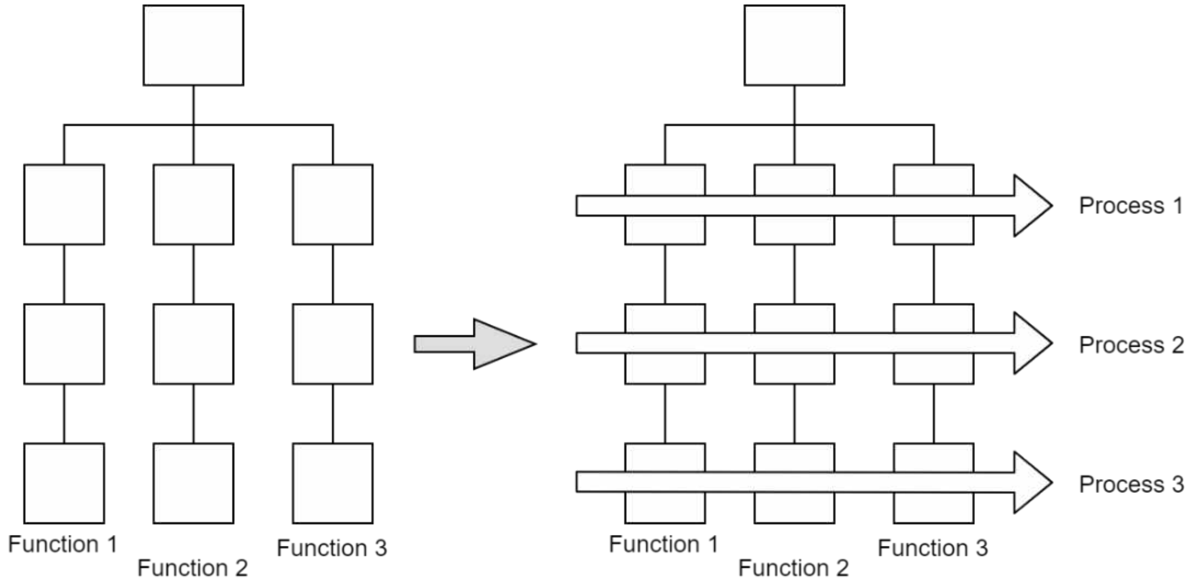

Figure 18: Organizational structure of organizations adopting BPM. Adapted from Palmberg (2010, p. 99).

make decisions, achieving continuous improvement becomes difficult as managing staff becomes an uphill struggle. The alternative, however, has not worked out in practice. For example, in a BPM-based improvement project at Texas Instruments, it was expected that the organization would end up with a fully process-oriented organizational design (Hammer & Stanton, 1999). The outcome was unexpected, as the functional departments pushed back against the organizational redesign. Subsequently, Texas Instruments ended up with a matrix organization, although expectations were otherwise. In this organization, processes coordinated operations, whereas the functional departments governed more indirect value-adding activities, such as building capacity. In a case study examining three organizations post-BPM-implementation, Palmberg (2010) found similar results. To summarize, the functional departments may act as a barrier to organizations fully process-oriented, which may be why Iden finds that most organization end up with a matrix structure (Iden, 2018).

3.4.3 BPM – in practice

Having reviewed how processes integrate with organizations, it is necessary to also understand how these processes are established and managed. A commonly used approach do so is process management cycles. As with definitions of BPM, there exist slight differences between different process management cycles, e.g. in terms of process outline, weights assigned to different activities, and the level of detail. Nevertheless, the essentials elements remain the same, as exemplified by the seemingly different cycles of Hammer (2010) and Dumas, La Rosa, Mendling, and Reijers' (2018). In this thesis, the former cycle is used, as Dumas et al. take it for granted that BPM is only initiated when there is a problem which requires solving. The cycle of Hammer (2010) has been visualised in Figure 19 on the next page.

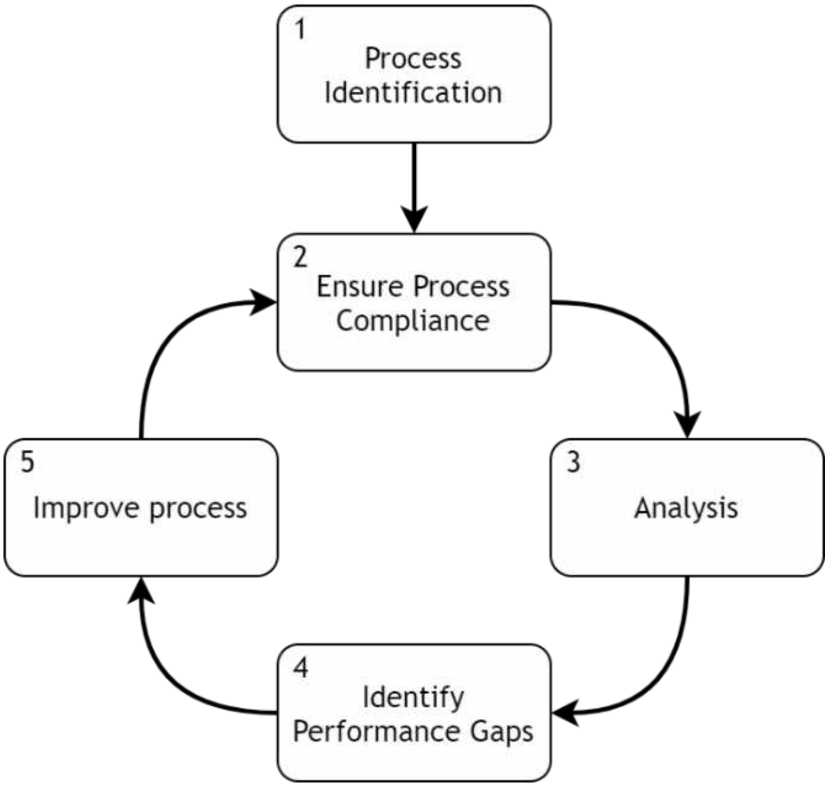

Figure 19: BPM management cycle. Adapted from Hammer (2010, p. 5).

1. Process identification: The first activity of BPM is to establish a formal process, with clear distributions of responsibility and performance indicators. Once the process is established, its current state must also be documented. As put by Hammer (2010), this is no small task. Some organizations are categorized by low degrees of consistency, with no defined end-to-end processes. Examples of this are companies treating each case as a new situation, e.g. companies viewing each maintenance work-order as a new task.

2. Ensure process compliance: Once the process is operational, the company needs to ensure that it remains in control of the process.

3. Analysis: In this step, the current state of the process is assessed. This entails measuring process performance and benchmarking. Note that different metrics are measured at different intervals, while some process indicators are measuring continuously. The border between step 2 and 3 is consequently not as clear in practice.

4. Identifying performance gaps: An analysis has no purpose if there are no targets to chase. Consequently, the next step consists of specifying performance targets, resulting in the identification of performance gaps. Hammer (2010) states that such gaps generally stem from either faulty process design or process execution.

5. Improve process: Once a gap has been identified, it must be closed. This is done by first investigating the source of the gap. Subsequently, an intervention plan is created, whereafter the intervention is implemented. To end this step, the company measures the effect of the intervention. Once the gap is closed, the company goes back to step 2.

3.4.4 Managers motivation for BPM

Porter (1985) found that the capability of firms to establish competitive advantage depends on the activities within companies' processes. Building on this, he argues that competitive advantage stems from performing similar activities as competitors more effectively and efficiently than rivals are. This brings us back to the sub-optimization mentioned previously; as most companies manage according to functions, adopting BPM can yield a competitive advantage since it allows the optimization of entire value-chains collectively instead of only similar tasks.

BPM realizes benefits in a pattern (Rudden, 2007). First, immediately after implementation, companies will experience that efficiency increases. Then, as processes are established, companies start continuously improving through process redesigns or improved process execution. In an article by Kohlbacher and Reijers (2013), it is found that the largest source of improvements stems from continuous improvement.

But how do companies realize benefits through BPM? Iden (2018) argue that many companies suffer from a low degree of process awareness, in turn resulting in a lack of end-to-end process performance measurements, sub-optimized inter-departmental interactions, and a low degree of procedural awareness. These issues are solved by BPM. For example, BPM builds process awareness among staff (Iden, 2018). This forces employees to break out of the common silo mentality, and to think about themselves as parts of a company-wide end-to-end value chain with the customer in focus. Customers are both those receiving partial deliveries from the various sub-activities in a process, as well as the end customer of the value chain. However, benefits do not only emerge from increased process awareness. Iden (2018) lists that (1) increased focus on customer needs, (2) increased distribution and clarification of responsibility that makes people take ownership of their work, (3) increased information about customer satisfaction, and (4) increased standardization and structure result in benefits.

In general, Hammer (2010) states that operational benefits from BPM are lowered costs, increased speed of activities, increased consistency, and increased quality. In sum, these benefits improve a company's performance by lowering operating costs while increasing customer satisfaction. Furthermore, Iden (2018) argues that BPM both raises employee satisfaction and allows managers to focus on what generates value in organizations, namely the staff and activities. Rudden (2007) states that companies utilizing BPM will be able to change to adopt changing environments quickly.

Several scholars have researched what motivates companies to adopt BPM. In an article, Rosemann (2015) describes two steps required to convince companies of adopting BPM. First, managers must become aware of, and understand, BPM. Roseman argues a lack of understanding of BPM often impedes adoption. Another barrier mentioned, also applicable to those familiar with BPM, is difficulties related to convincingly justifying and illustrating BPM's benefits to companies. The next step in BPM adoption is to create a desire to adopt, deemed critical since this is where the decision to adopt BPM is made. In this thesis, both steps are critical.

In an international survey conducted biennially, by the webpage BPTrends.com, international BPM trends are measured. Having measured since 2006, they allow trends to measure over time. Note that their sampling technique is subjectable to critique, as samples have been obtained using voluntary response sampling. This can induce a bias in the data set as respondents of such surveys tends to have strong opinions (Khan Academy, n.d.). Despite this, it is likely that the relevant results are generalizable to Karabin's context. First, and most importantly, the result of interest are not measurements concerning topics such as BPM's usefulness (i.e. measurement which the likely biased sample is expected to rate higher than a population sample), but the motivations for working with BPM. Furthermore, most answers come from companies relevant to Karabin, as 65% of respondents come from medium to large companies, and roughly 70% of the respondents come from industrialized countries (Harmon & Garcia, 2020). The largest motivations (over 20%) are presented in Table 8. Note that the average and standard deviance of motivations 2008 has been calculated to illustrate how motivations have remained constant over time. The first measurement, from 2006, was omitted since these measurements differed significantly. As illustrated, the largest drivers of BPM adoption are found to be improved efficiency, customer satisfaction, and improving quality. Note that "n/a" means there are measurements missing.

Table 8: Drivers of BPM adoption. Adapted from Harmon and Garcia (2020).

			[2008-2020]	
Drivers of BPM Adoption	2018	2020	$\bar{x}$	σ
Reducing costs / improving productivity (efficiency)	53 %	69 %	56.9%	5.6%
Improving customer satisfaction	42 %	38 %	38.3%	4.7%
Improving quality and delivering quality in new ways	28 %	35 %	32.9%	3.5%
Improvement of IT resource management	26 %	31 %	n/a	n/a
Reducing cultural resistance to process change	15 %	24 %	n/a	n/a
Government or certification motivated risk-management	21 %	20 %	16.9%	3.1%

A Norwegian study conducted by Brennhovd and Flatebø (2017) found similar results, as shown in Table 9. Note that the percentages vary from Harmon and Garcia's (2020) as Brennhovd and Flatebø only measure the main motivation. Their study gathered a large sample of 719 organizations, utilizing several criteria to get a representative sample of companies engaging in BPM, and obtained a good response rate (26.2 %) for a web-survey without incentives (Sekaran & Bougie, 2016). What makes these results particularly interesting is that they checked the job position of each subject in the survey, of which one category was "senior management". Although they did not include a t-test of whether senior managers answers differed significantly from the other job positions, Brennhovd recalls that he and Flatebø tested so for each position (personal communication, 17.06.2020). He, therefore, states that they likely would have included the t-test in the thesis if the data was significantly different from the remaining sample.

Table 9: Drivers of BPM adoption. Adapted from Brennhovd and Flatebø (2017, p. 61).

Drivers of BPM adoption	Answer
Increased customer satisfaction	23.3 %
Increased efficiency	22.6 %
Increased quality	18.9 %
External requirements or certification	16.4 %
Increased control and management	9.4 %
Cost reductions	4.4 %
Increased adaptability	1.3 %
Other	3.8 %

It is interesting that Brennhovd and Flatebø (2017) do not find a large emphasis on cost reduction in their survey. This is interesting as this is the clearly largest motivation in BPTrends.com surveys. However, it is seen in Table 9 that efficiency improvements have a high score. As efficiency improvements are about utilizing resources better, it is questionable to split cost reductions and efficiency into two separate measurements, as cost reductions are a part of increasing efficiency.

Considering cost reductions as a part of efficiency improvements, it is seen that see that the largest motivations, from high to low, is improved efficiency, customer satisfaction, and quality. These findings agree with the measurements of BPTrends.com.

In the studies of Brennhovd and Flatebø (2017) and BPTrends.com, there is one motivation which differs significantly from the others, namely external requirements, e.g. requirements imposed by governments. Iden (2018) describes two general motivations to work with BPM, namely, internal and external demands. Internal demands catalyst a BPM initiative from within a company, e.g. a desire to cut costs to remain competitive from the senior management. External demands, on the other hand, are imposed by external stakeholders such as customers or governments. In an interview-based study based on a sample of managers from different companies, Iden (2011) found that externally motivated BPM initiatives are less likely to succeed. He argues that this is due to managers lacking motivation, as BPM is rather seen as an enforced requirement instead of as a potential source of improvements. The consequence is a lack of active management, e.g. resulting in insufficient performance measurements and management, role distributions, and a lack of process awareness among staff (Iden, 2018).

3.4.5 Different approaches to BPM

The specific way a competitive advantage manifests itself depends on the approach taken by an individual company. Hammer (2010) and Iden (2018) describes three different approaches to BPM: lean, six sigma, and quality management:

- **Quality Management**: Quality management has a history spanning over 100 years, and is based on the fundamental principle that business processes must be managed actively to achieve quality in both performance and deliveries (Iden, 2018). Iden further states that while there are many different ways of realising this quality, quality control and quality assurance is essential. Quality control is related to measuring whether a process achieves its predetermined quality and taking measures to close performance gaps when required. Quality assurance, on the other hand, is about standardizing processes and ensuring that the staff use these standards, to increase the chances of reaching the set quality objectives.

- **Lean:** Lean is a concept originating from the Toyota Production System. It was developed by Taiichi Ohno and his staff in Toyota motors in post-war Japan until 1975 and later popularized globally through Womack, Jones and Roos in the book "*The Machine That Changed the World: The Story of Lean Production*" in 1991 (Hammer, 2010). Lean is based on two concepts: a focus on aspects creating customer value and removal of elements which does not (Iden, 2018). Waste is categorized according to 8 categories: overproduction, waiting, defects, over-processing, motion, unnecessary inventory, transportation, and unutilized talent.
  To reduce waste, Iden specifies five principles. First, customers should specify what value is. Second, the end-to-end value chain, i.e., the entire process used to produce a product, should be identified so that it can be improved. Note that maintaining an asset is also a product. Third, a product should be produced with a process that flows, i.e., without any

of the eight wastes mentioned above. Fourth, only products that are required should be produced. Last, continuous improvement is about constantly improving the value-chain by eliminating waste. In an article examining how lean works in practice, Spear and Bowen (1999, p. 98) define four rules categorizing lean work: (1) all work must be highly specified according to content, sequence, timing, and outcome, (2) customer-supplier connections must be direct and unambiguous, (3) every process must be simple and direct, and (4) every improvement must be based on hard facts. These will later be highly recognisable in The Maintenance Wheel.

- **Six Sigma:** Six Sigma originates from Motorola, and entails a focus on eliminating defects and deviations both while processing a product and in the final output (Dumas et al., 2018). In the context of BPM, Sig Sigma means that a given process should produce as few defects as possible (Iden, 2018).

These three approaches focus on realizing different benefits: namely improved quality, improved customer value, and a low number of defects, respectively. Despite this, all three approaches are connected and based on most of the same principles, stemming from the quality movement (Dahlgaard & Dahlgaard-Park, 2006). Based on this, Dahlgaard and Dahlgaard-Park argue that Lean and Six Sigma must not be considered as alternatives to quality management, but as complementary techniques pursuing the same underlying concepts as in quality management.

3.5 Conclusion

In this chapter, four separate fields of literature were reviewed. This was done both to find applicable knowledge to solve The Maintenance Wheel's knowledge-based diffusion problem, as well as to provide the theoretical foundation to analyse The Maintenance Wheel in Chapter 4.

First, Chapter 3.1 reviewed a small section of literature on the diffusion of innovations to help answer [RQ1]: "which attributes of an organizational innovation can be influenced to solve a knowledge-based diffusion barrier?" This was done, seeing that The Maintenance Wheel will be perceived by senior managers as an innovation. The goal is to use some of these attributes while designing an MMF in Chapter 6, to help overcome the knowledge-based diffusion barrier of Karabin. While a total of ten attributes of an innovation affecting diffusion were identified, it is first in Chapter 5.1, in connection to the design requirements identification, that [RQ1] is answered.

Second, Chapter 3.2 reviewed different MMFs. MMFs, or maintenance management frameworks, are theoretical frameworks of different approaches to maintenance management and are based on different concepts from different fields of maintenance management literature. Thus, in the introduction to this MMF review, an extensive introduction to maintenance and maintenance management was given. Additionally, the reason for the gap between academic attempts to optimize maintenance was assessed in Chapter 3.2.3, thus answering [RQ2]. After the extensive introduction, nine different MMFs were finally reviewed to answer [RQ3]: "what functions or elements should be in an MMF, and do the reviewed MFFs experience the same deficiencies identified in [RQ2]?". This question was addressed in the summary of the review in 3.2.14. This review informs the design process by showing which functions or elements that should be in an MMF, as is explained further while identifying design requirements in Chapter 5. Note that this review provides part of the theoretical understanding necessary to understand The Maintenance Wheel.

Third, Chapter 3.3 reviews different maintenance performance measurement methods. A brief summary of its findings is provided in Chapter 3.3.6. Performance measurements are essential in The Maintenance Wheel, as will be illustrated in Chapter 4. Thus, this review was initially conducted to provide benchmarks for The Maintenance Wheel. While the approaches reviewed are compared to The Maintenance Wheel in Chapter 4.3.2, to foreshadow the results, the performance measurement approach of The Maintenance Wheel was not seen in any of the publications reviewed. Despite it not providing benchmarks, it does provide part of the theoretical foundation necessary to analyse The Maintenance Wheel in Chapter 4.2. In other words, it helps answer [RQ4].

Last, BPM was reviewed as preliminary research indicated that The Maintenance Wheel was based on it. In effect, it was necessary to review BPM to get the theoretical foundation necessary to understand and analyse The Maintenance Wheel in Chapter 4. Topics covered in the review range from how BPM affects the organizational structure to the BPM management cycle used to chase continuous improvements through performance gap analysis.

"Work is a process, and any process needs to be controlled. To make work productive, therefore, requires building the appropriate controls into the process of work."

Peter Drucker

4. THE MAINTENANCE WHEEL

In the following chapter, [RQ4] is answered. Recall that this question aimed to identify the main concepts of The Maintenance Wheel, and how they combine to realise benefits. This information is key to creating an MMF on how The Maintenance Wheel works.

However, Chapter 1.3 explained how the pinnacle of Karabin's problem is that The Maintenance Wheel lacks a conceptual description. Simply conducting desk research on the few available, internal documents would thus not provide the depth of information required, as essential information is not yet put on paper. Recognising the depth of information required, Chapter 2.3 saw that semi-structured interviews would be used to collect the necessary information. For an overview of this chapter's role in the design process, see Figure 20.

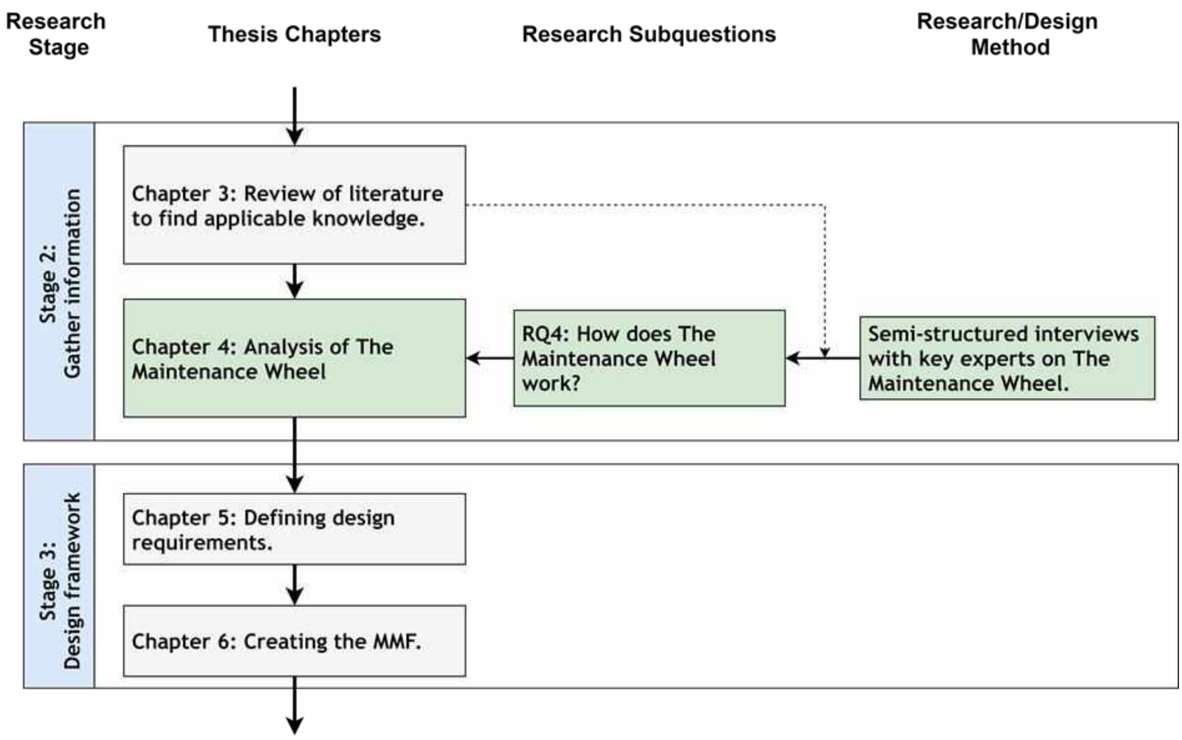

Figure 20: Overview of Chapter 4 in the design process.

The chapter starts with a brief explanation of how the semi-structured interviews were conducted in Chapter 4.1. Then, based on the qualitative data gathered, The Maintenance Wheel is explained in-depth in Chapter 4.2. Concludingly, The Maintenance Wheel is compared to the maintenance management approaches reviewed in Chapter 3, in Chapter 4.3.

While the chapter is primarily based on qualitative data gathered through semi-structured interviews with key experts on the maintenance management approach, some internal documents of Equinor and Karabin have also been reviewed for this chapter. But, because these documents were not given permission to be included in full as appendixes, the use of them is restricted.

4.1 Gathering data– semi-structured interviews

The interview procedure used to collect the qualitative data was covered in Chapter 2.3.2. This subchapter briefly reiterates some of the main points and introduces the interviewed subjects. For an overview of how the collected data was processed, see Chapter 2.3.3. Also, note that the summaries of the interviews are found in Appendix C. Given the large importance of the interviews with The Maintenance Wheel's creator, the complete transcripts of these interviews are found in Appendix D.

Table 10: Overview of the interviews on The Maintenance Wheel.

	Interview Set 1	
Purpose	Get an in-depth understanding of The Maintenance Wheel to answer [RQ4].	
Interview Length	60-90 min	
Sampling Technique	Judgement sampling	
Subjects	Three subjects with much knowledge of The Maintenance Wheel	
Data type	Qualitative	
Data analysis	Deductive and inductive	
	Interview Procedure	
Introduction	Introduce the purpose of the interview. Establish ground rules.	5 min
Interview	In-depth interview on the maintenance Wheel	50-80 min
Conclusion	Conclude interview, alternatively set up a new interview.	1 min

4.1.1 Sampling

Due to the type of data required, judgement sampling has been used to select interview subjects. Characteristic of this form of sampling is that interviewees are selected based on their knowledge and expected contributions to the research (Harrell & Bradley, 2009). In other words, since the goal of the interviews was to explore and describe The Maintenance Wheel in-depth, key experts with an in-depth understanding have been interviewed.

The dominant type of data gathered is objective background information. Background information refers to information such as facts and descriptions of contemporary phenomena (Harrell & Bradley, 2009). The largest risk of bias in this type of data was considered to be interview subjects forgetting crucial information. Based on this, a smaller sample size but with in-depth interviews was deemed sufficient, as it was considered unlikely that all the experts would forget the same essential information. In total, three subjects were interviewed, with more than 6 hours of recorded interviews.

4.1.2 Interview subjects and interview length

Subject 1 created The Maintenance Wheel. He has more than 20 years' worth of maintenance management experience and was both responsible and the initiative taker behind The Maintenance Wheel's creation and implementation. Based on his background and expertise, he was considered essential to being able to explain The Maintenance Wheel in-depth. Resultingly, two full interviews of 90 minutes were held with him.

Subject 2 is a senior manager and lead consultant of Karabin. Like Subject 1, Subject 2 has a long experience with maintenance management, having both worked as a maintenance and plant director in two large companies. Additionally, he has worked with The Maintenance Wheel for over five years. Two interviews of one hour each were held with him.

Subject 3 is the head of all maintenance operations in a large company (worth >5 Billion EUR), currently implementing The Maintenance Wheel. She has experience from Equinor, and it was based on this experience that she decided to implement The Maintenance Wheel. She was mainly asked about her motivations for adopting The Maintenance Wheel, and what challenges she has and is experiencing. One interview of one hour was conducted with her.

Originally, the plan was to keep each interview below 60 minutes to avoid fatigue biasing answers. This meant that some interviews were split midways, i.e., two of the subjects were interviewed twice. However, The Maintenance Wheel's creator took the initiative to 90-minute interviews himself, which is why these interviews were longer than the others.

4.2 The Maintenance Wheel

This chapter explains The Maintenance Wheel in-depth. First, its history is briefly explained in 4.2.1. Then, The Maintenance Wheel is broken up into elements, and it is explained how it realises benefits. After this, proven and verified benefits realized from this way of managing maintenance is covered. Last, some of the operational issues are discussed.

4.2.1 Development and implementation

The development history of The Maintenance Wheel is complex. It developed from being a simple model used to train staff, to becoming a complete maintenance management approach. This subchapter summarises the main trends of its development. And again, recall that "The Maintenance Wheel" is used to refer to complete maintenance management approach, as explained in Chapter 1.2.

The history of The Maintenance Wheel began in 2007 when a simple wheel-shaped model was created. This was a simpler version The Maintenance Wheel value-chain seen in Figure 21 on page 79. It was created for a maintenance subdivision in what is currently the biggest gas processing plant in Europe: Kårstø (Equinor, n.d.-b). This prototype was a model, illustrating Kårstø's maintenance value-chain. It was used as a tool to train and make staff aware that by working with maintenance, they were working in a process. Specifically, the prototype acted as a "blueprint" for how all maintenance tasks should flow through the organisation, from when a maintenance need is reported until the asset has been serviced and is operational again. In the words of The Maintenance Wheel's creator: "I was the manager of a large department and needed to create a shared understanding among my staff of how we had to work" (see Appendix D).

In 2010, this prototype was brought into a company-wide improvement initiative by Equinor, as one of several projects. Here, multiple extensions were added to the prototype, over the span of three years. This resulted in The Maintenance Wheel. While the prototype was a model used to communicate to staff how to work, The Maintenance Wheel built further on the underlying concepts of BPM and performance management to provide an overarching approach for how to manage a maintenance process (see Appendix D).

In late 2013, Equinor decided to implement The Maintenance Wheel in Sture and Kollsnes, i.e., the oil and gas facilities presented in Chapter 1. In total, these facilities spent more than 50 million euros on maintenance per year at the time (K. Gjellestad, personal communication, 11.11.2019). In the years prior to 2013, optimism in the market space had decreased, resulting in a drastic reduction in profit margins for Sture and Kollsnes. This was further complicated by internal issues such as a considerable silo mentality among workers, improvement projects not resulting in lasting benefits, an increasing backlog of work orders, and managers being forced to fire-fight short-term instead of pursuing lasting improvements. These issues affected the profitability of both facilities severely, resulting in a situation summarised through the words of a manager as one where "business as usual is [was] not an option" (K. Gjellestad, personal communication, 11.11.2019).

4.2.2 Breaking down The Maintenance Wheel

As explained on several occasions, there was no conceptual description of how The Maintenance Wheel worked prior to this thesis. Thus, to explain it, this chapter will base the explanation on the model used to communicate to staff how to work according to this approach is seen in Figure 21, on the next page. The goal is that by basing it on this model, the explanation will be somewhat easier to understand.

The fundamental idea of The Maintenance Wheel is that maintenance is a process, dependent on multiple functional departments, which can be managed as a process. Knowing this, The Maintenance Wheel value-chain seen in Figure 21 illustrates Equinor's company-wide, end-to-end maintenance value-chain from when a corrective maintenance notification is created until a work order is processed. First, this model's structure is first explained. Thereafter, it is explained how BPM and performance management is applied in it.

First of all, the value-chain visualised in Figure 21 is set up sequentially and should be read in a clockwise fashion, starting from "noon". Second, each of the illustrations "layers" contain distinct categories of information. The first layer (starting from the circle's centre) demarks which part of the value-chain a given task is in. The overarching maintenance process is divided into two sub-processes. In the first subprocess, in the sector spanned by "M2", it is decided whether a corrective maintenance notification needs to become a work order.[1] In this sub-process, the maintenance notification is the unit of flow. In the second process, spanned by the sector "Arbeidsordre PM01/02", the various activities needed to fix the work order is sequenced. Note that

[1] Sector is defined as "[…] a pie-shaped part of a circle" (Math Open Reference, 2011).

“arbeidsordre” means “work order” in Norwegian. In this sub-process, the work order is the unit of flow.

The second layer breaks the sub-processes into specific stages of the work order processing. For example, the stage called “PREP” concerns the preparatory work for each work-order. Overarchingly, these stages are to (1) selecting maintenance work-orders (“CRTE”), (2) prepare (“PREP”), (3) create work order plan (“PRCO”, “RDEX”, and “RDEX PLAN”), (4) execute task (“STRT PLAN”), and (5) finalizing work-order (“RDOP Plan” and “TECO PLAN”) (K. Gjellestad, personal communication, 11.11.2019).

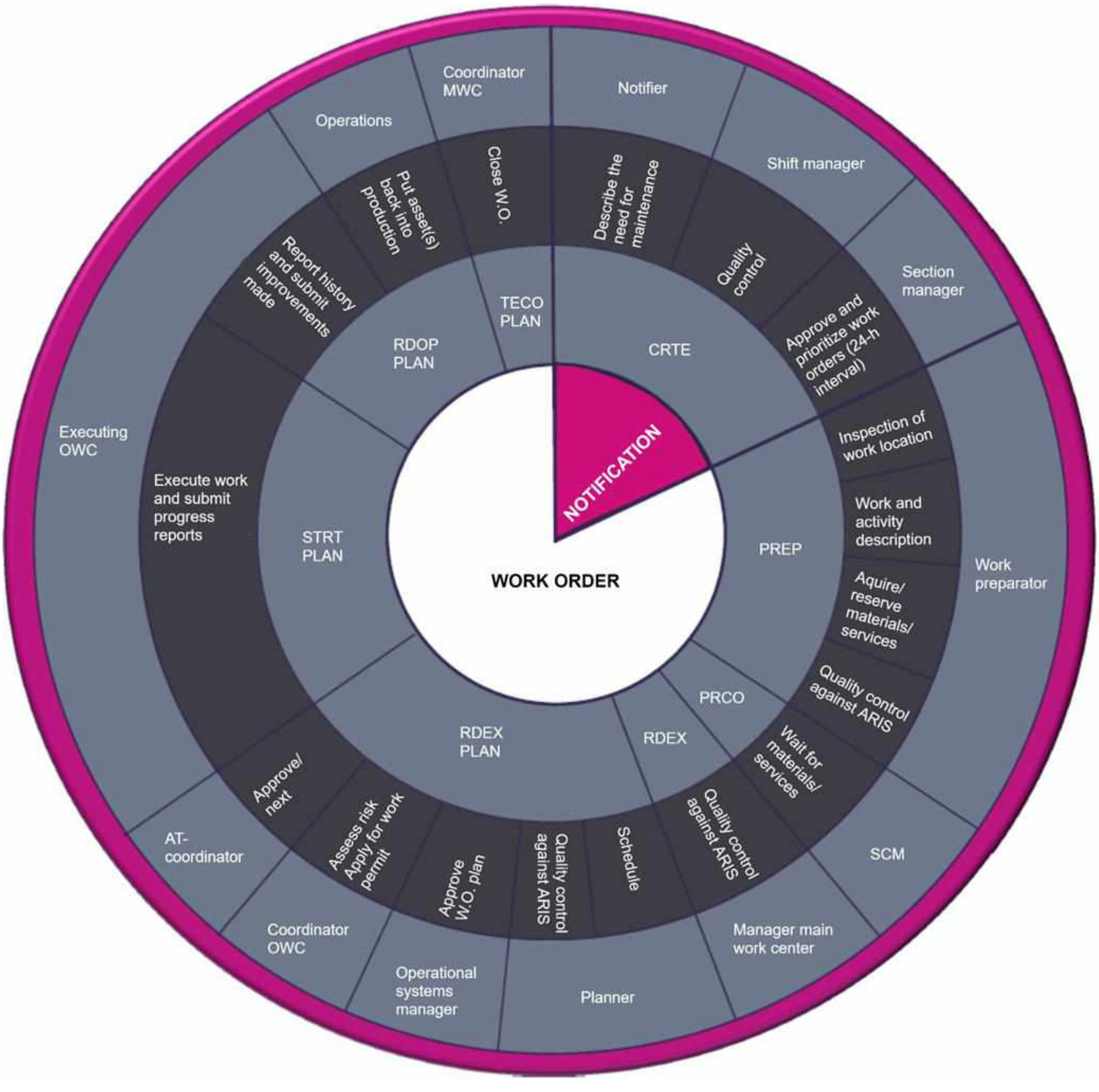

Figure 21: The Maintenance Wheel value-chain © 2020 Equinor ASA (K. Gjellestad, personal communication, 11.11.2019). The model has been translated from Norwegian to English by the author.

In the third layer of Figure 21, the work order stages are divided into specific tasks. It is not necessary with an in-depth understanding of these tasks to understand how The Maintenance Wheel works. The first process covers the generation of corrective work orders, through three steps: (1) create maintenance notification, (2) quality control of notification, and (3) approval and prioritization. The goal of these steps is to screen and eliminate non-value-adding work orders. After deciding to process a notification, the next job is to prepare and plan for how to execute the work order. During the preparation, they start preparing for how the work will be conducted, identifying and procuring the necessary material, and conduct an assessment of quality once everything is ready. Then, the next step is to schedule when to conduct the maintenance. Resulting from these steps, the work order plan is finalized and approved. Subsequently, a risk assessment is conducted before a final approval to execute the work order plan is given. After the job concludes, reports are submitted, in which possible improvements identified throughout the processing of the work order are logged and reported. In the end, the maintenance process finishes when the fixed equipment is put back into production.

Lastly, the fourth layer describes which person or group that is responsible for each task and its performance. So, in effect, each sector of the model represents a different step of the overarching maintenance process, with the various layers explaining different aspects of this specific step. For example, when a maintenance notification is created, it is sent to the shift supervisor, who is responsible for assessing this notification's quality. If the manager agrees that there is a need for maintenance, the notification is sent to the next sub-process.

To summarize, the purpose of the first sub-process is to examine whether a maintenance notification warrants the creation of a new work order, to control the input of work orders. The purpose of the second process is to process the work order. All of this is done in a standardised sequence of tasks, with a person or group responsible for each task.

4.2.3 BPM and performance management

In Equinor's internal documents, they highlight four principles affecting how the process shown in Figure 21 is managed: standardisation of work, process flow, customer-supplier agreements, and continuous improvements (K. Gjellestad, personal communication, 11.11.2019). This was reiterated in the interviews with Subject 1, where performance management was also mentioned. Upon inspection, it became clear that performance management is an underlying principle of continuous improvement. Note that performance management may be defined as "[…] the use of performance measurement information to effect positive change in organizational culture, systems and processes […]." (Procurement Executives' Association, 1999, p. 5). After explaining each of the four principles briefly, it is discussed how Equinor has integrated them in The Maintenance Wheel.

Standardisation of work refers to the detailed specification of how to conduct specific tasks (Spear & Bowen, 1999). Note that this concerns the standardisation of singular jobs only, e.g. how to change a filter. It also entails specifying whom that is responsible for any given task in the maintenance process.

Second, **customer-supplier agreements** are used to standardize interfaces within processes. Scholars have stated that such agreements must ensure that each connection is standardized, direct and in a predetermined shape (Spear & Bowen, 1999).

Third, **process flow** entails achieving a direct and simple flow of a process' flow unit. In other words, process flow is about setting up the standardized tasks in a purposeful sequence, from one person to another. This means that there should be no forks or loops in the process and that the work order must flow from one specific person to another, predetermined person.

Last, **continuous improvements** are about creating a system which continuously looks to improve itself; in this case, the maintenance process (K. Gjellestad, personal communication, 11.11.2019). An important, underlying principle is to make improvements based on evidence, not on hunches, and that improvements originate from the lowest levels of the organization (Spear & Bowen, 1999).

4.2.4 Application of BPM and performance management

In the following subchapter, it is discussed how The Maintenance Wheel utilises the principles discussed above.

Standardisation of work

Each task of the model (the third layer of Figure 21) has an underlying process made up of different sub-tasks. The Maintenance Wheel uses standards (documents) to describing the best practice to conduct these tasks, based on the current best practice. The more critical a task is, the more detailed is the description of how to do it. For example, critical tasks have established standard operating procedures (SOP). These are highly structured, stepwise checklists for a job. For other, less critical jobs, documents such as one-point lessons (OPL) exist, which are shorter documents, often based on visual aids (INOSA, 2018).

While there is some variation between the best-practice documents, they should describe the procedure, the resources, the expected time required, and the outcome of any job (Appendix D). Note that estimated time to complete and the expected outcome are the performance requirements of a job, specifying performance objectives on the quality and time. Here, it is highly important to recognise that quality is not necessarily based on typical performance indicators such as those reviewed in Chapter 3.3. Recall that there are two types of performance indicators: leading and lagging, as explained in Chapter 3.3.1. While the maintenance process also has defined lagging quality indicators to measure maintenance performance, such as the costs or availability of assets, the best practice standards aim to specify leading quality objectives. In effect, by following the best-practice standards, work will be executed in a way that will *lead* to quality. The quality objectives can be on a very simple level, e.g., whether the correct person filled out the correct scheme to ensure that the right competency is used. The idea is that by ensuring that factors such as having the right competence fill out parts of a work order such as the work description, the probability of rework decreases. In effect, complying with objectives lead to quality later on.

The purpose of the best-practice documents is to increase the consistency, safety, and quality of each task performed (Appendix D). Additionally, they are used to identify performance gaps, as explained later in this subchapter. As put by the creator of The Maintenance Wheel, "the standards act as barriers against making the wrong decisions" (Appendix D), meaning that resources are utilised in the way adding the most value.

Customer-supplier agreement

As mentioned, customer-supplier agreements standardize interfaces in a process. In The Maintenance Wheel, they are used at the interfaces where the maintenance notification/work order is sent to another stage of the maintenance process, i.e., between (1) selecting maintenance work-orders, (2) preparing, (3) creating a work order plan, (4) executing task, and (5) finalizing work-order. These exchanges should be according to a predefined form, with a defined sender and receiver. In effect, there should be no ambiguity regarding content nor whom or how the receiver should process the received unit. Additionally, the work should comply with some quality criteria. In other words, irrespective of staffs' location in the organizational chart, direct links are set up to standardize the handovers between different stages. Additionally, the agreements act as internal controls of work having been executed according to the correct quality.

Process Flow

How does one think about flow in a maintenance process? The Maintenance Wheel is based on the idea that the maintenance process is like an imaginary assembly line, much like that of a car manufacturer. However, while a car manufacturer sends a physical chassis down on the assembly lines, The Maintenance Wheel is based on the idea that the unit of flow is a work-order. Therefore, the sequence of tasks shown in Figure 21 illustrates how a work order should flow. Consequently, the maintenance value-chain is set up to process these work orders efficiently and simply.

However, there is a catch. How does one ensure and measure flow in a maintenance process? As discussed, The Maintenance Wheel divided the maintenance process into two sub-processes. These are set up with different goals in mind in order to achieve the desired process flow. The first process aims to identify work orders which will add value to the organisation. The second process aims to process these work orders efficiently, i.e., the priority is to achieve flow in the latter sub-process.

The idea is that by sacrificing flow in the first sub-process, by quality assessing each maintenance notification, the company will realise benefits by avoiding duplicate work orders, increasing the quality of the work order created, and cancelling unnecessary notifications before they are processed. To illustrate this further, Equinor and Karabin's customer has said that they want to cancel 20% of all maintenance notifications, i.e., only create and process 80% of the current corrective maintenance work orders. An analogy drawn by Subject 3 is that the careful selection of work orders is the same as avoiding a faulty car chassis on an assembly line; they will only cause more problems downstream (Appendix C). Research has found that maintenance planning and scheduling performs worse than production planning due to stochastic variations in maintenance work demand, lacking coordination with other functional units, and as similar maintenance tasks may vary significantly (Al-Turki, 2009). Thus, by strategically reducing the number of work orders, stochastic variations may be dampened, having a positive influence on the downstream activities in processing.

However, how is flow achieved? And more importantly, what is flow? Underlying The Maintenance Wheel is the idea that flow is effective processing of work orders (and maintenance notifications), in a way that maximizes customer value. Activities which do not generate value, e.g. unnecessary waiting, is thus preventing flow. To exemplify what this means, some illustrative examples of how Sture and Kollsnes achieved flow is given, based on one of the internal documents of Equinor (K. Gjellestad, personal communication, 11.11.2019). First, technicians should not have to walk more than 7-minutes to the closest storage facility to minimize unnecessary transportation. Second, workers were given sufficient training, to avoid unnecessary stops, e.g. resulting in minimizing outsourcing of tasks staff would be able to do themselves. Additionally, customer-supplier agreements have been set up to reduce uncertainty in internal handovers of the work orders.

Continuous Improvements

Continuous improvement is a based on two concepts; there is the inevitable corporate culture which is required to continuously change and adapt the way staff has to work, and then there is the performance management system required to identify possible room for improvement to act on. The idea is that through continuous improvement, you "[…] increase the competitiveness of the organization to a higher level" (see Appendix D).

Starting with the corporate culture, the importance of having committed staff knowing how to work, and how to improve, is raised throughout all subjects interviewed for this subchapter (see Appendix C and D). However, creating a corporate culture supporting The Maintenance Wheel is a highly important prerequisite, not something to be introduced by the management approach itself.

The last principle is performance management. Performance management is about measuring the performance of the maintenance process and making managerial decisions accordingly. It is about controlling the maintenance process, according to a predetermined list of goals, for the different hierarchical levels in the organization. In discussions with The Maintenance Wheel's creator, it became apparent that the performance measures used are fundamentally different from those explored in the literature reviews (see Appendix D).

The first requirement to measure performance is to capture data. But before discussing how data is captured, it is necessary to understand that The Maintenance Wheel relies on two types of indicators to measure performance: quality and time. Also, note that the standards mentioned earlier for each task have specific objectives for each of these indicators.

Quality is subjective. This signals the importance of the standards discussed earlier: each internal delivery in the maintenance process has a standard, specifying what quality in fact is. Depending on what sub-process one is in, the measurement of quality will vary. Some examples, however, can be the rate of work orders that need to be rescheduled, or the resources used for one task such as costs. After any task is finished, the person responsible for that task has to enter the data required to determine the quality of the work done. Note that it is important to use leading indicators, i.e., indicators which ensure that quality is achieved downstream in the maintenance process.

The second indicator, time, is captured automatically by the supporting ICT system. While discussing process flow, it was mentioned that the sequence of tasks in Figure 21 describes the flow of a work order. Thus, as tasks are completed, and the work order is sent to the next stage, the time used at each stage is measured. Additionally, each task has an estimated amount of time, which is based on the best practice defined in the standard. Thus, by measuring how long it actually takes for a work order to be sent to the next task, the process flow performance is measured. This makes it possible to easily identify what tasks in the maintenance process prevent flow, upon which process performance improvements may be used.

As mentioned, the progress of all work orders (and notifications) through The Maintenance Wheel is tracked by an ERP system in Equinor. Note that it is not important that it is an ERP system, any ICT system allowing the same functions described here will do, according to The Maintenance Wheel's creator. Some of the ERP codes are found in Figure 21, such as "PREP" and "M2". The purpose of these codes is that managers can access performance data easily, with automatic performance reports being generated.

When performance gaps are identified between the specified measurements of quality and time standards, and the measured performance, the person responsible for this task is required to close the gap. The Maintenance Wheel does not describe how to do this. However, it does provide a simple way for staff in the maintenance process to get the required data to manage the maintenance process. The lack of easy to use data to improve maintenance performance has, as explained in Chapters 1.1 and 3.2.1, been a large problem for maintenance managers.

However, while these measurements of performance make it easy for staff on the operational level to know when performance must be improved, the individual performance measures are not useful for managers on the higher organizational levels. Regarding middle managers, they are interested in a process overview, while senior managers focus on the strategic KPI's. This is solved by aggregating the singular measurements of performance per work order. For example, for an overview of the maintenance process' performance, aggregation makes it possible to tell the rate of maintenance notifications rejected per month, which is useful to have a process overview. Additionally, by aggregating all individual costs in work orders for a month, the total expenditure for this month is found. This is interesting for senior managers. Note that it was seen in Chapter 3.3 that this process of identifying indicators down-up avoids indicators that are difficult to interpret for people lower in the organizational hierarchy, i.e., technicians (Alsyouf, 2006).

4.2.5 BPM approach

In the literature review on BPM in Chapter 3.4, three different approaches to BPM were mentioned: quality management, lean, and six sigma. The Maintenance Wheel has been based partly on all three of these approaches (see Appendix D). As discussed in the literature reviews, quality management is about the achieving the desired quality through active management, lean is about creating customer value in a consistent flow of value-generating activities, and six sigma is about ensuring that errors in the maintenance process are minimized. The active management in The Maintenance Wheel may be seen by the usage of performance indicators on each delivery in the maintenance process. Lean is about achieving flow through the elimination of the eight categories of waste, namely over-processing, defects, overproduction, waiting, unnecessary inventory, motion, transportation, and non-utilized talent. This is, e.g., achieved by having staff identify and eliminate unnecessary waiting, based on the measurements of time. Last, six sigma is based on minimizing the number of errors, and on doing so consistently. This is done by following the best practice standard. Additionally, through performance measurements of all tasks performed, it is checked that staff actually follows these standards.

4.2.6 Alternative paths

The sequence of tasks in the models must not be strictly followed, exceptions exist. In total, five such exceptions were identified in the interviews.

The first, and possibly the most obvious exception is related to **emergency maintenance**. Critical assets may fail. In this event, the standardized preparation and planning cycle may be skipped, as the availability of these assets is critical for the entire plant. However, as this type of maintenance has ramifications for the entire maintenance process, e.g. the work order schedule, and is costly, measures should be taken to minimize it.

Another event where a complete lap must not be completed is one where the **asset wear is normal**. In this case, the work-order can be completed based on history, i.e., on how the asset was fixed previously. This is possible by relying on data stored from previously completed work-orders on the asset.

The third and fourth event stems from the first stage of The Maintenance Wheel, were deciding on how to treat maintenance notifications. Anyone may submit a notification stating that maintenance is required. However, it is not given that this notification is correct. This was illustrated by The Maintenance Wheel's creator. He used an example of a car. If you are driving your car, and you hear strange noises coming from the car, you will probably hand it over to an auto repair eventually. You may then describe this issue, based on your own competency, and state that the sound comes from the gearbox. However, in this event, the car mechanic should not blindly trust your observation. The mechanic investigates for himself, and then either finds that the car's wheel bearings are the problem, or that maintenance is in fact not needed at all. It is the same principle as The Maintenance Wheel. It is not allowed to decide what to with a maintenance notification without investigating. Based on this investigation, two alternatives, besides the common route where a work order is created exist. The third exception is where there is a **faulty maintenance notification**, and no maintenance is needed. In this event, the notification should be cancelled. The fourth and last exception is in the event of **simplified maintenance**. The investigator assessing the asset may simply fix the asset while inspecting it.

The last exception identified is **preventive maintenance**. This differs from the other exceptions, as it first "enters" the maintenance process after the first sub-process. Since preventive maintenance work-orders are conducted based on specific intervals, or machine hours, the first sub-process is not needed. From, the start of the work-order process, however, the preventive maintenance work-order follows the same wheel.

4.2.7 Realised benefits

The following section is based on data from one of Equinor's internal documents. This data was gathered and validated by Karabin, in an effort to describe and validate the effects of The Maintenance Wheel in Sture and Kollsnes. The purpose of including it is to illustrate the effects The Maintenance Wheel had in two full-scale facilities. However, it is important to realise that these benefits are only meant to act as a proof-of-concept.

The benefits were identified based on data from a three-year period, from 2013 to 2016, i.e., before and after implementing The Maintenance Wheel. Karabin took several measures to ensure that all findings were correct. For example, all data sources are referenced. Moreover, all calculations were validated by a third-party in Karabin, not involved with the documenting of benefits. These findings were also backed up in the interviews with The Maintenance Wheel's creator. A summary of the findings is presented below.

Table 11: Summary of identified benefits, based on desk research of internal documents (K. Gjellestad, personal communication, 11.11.2019).

Benefit
Cost reductions of roughly 10 Million EUR per year from 2013 to 2016. Approximately 25% of all maintenance costs cut.
Increased employee satisfaction (+12%).
Reduction of in-house maintenance hours by 17 %.

A reduction of HSE incidents.
A reduction of outsourcing maintenance hours
Increased value-creation for fewer resources
Cross-departmental optimization instead of silo-based improvements.
Improvement initiatives now result in lasting benefits.
Removed silo-mentality among staff.
Increased maintenance quality.
Increased competency among staff.

It is natural to ask what the performance drivers of The Maintenance Wheel are. The four principles of work standardisation, customer-supplier agreements, process flow, and continuous improvements underlying it have a set of intended effects (K. Gjellestad, personal communication, 11.11.2019). Standardization of work based on the best practice aims to improve consistency, flow, quality, and safety. Customer-supplier agreements look to improve resource utilization and flow by improving interfaces. Process flow is about conducting maintenance as efficiently and consistently as possible. Last, continuous improvement aims to improve the resource utilization and quality of the process continuously.

Most of the causal relationships between the principles and benefits listed above are self-explanatory. For example, it is not surprising that standardising interactions between different stages of the maintenance process improves resource utilization, as it eliminates unnecessary waiting as staff must determine whom that should receive the work order next. However, overarchingly, the effects of standardization on an entire business process may not be as clear. Therefore, it was considered beneficial to support the realised benefits from Sture and Kollsnes with evidence from academia. Consequently, the table does also contain some sources of evidence from peer-reviewed journals on the effects of standardisation in business processes elsewhere.

Table 12: Peer-reviewed studies with evidence on the effects of business process standardisation.

Benefit	Source
Costs reductions	(Münstermann et al., 2010), (Hammer & Stanton, 1999)
Increased quality	(Münstermann et al., 2010)
Reduced throughput time	(Münstermann et al., 2010), (Lundquist et al., 2000)
Increased collaboration	(Hammer & Stanton, 1999)

4.2.8 Operational issues

In the following section, operational issues with The Maintenance Wheel are discussed, i.e., issues experienced while implementing or operating according to the maintenance management approach. The information stem from Sture and Kollsnes, and Karabin's customer which are currently implementing The Maintenance Wheel.

The first and seemingly largest issue relates to implementation. Each interview subject points to one cause: convincing staff to adopt the new way of working is challenging (see Appendix C and D). In particular, subjects state that staff opposes the change due to it imposing a radically different way of working than people are used to. To exemplify this, subject 3 explained that implementing The Maintenance Wheel requires all staff to change their work patterns, even those who have worked there for 30+ years. For example, staff are not used to being measured on every single task they do.

No other large issues were discussed, either in the interviews or in Equinor and Karabin's internal documents. However, Karabin's analysis of The Maintenance Wheel's effects in Sture and Kollsnes shows that overtime increased (+5%) and that maintenance materials expenditures increased (+8%) (K. Gjellestad, personal communication, 11.11.2019). Nevertheless, as this report also found that both employee satisfaction and the overarching maintenance expenditures improved, these issues are considered to be necessary costs, no problems.

4.3 Comparison to the reviewed literature

In this subchapter, The Maintenance Wheel will be discussed in relation to the MMFs and maintenance performance measurements reviewed in Chapter 3.

4.3.1 Maintenance management frameworks

In Chapter 3.2.14, the reviewed MMFs were summarized. There it was concluded that while there is no standardised form of MMFs, generally they explain elements related to strategic maintenance activities (e.g. how to control the maintenance process against the corporate strategy), the control of maintenance activities, maintenance planning, maintenance execution, and continuous improvements.

As Figure 21 only shows *what* is being managed, and not *how* it is managed, it is clear that Equinor's model of a value chain does not qualify as an MMF. For this, it would have had to explain how BPM and performance management is applied. This is no surprise, as Figure 21 was not designed to communicate the maintenance management approach, as MMFs do.

Possibly the most important element with The Maintenance Wheel is that it applies BPM and performance management to realise benefits. In the literature review in Chapter 3.2, it was found that all of the reviewed MMFs perceive maintenance as a process. Despite this, only the frameworks of Hassanain et al. (2003) and Campos and Crespo Márquez (2011) attempts to manage maintenance as a business process. However, Hassanain et al. have one glaring hole in their framework: they do not provide a way to optimize the maintenance process. Campos and Crespo Márquez (2011), on the other hand, does discuss optimization techniques and are as such the framework most comparable to The Maintenance Wheel. However, they take a rather generic approach to improving and managing the maintenance process. Unlike The Maintenance Wheel, Campos and Crespo Márquez (2011) do not specify how to generate the data used to manage, and it does not discuss what gaps to look for. What Campos and Crespo Márquez does do, is to show how data generated on the operational level may be used for decision making on the higher-organizational levels. As they use a similar top-down approach to derive maintenance objectives as in The Maintenance Wheel, this will be useful while designing the new MMF, as this is currently missing in The Maintenance Wheel.

Besides this, there are several aspects separating The Maintenance Wheel from the reviewed frameworks. It is one of two approaches to maintenance management with proven benefits, the other one being Pramod et al. (2006). However, The Maintenance Wheel is the only framework which has been applied on a large scale, as Pramod et al. (2006) only tested their framework with five engineers. Additionally, none of the frameworks discusses the careful selection of work orders as a strategic tool to improve performance, as The Maintenance Wheel does. Last, it is also the only approach to maintenance management using process-based performance measures as a tool to manage the maintenance process end-to-end.

4.3.2 Maintenance performance measurements

The Maintenance Wheel uses an approach to performance measurements not seen in any of the MMFs. However, as none of the reviewed MMFs provided in-depth discussions of how to measure maintenance performance, an in-depth review of different maintenance performance measurement approaches was conducted in Chapter 3.3. By comparing the findings of this review against the analysis of The Maintenance Wheel in Chapter 4.2.4, it should be clear that The Maintenance Wheel provides a new way of measuring maintenance performance to the body of knowledge on maintenance performance measurements.

The Maintenance Wheel is the only approach which provides a way to measure the performance of the entire maintenance process using process performance measures on time and quality. Although Muchiri et al. (2011) do discuss process-related, time-based performance measures, they focus on time-based performance measures for only maintenance task execution, not for the overarching maintenance process. In other words, prior research on maintenance management has primarily focused on improvements for one and one maintenance activity, and not on collective process-improvements. What is the consequence of this? First of all, maintenance encompasses activities from a broad array of functional departments. Seeing that maintenance is perceived as a strategic, value-adding activity today, it is important to facilitate for continuous improvements in all of these activities (Simões et al., 2011). Prior literature has thus focused on measuring the performance of, and subsequently improving each activity one an individual basis. Effectively, a new way of measuring maintenance performance is seen, where one can, for example, identify the wastes in the hand-overs between different stages of the maintenance process.

Besides assessing whether different approaches measured process performance, the literature review aimed to find out what features were common in the different performance measurement approaches. Although there was some variation, common features were found to be balanced indicators (short- and long-term measurements), leading and lagging indicators (performance drivers and outcome measures, respectively), multi-criteria indicators (measurements for different stakeholders, e.g. different functional departments and customers), and hierarchical measures (for different hierarchical levels of the organization). This information was important to know what to focus on and how to describe how performance is measured in The Maintenance Wheel.

4.4 Conclusion

In this chapter, The Maintenance Wheel was analysed in-depth based on five semi-structured interviews with key experts on The Maintenance Wheel. The interview procedure was explained in Chapter 4.1. Additionally, desk research of internal documents of Equinor and Karabin supplemented the analysis. But, because these documents were not given permission to be included in full as appendixes, the use of them was restricted.

The analysis was done to answer [RQ4], i.e., what the main concepts of The Maintenance Wheel are, and how do they combine to realise benefits. This information will be crucial in the design of the MMF. Chapter 3.2 explained how MMFs are theoretical frameworks for different approaches to maintenance management. Chapter 4 has effectively identified what the MMF has to communicate.

The Maintenance Wheel is a maintenance management approach based on BPM and performance management that covers both corrective and predictive maintenance. Essential to this is the standardisation of tasks required to process work orders, the interfaces between the different stages of this work order processing, and to set up the task sequence by the flow of how work orders are processed.

By standardising the maintenance process with best-practice standards, the best way to execute each task is codified. In these best-practice standards, there are also performance metrics for the expected quality and estimated time when following this best practice. Thus, when measuring the actual performance of each task by tracking the time it takes for a work order to be processed (by simply using the ICT system) and having staff submitting the actual quality performance into the organization's ICT system, performance gaps are easily identified. The time indicators easily identify whether there is waste in the maintenance process, and together with the quality indicators also measures whether the best-practice has been followed, ensuring regularity and quality in each task.

However, besides the standardisation of the maintenance process to achieve regularity and higher quality of work, continuous improvements are also essential. First, they may be realised by closing the performance gaps identified in the previous paragraph. Second, whenever new best-practices are identified, the constructed MMF provides a simple way to ensuring that all staff follow the same best practice by codifying the new best-practice and using the updated performance metrics to ensure that staff complies with it. In effect, the constructed MMF shows how to effectively organize and manage human efforts using technologies.

Chapter 4.3 compared The Maintenance Wheel against both the MMFs and different approaches to maintenance performance measurement reviewed in Chapter 3.2 and 3.3, respectively. This subchapter concluded that The Maintenance Wheel provides a novel approach to maintenance management, as it shows how to effectively use BPM and performance management based on time and quality performance indicators for the entire maintenance process.

"Design is not just what it looks like and feels like. Design is how it works. "

Steve Jobs

5. DESIGN REQUIREMENTS IDENTIFICATION

This chapter describes the first of two steps in Stage 3 of the design process. See Figure 22 for an overview. The goal of the chapter is to identify the design requirements, i.e., to answer [RQ5]. The design requirements specify the outer boundaries of what a satisfactory design has to do to reach the research objective. The requirements are based on the information gathered in the previous stage of the design process, i.e., Chapter 3 and 4. Recall that Chapter 3 identified how to design an MMF and how to solve the diffusion problem of Karabin. Also recall that Chapter 4 identified how The Maintenance Wheel worked, i.e., what the MMF has to communicate.

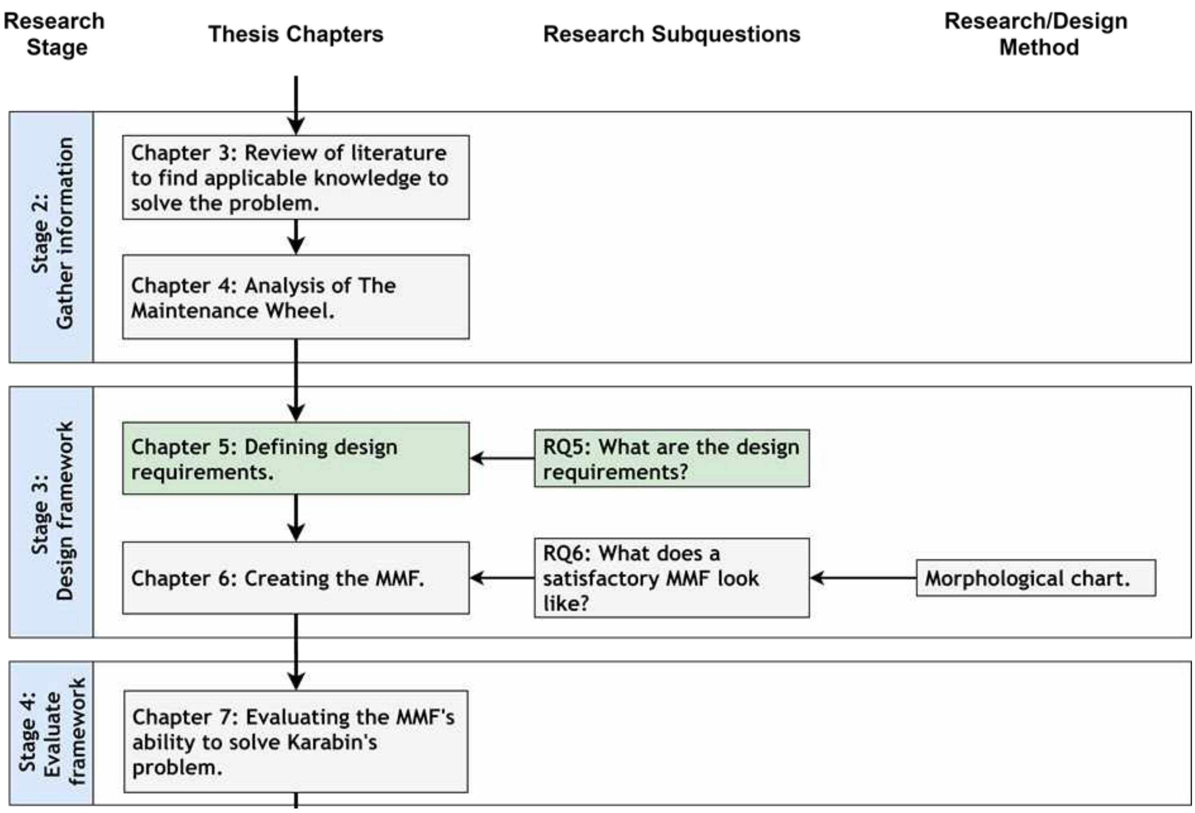

Figure 22: Overview of Chapter 5 in the design process.

5.1 Defining design objectives

Recall the thesis' research objective defined in Chapter 1.4.1:

> Design an MMF aimed at supporting Karabin in communicating how The Maintenance Wheel works to help cope with the knowledge-based diffusion barrier.

In this subchapter, design objectives are formulated. This is an intermediary step in the design requirements identification. The design objectives are simply the research objective further operationalized. Some researchers would likely derive design requirements directly from the research objective but seeing that the research objective is complex, design objectives are first defined to increase the thesis' procedural transparency. A particular concern has been to clarify which of the diffusion attributes identified in Chapter 3.1.2 that have been considered in the design process, to overcome the knowledge-based diffusion barrier of The Maintenance Wheel. Later, in Chapter 5.2, these design objectives are used as the starting points for the formulation of design requirements.

The design objectives defined are seen in

Table 13. Below this table, the rationale of each objective is discussed.

Table 13: Design objectives and their sources.

#	Design Objectives	Source
D.1	The framework should align with Karabin's benefits realisation process.	Chapter 1.5: The thesis scope.
D.2	The framework should provide a conceptual explanation of how to manage maintenance through an MMF, based on The Maintenance Wheel.	Chapter 1.3: Problem statement.
D.3	The framework should effectively communicate how to manage maintenance based on The Maintenance Wheel to customers of Karabin.	Chapter 3.1.2: Review of literature on the diffusion of innovations.
D.4	The framework should be easy to use and understand for the senior managers of Karabin's customers.	Chapter 3.1.2: Review of literature on the diffusion of innovations.
D.5*	The framework should be perceived as compatible by organizations considering implementing it. *	Chapter 3.1.2: Review of literature on the diffusion of innovations.

5.1.1 [D.1]: The framework should align with Karabin's benefits realisation process.

Rationale: The to-be-designed MMF is designed for Karabin (see Chapter 1.5). As explained in Chapter 1.2.3, Karabin has a standardised approach to realise benefits for their customers. It is in this process that the designed MMF will be used, i.e., the framework should be designed so that it aligns with this process.

5.1.2 [D.2]: The framework should provide a conceptual explanation of the most important aspects of maintenance management, based on The Maintenance Wheel.

Rationale: In Chapter 1.3, it was explained that potential customers of Karabin have struggled to understand how The Maintenance Wheel works. Effectively, this has resulted in a knowledge-based diffusion barrier. Resultingly, [D.2] was formulated. The idea is that by making an MMF, it will be easier to communicate how potential adopter's maintenance processes will be managed post-implementation. Karabin also mentioned the desire for this objective in this master thesis' "Kick-Off Meeting" (see Appendix A).

5.1.3 [D.3] - [D.5]: The MMF should help overcome the knowledge-based diffusion barrier.

Since Karabin's customers will perceive The Maintenance Wheel as an organizational innovation, diffusion research was reviewed in Chapter 3.1. A total of ten attributes affecting an innovation's diffusion were identified. Effectively, these could aid overcome the knowledge-based diffusion barrier. However, not all of the identified attributes are relevant to the thesis' design scope. Below, it is assessed which of the ten attributes that are possible to improve. The results are summarized in Table 14 on the next page. The relative importance of the various attributes when an innovation is not designed for a particular business context is also listed in the table, as identified by Vagnani and Volpe (2017).

It is not a goal to change how The Maintenance Wheel works when implemented. Thus, of the ten attributes identified in Chapter 3.1, operational attributes are therefore not considered, i.e., trialability, task relevance and usefulness, risk, and implementation complexity. Furthermore, of the remaining attributes, it is not possible to improve the relative advantage, observability, nor reinvention, given the design scope. The inability to include these attributes is discussed in Chapter 8.2, when discussing the limitations of the thesis.

The three remaining attributes of transferability, complexity, and compatibility are both possible to affect and important to consider when designing. These attributes affect how senior managers understand the MMF. However, note that compatibility refers to how potential implementers perceive the framework, not Karabin. This results in a conflict with [D.1]. Karabin requires a generic MMF that they can adapt to different business contexts, while to be perceived as compatible, the to-be-designed would have to reflect the state of a given business' context. This is solved by formulating [D.5] now, but not using it before in the evaluation of the framework. In the evaluation step, seen in Chapter 7, the framework is adapted to reflect a particular context. While this "division" of design activities is not optimal, it is considered the best alternative.

Table 14: Innovation attributes, their relative importance. The descriptions are adapted from Greenhalgh et al. (2007).

Innovation Attribute	Description	Importance	Improvable
Relative Advantage	The perceived advantage of one innovation, in comparison to its alternatives.	✓	-
Complexity	The difficulty of using and understanding an innovation.	✓	✓
Compatibility	If a potential adopter believes the innovation aligns with its values, experiences, and needs.	✓	✓
Trialability	Whether potential adopters may experiment and try out an innovation before adopting it.	-	-
Observability	Whether the benefits of a given innovation is visible to others.	✓	-
Reinvention	Whether potential adopters may adapt the innovation to suit their own business context.	-	-
Task Relevance and Usefulness	If the innovation is relevant and will help increase the performance of tasks in the organization.	-	-
Implementation Complexity	The more complex an innovation is to implement, the less likely it is that organizations will adopt it.	-	-
Risk	The higher the uncertainty and undesired consequences associated with the implementation of an innovation, the less likely is adoption.	-	-
Transferability	Whether it is possible to communicate how the innovation works, both in-use and the underlying principles, to potential adopters.	✓	✓

[D.3] - The framework should effectively communicate how to manage maintenance based on The Maintenance Wheel to customers of Karabin.

Rationale: As explained in Chapter 1.3, Karabin has struggled to explain how to manage maintenance based on The Maintenance Wheel. Resultingly, improving transferability is considered key to overcoming the knowledge-based diffusion barrier.

[D.4] - The framework should be easy to use and understand for the senior managers of Karabin's customers.

Rationale: While [D.3] is concerned with the to-be-designed MMF informativity, [D.4] specifies that the framework should also not be too complex. Otherwise, it will be challenging for senior managers to understand it, effectively lowering the probability of the knowledge-based diffusion barrier being solved.

[D.5*] - The framework should be perceived as compatible by organizations considering implementing it. *

Rationale: To increase the to-be-designed framework's ability to solve the diffusion barrier, it should be perceived as compatible by senior managers, i.e., as relevant to the organization previous experiences, needs, and values. Note that compatibility in this sense speaks to the terminology used, concepts included in the framework, and so on. In effect, senior managers should be able to recognise the elements of the framework to make it easier for them to understand it. To illustrate the significance of this objective, Chapter 3.2.3 showed that the separation between academic solutions to maintenance issues and their real-world application is generally attributed to the lack of a practical focus, i.e., the perceived compatibility by practitioners is low.

5.2 Design requirements

In this subchapter, design requirements are identified. As the design requirements are heavily interlinked, generally affecting more than one of the design objectives, the requirements are not categorized per objective.

The categories of design requirements used are derived from Verschuren and Doorewaard (2010), who propose three types of requirements for design-oriented research projects: functional, contextual, and user requirements. Functional requirements are what an artefact should do to solve the problem at hand. Contextual requirements are requirements posed by the environment in which the artefact will be used. Last, user requirements are the demands of those who will use the artefact.

Considering the problem that the to-be-designed framework should solve, both contextual and user requirements are combined under the term contextual requirements. The reason for this is that the separation between these two requirement categories is not clear cut in this thesis. The to-be-designed MMF is created for Karabin's benefits realisation process (the context), and Karabin and their customer's senior managers (the users). Karabin will customize the to-be-designed framework themselves, based on the customer they are attempting to realise benefits for, during Phase 2 of Karabin's benefits realisation process (as described in Chapter 1.2.3). Given that the rationale of the different requirements is discussed, this should not affect the thesis' procedural transparency significantly.

The functional and contextual requirements have been further separated into three categories: keep, need-to-have, and nice-to-have. The "keep" category has been formulated to specify which requirements that describe elements that are brought forward from The Maintenance Wheel. The two latter categories are derived from a book on how to conduct engineering design, by Dym et al. (2014). "Need-to-have" requirements are absolute, inflexible requirements that the framework must satisfy to be considered successful. Last, "nice-to-have" requirements provide value if included, but they are not strictly necessary. It is not always feasible to include each "nice-to-have" requirements in the design. There are two reasons for using these sub-categories. First, they increase the procedural transparency of the design process, making it clear to a reader which requirements that are prioritized. Second, the requirements are not equally important. Using these sub-categories make it possible to distinguish which that are prioritized.

The resulting requirements, and the objectives formulated in Chapter 5.1, has been illustrated in Table 15. Note that in the table, "D.x", refers to design objective number x, with the same logic for the functional requirements ("F.x.") and contextual requirements ("C.x"). After Table 12, the rationale for each requirement is discussed. Note that under "Source", both the chapter where the reason for the objective/requirement was discussed and the person/organization who suggested it has been included.

Table 15: Design objectives and requirements.

Design Objectives	Description	Affected Diffusion Attribute	Source
D.1	The framework should align with Karabin's benefits realisation process.	n/a	Chapter 1.2.31.5: Karabin
D.2	The framework should provide a conceptual explanation of how to manage maintenance through an MMF, based on The Maintenance Wheel.	n/a	Chapter 1.3: Author Appendix A: Karabin
D.3	The framework should effectively communicate how to manage maintenance based on The Maintenance Wheel to customers of Karabin.	Transferability	Chapter 3.1.2: Author
D.4	The framework should be easy to use and understand for the senior managers of Karabin's customers.	Complexity	
D.5*	The framework should be perceived as compatible by organizations considering implementing it.	Compatibility	
Design Requirements	**Description**	**Type**	**Source**
F.1	Each element in the framework must be clearly identified and described in text.	Need-to-have	Chapter 5.1: Author
F.2	The connection between elements in the framework must be clear.	Need-to-have	Chapter 3.2: Author
F.3	The elements ensuring the functionality of The Maintenance Wheel must be included in the framework.	Keep	Chapter 4.2: Author
F.4	The framework must include the most important maintenance management activities.	Need-to-have	Chapter 3.2: Author
F.5	The framework must include alternative paths through the framework.	Nice-to-have	Chapter 3.1.2 and 4.2.6: Author
C.1	The framework must be adaptable to different business contexts.	Need-to-have	Chapter 1.5: Karabin
C.2	The framework should be generalized.	Need-to-have	Chapter 1.5: Karabin
C.3	The framework should be easy to read and understand.	Need-to-have	Chapter 3.1.2: Author

[F.1]: Each element in the framework must be clearly identified and described in text.

Rationale: In Chapter 5.1, the importance of clearly communicating how and why an innovation works were discussed, in relation to improving transferability. To improve transferability, there should therefore be an explanation of the constructed MMF in text. Describing and clearly identifying each element is therefore considered essential.

[F.2]: The connection between elements in the framework must be clear.

Rationale: To make senior managers understand how the elements of The Maintenance Wheel combine to realise benefits, it is considered useful to make the relationships between different elements clear. Additionally, while explaining which types of MMFs to review in Chapter 3.2.4, it was explained that there are two types, namely declarative and process-oriented MMFs, as identified by Campos & Crespo Márquez (2009). It was further explained that process-oriented are easier to understand because they explain how the various concepts inside the frameworks are interconnected. Thus, a process-oriented framework is created.

[F.3]: The elements ensuring the functionality of The Maintenance Wheel must be included in the framework.

Rationale: The whole purpose of constructing the MMF is to better communicate how The Maintenance Wheel works. This should help Karabin transfer knowledge on how The Maintenance Wheel works, to solve the knowledge-based diffusion barrier. The elements below, marked as varieties of "[F.2.x]", are considered the most important elements to the way that The Maintenance Wheel realises benefits, and are in turn considered absolute requirements for creating an MMF based on The Maintenance Wheel. These were analysed in the analysis of The Maintenance Wheel in Chapter 4.2.

Unfortunately, it is difficult to provide an exact replication of the process used to determine which elements that are considered the most important, as it took place over an extended period of time and has also been affected by several other aspects such as several preliminary meetings with Karabin, the literature reviews in Chapter 3, desk research of internal documents of both Equinor and Karabin, and a visit to a company currently implementing The Maintenance Wheel.

To satisfy [F.3], the following should be included:

[F.3.1]: The framework must include the standardization of tasks.

[F.3.2]: The framework must include the standardization of deliveries between different steps of the maintenance process through customer-supplier agreements.

[F.3.3]: The framework must include the standardization of task sequences.

[F.3.4]: The framework must include the strategic selection of corrective maintenance work orders.

[F.3.5]: The framework must include cross-functional staff.

[F.3.6]: The framework must include the idea of realizing benefits through process flow.

[F.3.7]: The framework must include the process-based performance measurement system used to control and improve activities related to processing work orders.

[F.3.8]: The framework must include the 5-step work-order sequence.

[F.3.9]: The framework must show how the unit of flow in the maintenance process is maintenance notifications and work orders.

[F.4]: The MMF must include the most important maintenance management activities.

Rationale: To understand how to create an MMF (i.e. a theoretical framework communicating an approach to maintenance management), different MMFs were reviewed in Chapter 3.2. This was done to examine which traits that were common across the different frameworks. To summarize this review, it was concluded in Chapter 3.2.14 that while there is no standardised form of MMFs, MMFs generally explain elements related to strategic maintenance activities (e.g. setting objectives), the control of maintenance activities, maintenance planning, maintenance execution, and continuous improvements. Additionally, as explained under [F.2], the connection between these elements should be clear. Thus, to satisfy [F.4], the following has to be achieved:

[F.4.1]: The framework must explain how strategic maintenance activities are managed based on The Maintenance Wheel.

[F.4.2]: The control and improvement system of The Maintenance Wheel (i.e. [F.3.7]) must be expanded to include other improvement initiatives.

[F.4.3]: The framework must include maintenance planning activities.

[F.4.4]: The framework must include maintenance execution activities.

[F.4.5]: The connection between the different elements of the framework, which combine to manage the maintenance activities, must be clear.

[F.5]: The framework must include alternative paths through the framework.

Rationale: The Maintenance Wheel value-chain (page 79) does not illustrate alternative paths through the framework (Chapter 4.2.6). Based on the author's personal experience while analysing The Maintenance Wheel in Chapter 4.2, this makes it seem as if there is only one way through the maintenance process being managed. As this is not the case, not visualizing or somehow making it clear that there are several alternative paths lowers the transferability. While this also lowers complexity, which is positive for the research objective, it is considered better to include examples of alternative paths. If need be, it is easier to remove these examples, than to redesign the MMF to include examples at a later stage.

[C.1]: The framework must be adaptable to different business contexts.

Rationale: [C.1] stems from Karabin having no customer profile (see Chapter 1.5). For the to-be-designed framework to align with their benefits realisation process (explained in Chapter 1.2.3) as specified by [D.1], it is therefore important that the designed framework allows Karabin to adapt it. In practice, Karabin will use the framework as a foundation and adapt it to reflect their customer's maintenance processes, for example, by using their customer's in-house terminology to describe different parts of the framework.

[C.2]: The framework should be generalized.

Rationale: As Karabin operates with no customer profile (discussed under [C.1]), the MMF should also be generalized for it to align with their benefits realisation process.

The Maintenance Wheel was originally developed by and for Equinor. Exemplified by The Maintenance Wheel value-chain illustration (on page 79), it contains several characteristics of Equinor, e.g., the style and the ERP-codes. The MMF should not contain such stylistic business-specific elements, as it is believed that the presence of contextual factors lowers the perceived compatibility of a framework for other companies.

[C.3]: The framework should be easy to read and understand.

Rationale: The importance of managing an innovation's complexity has been discussed in Chapter 3.1.2 and 5.1.3. Therefore, [C.3] was defined. For the to-be-designed framework to be able to communicate efficiently how to manage maintenance to senior managers, the illustration should be as simple as possible.

5.3 Conclusion

In this chapter, design requirements have been identified. The design requirements specify the outer boundaries of what the MMF has to do to reach the research objective defined in Chapter 1.4.1. The requirements are based on the information gathered in the previous stage of the design process, i.e., Chapter 3 and 4. Recall that Chapter 3 identified how to design an MMF and how to solve the diffusion problem of Karabin. Also recall that Chapter 4 identified how The Maintenance Wheel worked, i.e., what the MMF has to communicate.

To identify the design requirements, an intermediary step was taken by first defining design objectives in Chapter 5.1. The design objectives are simply the research objective further operationalized. Some researchers would likely derive design requirements directly from the research objective but seeing that the research objective is complex, design objectives were first defined to increase the thesis' procedural transparency.

In the design requirements identification in Chapter 5.2, the design objectives were used as starting points for the identification. The categories of requirements identified were based on Verschuren and Doorewaard (2010), who propose three types of requirements for design-oriented research projects: functional, contextual, and user requirements. However, seeing that reality of the design project resulted in the line between contextual and user requirements being blurred, these requirements were simply combined under the name "contextual requirements". Seeing that the rationale of the different requirements is discussed, this should not affect the thesis' procedural transparency significantly. Functional requirements describe what the designed framework should do. Contextual requirements are requirements to design based on the environment that the framework will be used in. In total, 17 functional requirements and three contextual requirements were defined.

The next step of the design phase is to use these requirements to create a satisfactory design. This is done in Chapter 6.

"Management is, above all, a practice where art, science, and craft meet. "

Henry Mintzberg

6. Framework Design

This chapter describes the second of two steps in Stage 3 of the design process, as seen in Figure 23. Particularly, this chapter sees the construction of an MMF satisfying the design requirements identified in Chapter 5. This is done in two steps. First, Chapter 5.1 uses a morphological chart to construct the design space, i.e., the space of possible design alternatives. Second, these propositions are synthesised into an MMF based on The Maintenance Wheel in Chapter 6.2. This ultimately answers [RQ6]: "What does a satisfactory MMF from the design space look like?"

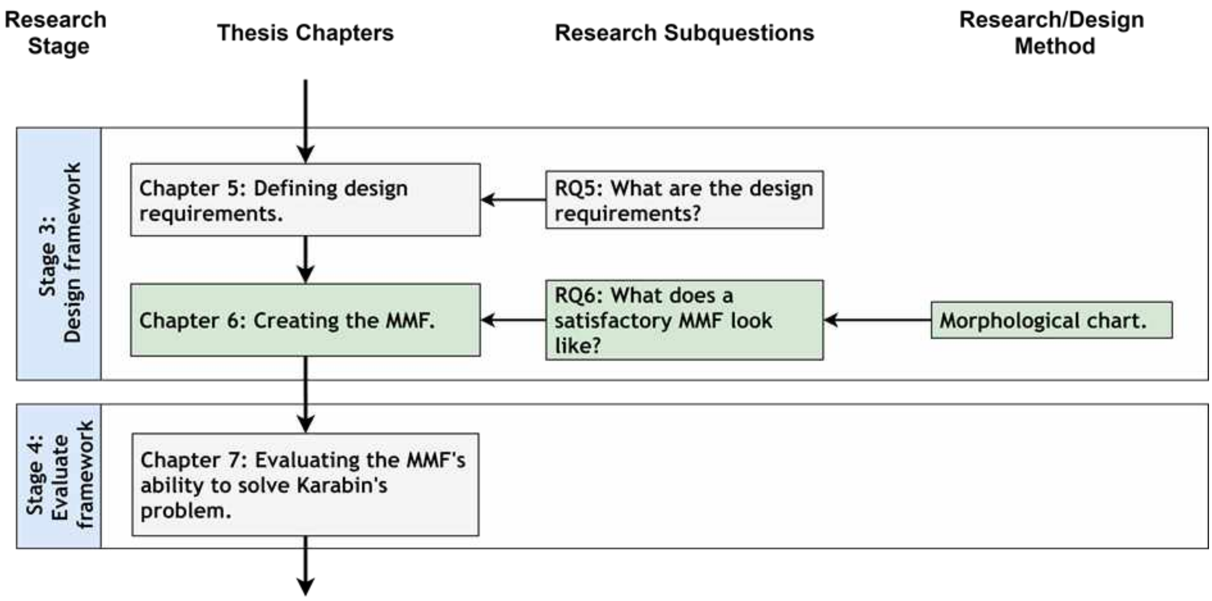

Figure 23: Overview of Chapter 6 in the design process.

6.1 Means

The design requirements defined in Chapter 5.2 describe what that the to-be-designed framework must do or include in order to achieve the research objective. In the following subchapter, the first of two steps used to convert them into the final MMF is described.

According to Dym et al. (2014), the first step of generating a final design is to establish a design space. They define this as an imaginary intellectual region of design alternatives that contains all of the potential solutions to the design problem at hand (Dym et al., 2014, p. 92). However, they also state that for projects with many variables such as this thesis, creating this design space may be challenging. Ultimately, they suggest a design technique to help establish the design space, namely, a morphological chart.

A morphological chart is a matrix which establishes the design space by listing the design requirements on the vertical axis, and different propositions for how to realise each of these requirements on the horizontal axis (Dym et al., 2014). The idea behind this chart is that a satisfactory design is created by selecting one or more of the proposed means per row. Subsequently, these means are synthesised into a final design in the next step of the design process, i.e., in Chapter 6.2. The resulting morphological chart is seen in Table 16, on the next page. Where two different options were considered, the chosen option has been bolded.

Note that the morphological chart shows how some of the requirements are solved by the proposed means for another requirement. This shows that there is an overlap between design requirements. While this would have been undesirable if a design optimization approach such as Suh's (1998) axiomatic design process had been applied, this was not considered a problem as a satisfactory design approach was taken.

Table 16: Morphological Chart

D.Req.	Description	Means 1	Means 2
F.1	Each element in the framework must be clearly identified and described in text.	Provide a list of each element included in the framework, with a description of that element.	
F.2	The connection between elements in the framework must be clear.	Make a process-oriented MMF.	
F.3.1	The framework must include the standardization of tasks from The Maintenance Wheel.	Illustrate and explain how tasks are standardised based on The Maintenance Wheel. Therefore, describe that it contains person responsible, a description of the best-practice, and time and quality objectives.	
F.3.2	The framework must include the standardization of deliveries between different steps of the maintenance process through customer-supplier agreements from The Maintenance Wheel.	Illustrate and explain exchanges between different stages of the maintenance process conceptually. Describe predetermined recipient and way of submitting work. Interactions between workers of different sub-processes are described.	
F.3.3	The framework must include the standardization of task sequences from The Maintenance Wheel.	Illustrate and explain task sequence standardisation conceptually.	
F.3.4	The framework must include the strategic selection of corrective maintenance work orders from The Maintenance Wheel.	Illustrate and explain the strategic selection of work orders as a gate with two main alternatives: creating a work order or an alternative path.	**Illustrate and explain the strategic selection of work orders as a gate. Describe each alternative path.**
F.3.5	The framework must describe how cross-functional staff are used in the maintenance process, as in The Maintenance Wheel.	Describe how cross-functional staff is used in the different processes conceptually.	
F.3.6	The framework must include the idea of realizing benefits through process flow.	Provide a conceptual explanation of how to improve performance.	
F.3.7	The framework must include the process-based performance measurement system used to control and improve activities related to processing work orders from The Maintenance Wheel.	**Illustrate the elements required to control and improve the processing of notifications and work orders.**	**Provide examples of indicators used.**
F.3.8	The framework must include the 5-step work-order sequence from The Maintenance Wheel.	Illustrate the five steps as five different sub-processes.	

F.3.9	The framework must show how the unit of flow in the maintenance process is maintenance notifications and work orders, from The Maintenance Wheel.	Illustrate a typical work order and explain how the various sub-processes in the maintenance value chain work on it.	
F.4.1	The framework must explain how strategic maintenance activities are managed based on The Maintenance Wheel.	Illustrate strategic maintenance activities based on a top-down approach.	
F.4.2	The control and improvement system of The Maintenance Wheel (i.e. [F.3.7]) must be expanded to include other improvement initiatives.	Illustrate how data from work orders are used to improve preventive maintenance plans and to initiate design-out maintenance.	
F.4.3	The framework must include maintenance planning activities.	Covered in [F.3.8].	
F.4.4	The framework must include maintenance execution activities.	Covered in [F.3.8].	
F.4.5	The connection between the different elements of the framework, which combine to manage the maintenance activities, must be clear.	Covered in [F.2].	
F.5	The framework must include alternative paths through the framework.	Covered in [F.3.4]	
C.1	The framework must be adaptable to different business contexts.	**Provide an example of how the framework can be adapted.**	Provide a methodology for how to adapt the framework.
C.2	The framework should be generalised.	Remove the characteristics of Equinor, i.e., the style, the specific tasks in the value-chain and the ERP codes of The Maintenance Wheel.	
C.3	The framework should be easy to read and understand.	**Explain the framework based on reductionism.**	Explain the framework based on holism.

6.2 Synthesis of means

In the following subchapter, the MMF based on The Maintenance Wheel is designed. In order to create a satisfactory MMF based on the design objectives and requirements defined in Chapter 5, the to-be-designed framework is split into two parts. The first part will explain how the framework works conceptually. The second part is the framework itself, which in effect applies the concepts from the first part on a maintenance process.

Splitting the design into two parts is based on reductionism, i.e., the idea that any complex phenomena may be explained by reducing it into simpler parts (Nagel, 1998). In other words, the most important dynamics of the larger framework is explained by first describing its underlying components. The opposite approach, holism, would be to see the framework as a whole not possible to reduce due to synergies between parts (Østreng, 2007). The reason for using reductionism stems from the design requirements. One of the requirements is that the designed framework is able to explain to staff with no BPM experience how it works. Reductionism is considered a good way to achieve this. Additionally, as an adaptable framework is both a design requirement and objective, explaining the underlying parts is considered useful. By explaining the underlying concepts, it will be easier for Karabin to adapt the framework to their customer's processes.

Since reductionism is used, the first step of the design process was to explain the requirements/means necessary to describe how the framework works on the lowest possible level: [F.3.1], [F.3.2], [F.3.3], [F.3.5], [F.3.6], and [F.3.7]. Additionally, the requirements related to "overarching" design attributes were included, i.e., [F.1], [F.2], and [C.1.] - [C.3]. Additionally, it was prioritized to not make the conceptual models too complex, as this could work against the models' purpose: to explain how the to-be-designed framework works. The outcome of this design step is shown on page 106-107.

After these two models, a flowchart is made to illustrate the measurement, analysis, and improvement activities of the to-be-designed framework. Initially, this flowchart was not included, but it was considered purposeful to include it as the jump from the conceptual models to the designed framework was perceived to be too large. The flowchart is based on Campos and Crespo Márquez (2011, p. 814) MMF framework, who uses a similar top-down approach to identify maintenance objectives and a similar down-up aggregation of data for controlling the maintenance process as that used in The Maintenance Wheel (see Appendix D). This flowchart is seen on page 108, in Figure 26.

The framework itself is displayed on page 110 in Figure 27, with the explanation of its contents is on the subsequent pages. Designing this was challenging since it was necessary to strike a balance between information richness and reducing complexity due to the design objectives in Chapter 5.1. Ultimately, it was prioritized to make the framework simpler and rather describe in-depth how the framework works. This is based on Karabin having to adapt the framework to different business contexts. By rather aggregating activities under larger sub-processes such as "make improvements", Karabin can alter the description of these sub-processes to describe activities relevant to their customers business contexts while pitching it. This is shown in Chapter 7, where the framework is adapted to suit the oil and gas industry.

Last, since the framework needs to communicate how to process work orders, a mock-up of a work order to be processed by companies has been illustrated in Figure 28, on page 114.

Conceptual Model (page 1)

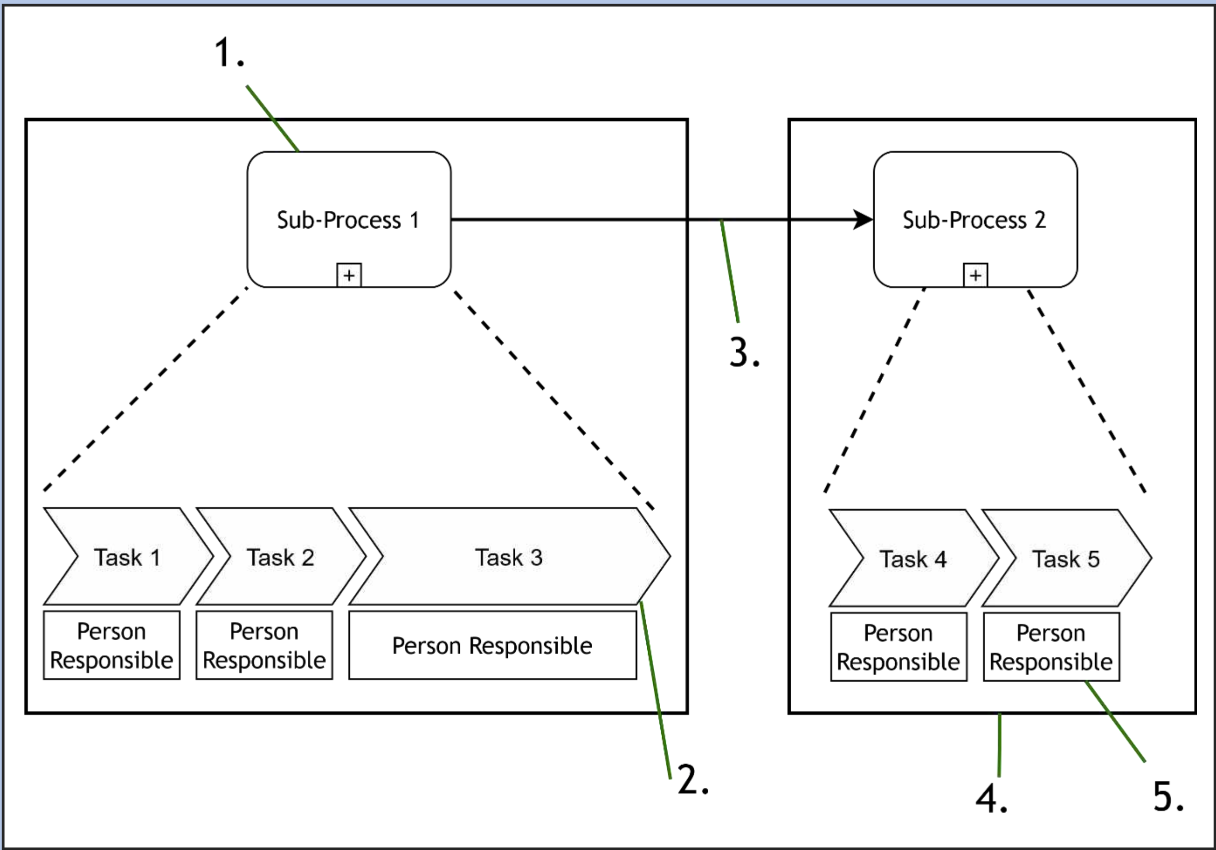

Figure 24: Conceptual model 1 of how the framework works. Visualisation by author.

Table 17: Description of concepts in Figure 24.

#	Concept	Description
1	Sub-process	A process is made up of several sub-processes. Each sub-process is made up of several tasks.
2	Standardisation of tasks	Each task of a sub-process has a standard, i.e., a document describing the best-practice way to complete that task. This document is found in companies ICT-system. This standard also specifies who is responsible for the task. It standardises what is considered a good quality way of conducting that task, and the estimated time to complete the job based on the best practice. Examples of such documents are standard operating procedures.
3	Customer-supplier agreements	Customer Supplier Agreements standardise deliveries between sub-processes. In other words, when a sub-process is completed, there is a predetermined recipient and way to send the work performed to the next sub-process.
4	Standardized task sequences	The task and sub-process sequence is standardised. Note that tasks in a sub-process may be performed sequentially or in parallel, but only sequential tasks are illustrated.
5	Cross-functional staff	The staff used in the various tasks of a sub-process are selected based on competency, not the functional department they belong to.

Conceptual Model (page 2)

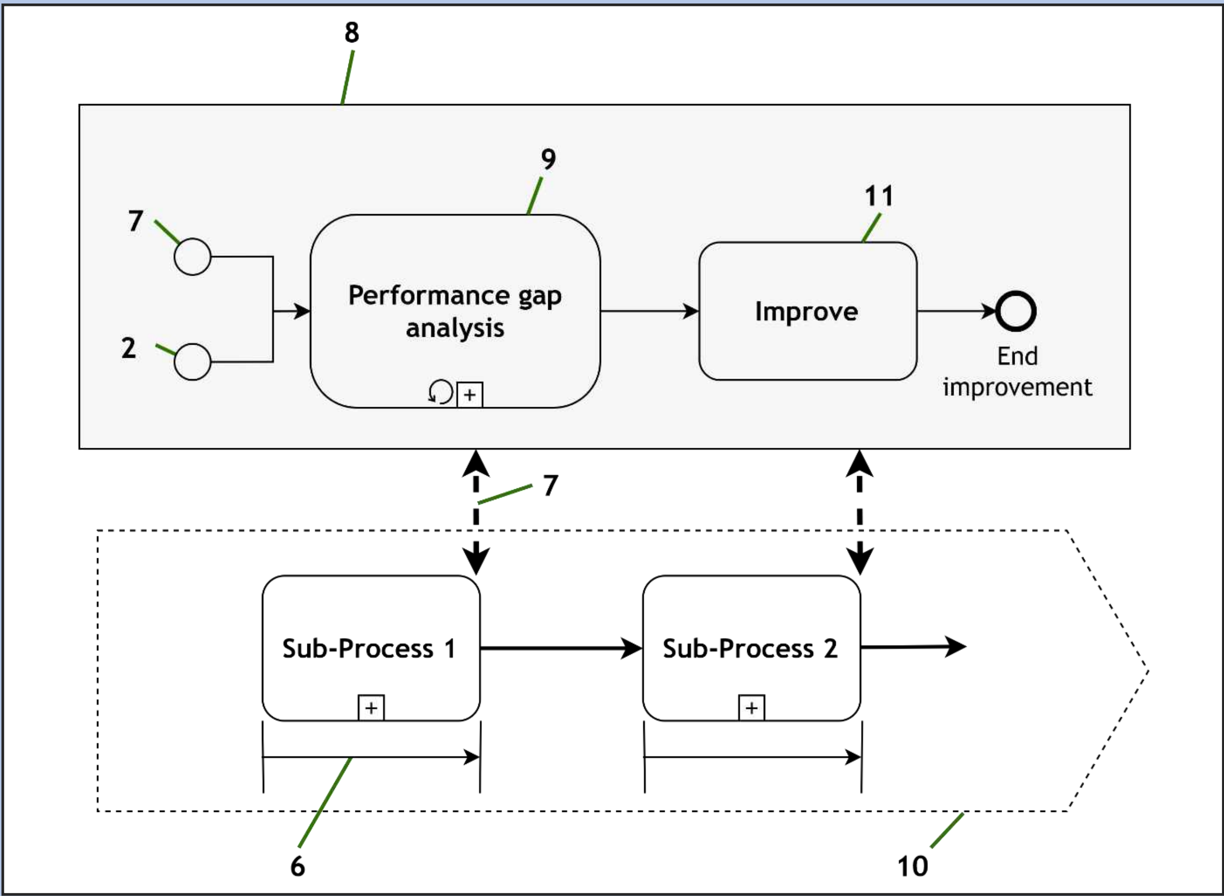

Figure 25: Conceptual model 2 of how The Maintenance Wheel works. Visualisation by author.

Table 18: Description of contents in Figure 25.

#	Concept	Description
6	Time measurements	The time taken to complete each task of a sub-process is tracked in real-time. Since time is measured, process progress performance is measured continuously.
7	Real performance data	The performance data of each task performed for each maintenance notification/work order is sent to the supporting ICT-system. This data is used to measure the performance in indicators of *quality* and *time*.
8	ICT-System	A supporting ICT-system tracks the progress of a work-order from a maintenance notification is created until the work order is finished.
9	Performance gap analysis	When processing a work order, performance is measured continuously by comparing the quality and the estimated time to complete a job specified in the best-practice standards with the real measurements. Note that the real quality measures are entered into the ICT-system manually by the staff performing the work. Also, note that the quality objectives are predominantly leading indicators.

10	Realising benefits through flow	A maintenance work order should be processed with process flow, i.e., without any disturbances or unnecessary stops, as quick as possible. This will realise benefits, as non-value adding aspects of the maintenance process is removed.
11	Improvement	Those responsible for a task, as identified in the standards, must close performance gaps once they are identified. Note that the measurements of time enable process-based improvements.

Flowchart (page 3)

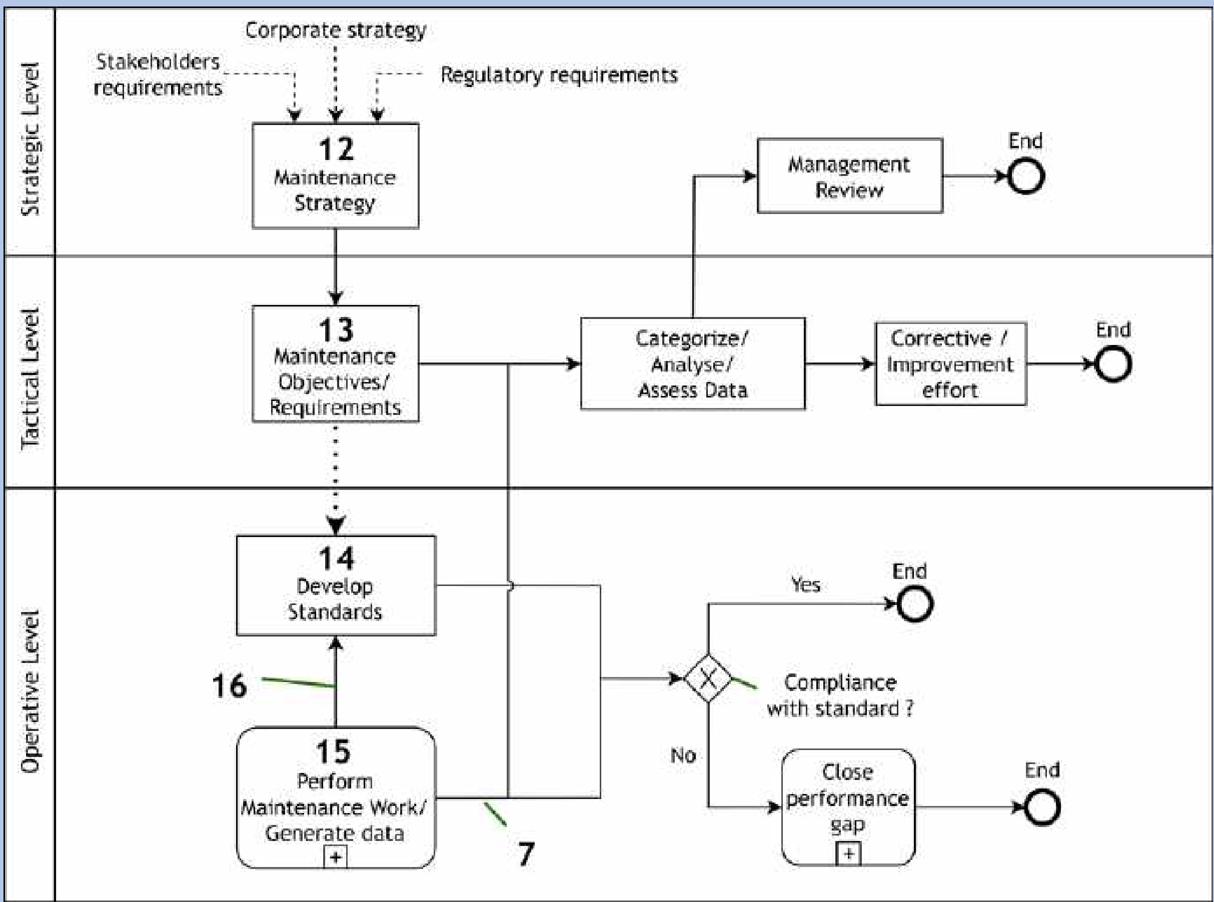

Figure 26: Flowchart of measurement, analysis, and improvement activities. Visualisation by author.

Table 19: Description of contents in Figure 26.

#	Concept	Description
12	Maintenance Strategy	A maintenance strategy is created, based on a set of requirements to the maintenance process.
13	Maintenance Objectives/ Requirements	From the maintenance strategy, a list of objectives/requirements which the maintenance activities should achieve/meet.
14	Develop Standards	Based on these objectives/requirements, standards are developed, which specify the best-practice way of performing a task in the maintenance value-chain. Indicators related to time and quality are specified.
15	Perform Maintenance Work/Generate Data	As described in the conceptual models, while operational staff perform work, they generate data (see concept [7]). Time measurements are tracked by the progress of work orders, and quality measurements are submitted by staff into the ICT system themselves. After submitting this data, it may be used to control or improve the maintenance process on all hierarchical levels, as exemplified in the flowchart.
16	Continuously improve standards	If operational staff identifies a new best-practice, they are responsible for updating the standard themselves. Through this, continuous improvements are achieved.

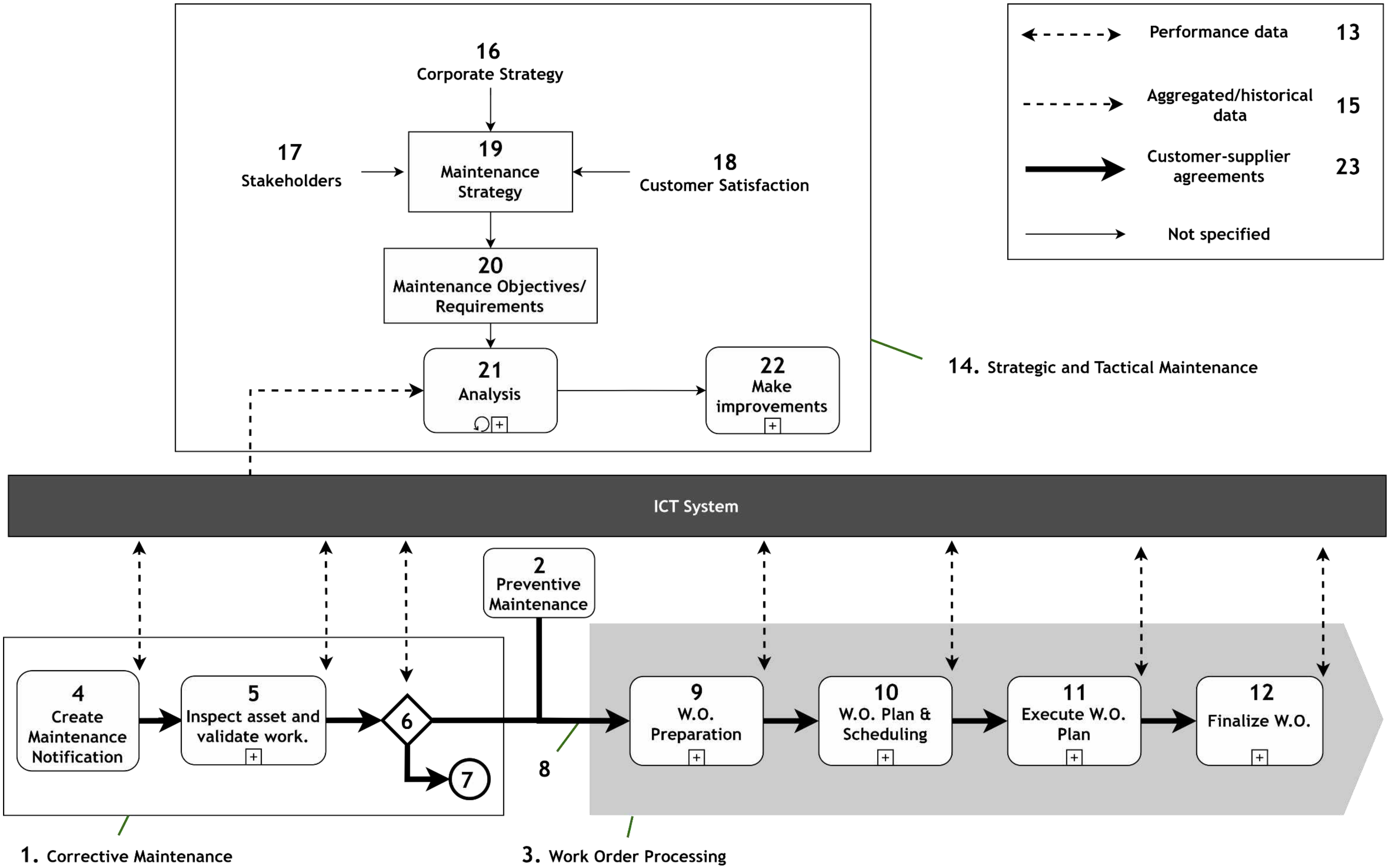

Figure 27: The MMF based on The Maintenance Wheel. Visualisation by author.

Table 20: Contents of the maintenance management framework in Figure 27.

#	Concept	Description
0	The Maintenance Value Chain	This element is not marked in the framework, as it is made up of the elements covered by concepts [1]-[3]. These elements together make up the maintenance value-chain, i.e., the activities required to process a work order end-to-end. The flow unit through this value-chain is maintenance notifications/work orders. The process can be regarded as an assembly line, with predetermined workstations, procedures, staff responsible, etc. But instead of a car, it is a work order being processed.
1	Corrective maintenance work orders	There are two potential sources of work orders in the framework, of which corrective maintenance is one source. The elements inside this box describe how corrective work orders are selected.
2	Preventive maintenance work orders	Preventive maintenance is the second source of maintenance work orders. These work orders prevent unplanned maintenance and are commonly based on operational hours, time-based intervals, or condition monitoring. Once a criterion for the creation of a work order is met, a work order is created, and it enters the maintenance value-chain.
3	W.O. Processing	The four sub-processes within this grey arrow contain the tasks required to process a work order. For these sub-processes, flow is emphasised. That means that once a work order is created, it should be processed as quickly and efficiently as possible. The main idea behind this framework is that benefits are realised by avoiding unnecessary stops and preventing bottlenecks.
4	Maintenance Notification	When staff observes an asset in need of maintenance, a maintenance notification is created. This notification is the unit of flow until concept [6].
5	Subprocess 1: Inspect and validate work	Maintenance notifications may be created by anyone, even staff without knowledge of the asset in question. Subprocess 1 do, therefore, hold that competent staff should inspect and validate whether the maintenance notification is valid. This is based on the logic that a car mechanic does not simply change a gearbox when a customer points to the gearbox making weird sounds.
6	Gate	After inspecting work-orders in concept [2], a decision must be made regarding the future of the maintenance notification. Overarchingly, there are two alternatives: creating a work order or an alternative path. A key element of the framework is that the number of maintenance notifications should be strategically reduced. An objective to the reject rate should be set here, e.g., a 10% reduction. Note that this assumes that more work orders are processed than necessary, which increases the pressure on the downstream maintenance sub-processes.
7	Alternative paths	The second option out of gate [3] is made up of alternative paths to the “standard” W.O. sequence. Do note that these alternative paths have not been illustrated.

		• Faulty maintenance notification: It is possible that a maintenance notification is incorrect. In that case, the person inspecting the asset (see concept [2]) may either reject the notification or update it so that it is precise. • Simplified maintenance: The person inspecting the asset may also simply fix it while inspecting it, if possible. • Emergency maintenance: A third option is emergency maintenance. Occasionally, assets critical to an organization may break down. In this case, the asset should not follow the "standard" W.O. sequence, as it should be prioritized over the other W.O. • History-based maintenance: Assets may also require maintenance after experiencing a previously experienced failure mode. In this case, the information from the last time may be used to process the work order.
8	Work Order	From here on, until concept [12], work orders are the unit of flow in the maintenance process. A mock-up of this type of form is visualised on page 114.
9	Subprocess 2: W.O preparation	During this sub-process, preparation for executing the work order is initiated. Examples of such preparatory activities are the inspection of the work location and acquisition of required materials.
10	Subprocess 3: W.O. Plan and Scheduling	During the third sub-process, the company should schedule the work and gain approval of the W.O. plan.
11	Subprocess 4: Execute W.O. Plan	During the fourth subprocess, the work planned is executed.
12	Subprocess 5: Finalize W.O.	To finalize a work order, assets are put back into operation and reports are submitted into the ICT system about the work done.
13	Performance data	Each sub-process in the maintenance value-chain, i.e., activities related to processing work orders, send performance data based on predefined indicators of quality and time specified in the best-practice standards to assess if work is performed correctly.
14	Overarching performance management	Besides the real-time performance gap analyses happening in the maintenance value-chain, by comparing the performed work with the best-practice standards, there are other maintenance management activities that rely on aggregated/historical data from this value-chain. All these maintenance management elements are "bundled" in this box.
15	Aggregated/ historical data	Aggregated/ historical data used to identify anomalies or performance gaps.
16, 17, 18, 19, 20	Corporate Strategy, Maintenance Strategy, Stakeholders and	A maintenance process must satisfy various criteria. For example, it plays a large part in organizations reaching their corporate objectives by ensuring equipment availability and compliance with safety and environmental regulations. A company defines a maintenance strategy for how to reach these goals. Subsequently, specific maintenance objectives and requirements are defined. The

	Maintenance Objectives/ Requirements	goal of these requirements is to have measures to determine whether the maintenance process operates so that the various criteria it needs to satisfy are met.
21	Analysis	In [20], the company compares aggregated and historical performance data to assess whether the maintenance process is, in fact, reaching the maintenance objectives/requirements defined, based on data generated on the operational level. Measures here may be the: • number of reworks per month, • critical assets downtime, • rate between preventive and corrective maintenance Also, besides assessing the state of the maintenance process, data is analysed to look for improvements not covered by the continuous improvements in the maintenance value-chain.
22	Make Improvement	Once an anomaly/ performance gap/ potential improvement is identified, the person or group responsible has to make this improvement. Three examples are to make changes in the preventive maintenance intervals, design-out maintenance, or changes to the maintenance strategy.
23	Customer-supplier agreements	Customer supplier agreements standardise deliveries between sub-processes in the maintenance value-chain. In other words, when a sub-process is completed, there is a predetermined recipient and way to end of the work performed to the next sub-process.

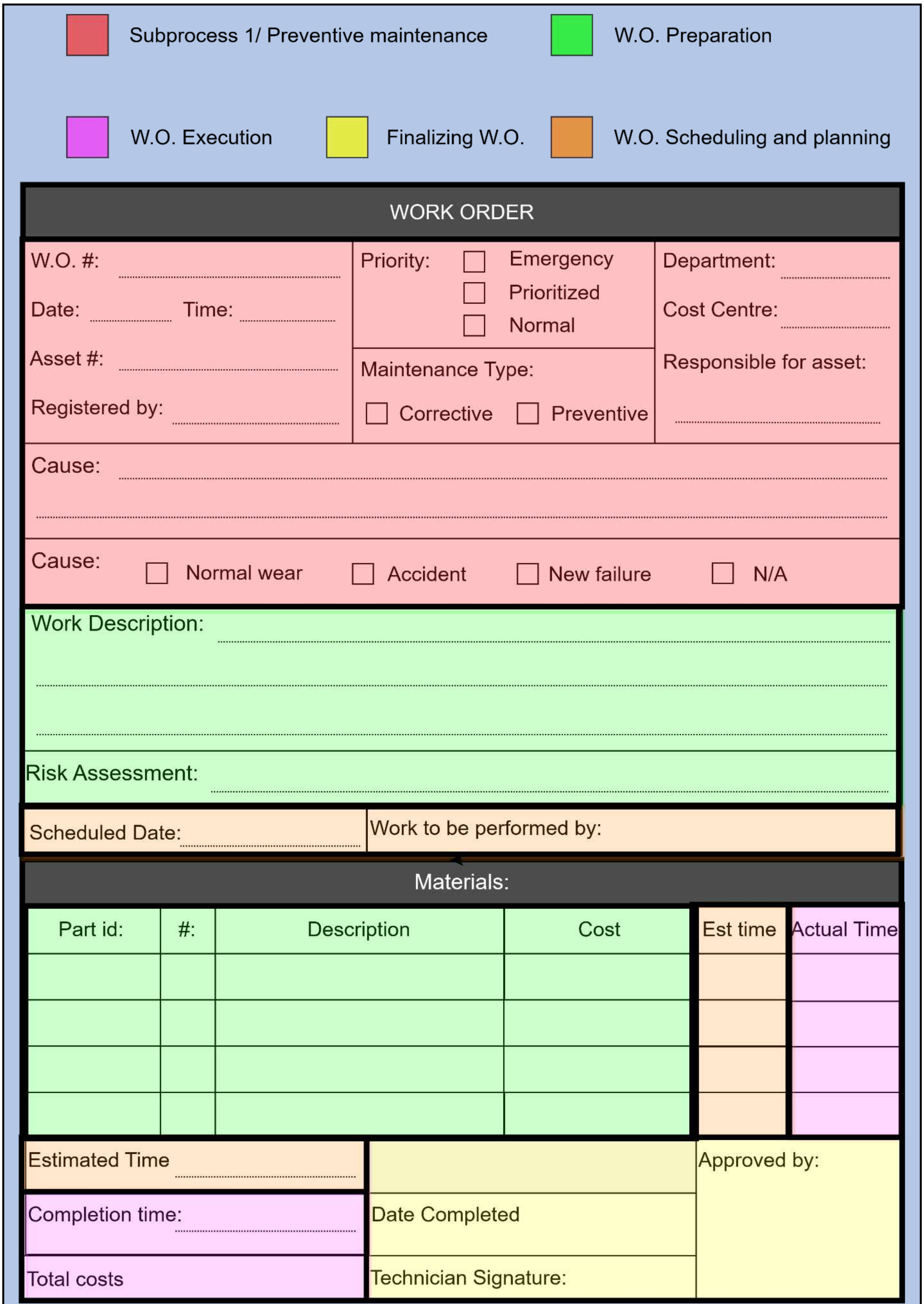

Figure 28: Colour coded W.O. form to show how different sub-processes complete different parts of a W.O. Visualisation by author.

6.3 Conclusion

This chapter describes the second of two steps in Stage 3 of the design process. Particularly, this chapter sees the construction of an MMF satisfying the design requirements identified in Chapter 5.

First, Chapter 6.1 took the design requirements defined in Chapter 5.2 as inputs and used a morphological chart to convert them into the design space, i.e., the space of possible design alternatives. A morphological chart is a design technique that provides a formal procedure to establish the design space. This is done through a matrix listing the design requirements on the vertical axis before a person or group comes with different propositions for how to realise each of these requirements on the horizontal axis (Dym et al., 2014).

After establishing the design space, Chapter 6.2 created the final design, thus answering [RQ6]: "What does a satisfactory MMF from the design space look like?" This was done by selecting from the various propositions in the morphological chart, and then synthesizing them. The designed framework is based on reductionism, where each of the core elements in The Maintenance Wheel is first explained through two conceptual models and a flowchart. Subsequently, these core elements are combined, resulting in the final framework.

"Have no fear of perfection – you'll never reach it."

Salvador Dali

7. FRAMEWORK EVALUATION

This chapter describes the fourth stage of the design process, namely where the framework constructed in Chapter 6 is evaluated on its efficacy. See Figure 29 for an overview. First, Chapter 7.1 describes the evaluation procedure. Then, Chapter 7.2 and 7.3 describes how the framework was adapted for the evaluation and the semi-structured interview procedure, respectively. Last, the framework's efficacy is evaluated in Chapter 7.4, ultimately answering [RQ7]: "Can the constructed MMF help Karabin overcome the knowledge-based diffusion barrier of The Maintenance Wheel?"

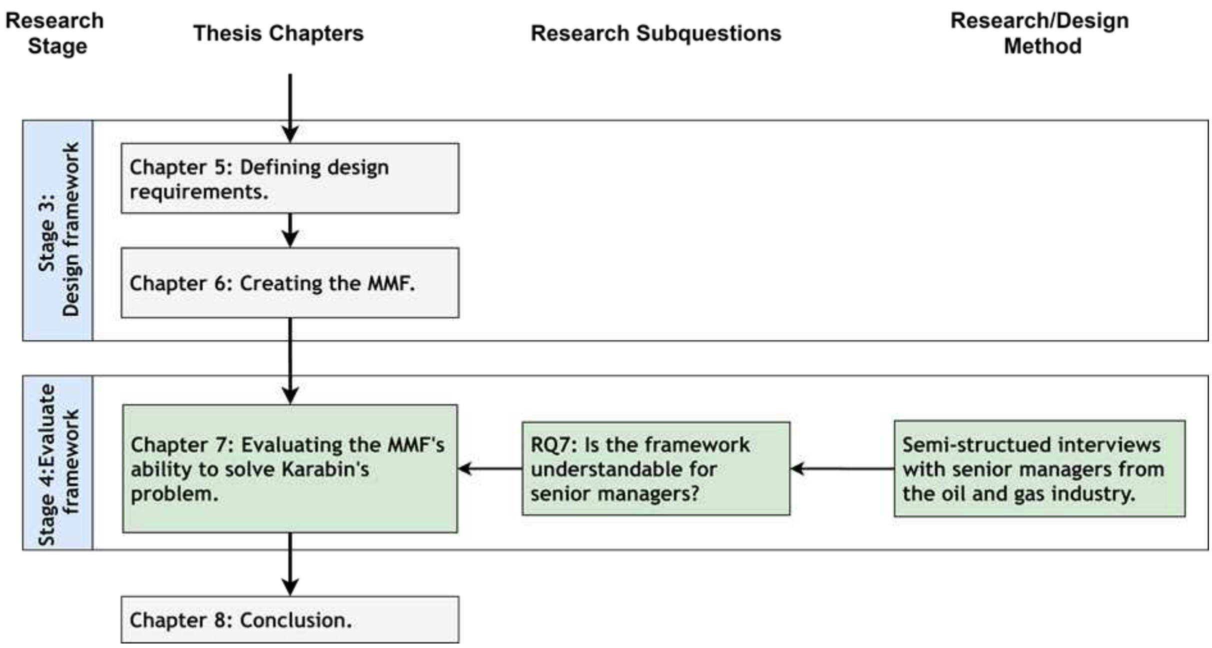

Figure 29: Overview of Chapter 7 in the design process.

7.1 Evaluation procedure

In this subchapter, the evaluation procedure is explained. The steps taken to execute it is summarized in Table 21.

Table 21: The evaluation procedure.

Step	Chapter	Activities
1	7.2	Adapt the framework to reflect maintenance in the oil and gas industry.
2	7.3	Present the adapted framework to senior managers from the oil and gas industry and interview them to gather qualitative data.
3	7.4	Analyse data from interviews to evaluate the framework's efficacy.

The framework is evaluated on its efficacy. This means that it is evaluated whether the framework is able to solve the knowledge-based diffusion barrier explicated in Chapter 1.3. As the designed MMF is a socio-technical artefact, where human interaction is required to prove its value, a naturalistic test was required (Venable et al., 2012). Additionally, the findings of the evaluation are not fed back into the design process, meaning that it is a summative (ex-post) evaluation (Venable et al., 2012). This stands in contrast to a formative, ex-ante evaluation, where feedback is used to improve an artefact (Peffers et al., 2012). For this, [RQ7] was formulated in Chapter 2.3:

- **[RQ7] Can the constructed MMF help Karabin overcome the knowledge-based diffusion barrier of The Maintenance Wheel?**

The specific evaluation method applied is an illustrative scenario, which was defined in Chapter 2 as the "[…] application of an artefact to a synthetic or real-world situation aimed at illustrating suitability or utility of the artefact" (Peffers et al., 2012, p. 402). This method is used, as it was not possible to evaluate the framework in its actual setting, i.e., to use it in a real pitch for a real customer of Karabin. This would have required Karabin to have a contract with a customer with maintenance issues, where no decision had yet been made as to what business case to pursue. This was not the case. An illustrative scenario is a weaker form of evaluation, as it is not possible to replicate the same conditions that would have been in the actual setting which the MMF was designed for. The various limitations of the evaluation procedure are discussed further when discussing the thesis' limitations in Chapter 8.3.

Karabin's issue has been that senior managers have struggled to understand how The Maintenance Wheel works, in turn resulting in the knowledge-based diffusion barrier. Thus, in the illustrative scenario, it will be evaluated whether senior managers indeed are able to understand the constructed MMF, which communicates how The Maintenance Wheel works. While it is possible to evaluate whether the senior managers understand the designed MMF removed from the pitching process, measuring if it indeed convinces so that the knowledge-based diffusion barrier is overcome is not. Being able to convince is dependent on the senior managers examining the designed MMF having an underlying desire to improve their maintenance performance. Identifying such interview subjects was not feasible, at least not within the time constraints. Resultingly, a compromise was made. The evaluation focuses on the framework's ability to communicate how it works to senior managers and a set of measures affecting the framework's ability to convince. The specific attributes focused on were identified in the review of diffusion research literature in Chapter 3.1 and are discussed further while discussing the interview procedure in Chapter 7.3.

To evaluate whether senior managers understood the MMF, the framework had to first be applied in a suitable context. Thereafter, the frameworks ability to solve the problem of Karabin could be evaluated. The selected "context" is senior managers from the oil and gas industry. This industry was selected for two reasons. First, companies from this industry make up a large part of Karabin's customer base. Second, the oil and gas industry is a capital intensive company with much to gain from efficiently managing maintenance (Maverick, 2018). Resultingly, evaluating in the oil and gas industry will both provide Karabin with a relevant indication of the designed MMF's efficacy, while the access to senior managers both interested in and with the required competence to evaluate the framework should be high.

However, the designed MMF could not be applied directly to this context. As described in Chapter 5.2, it was a contextual design requirement to make the designed framework generic, as Karabin has no customer profile. The direct application of this generic framework would not be ideal for the evaluation. Maintenance is a broad field, ranging from software-based maintenance to complex asset-based maintenance. Evaluating whether managers understood the framework would, therefore, suffer by leaving it as it was. Resultingly, the framework had to be adapted to reflect the characteristics of maintenance in the oil and gas industry first. This is done in Chapter 7.2.

After identifying the context, the research method to indeed test the efficacy could be identified. Since a naturalistic test was required, Chapter 2.3.2 described how three research methods were considered: surveys, interviews, and focus groups. First, to evaluate the efficacy, it was necessary to research in-depth about whether senior managers understood the framework. Considering that focus groups and interviews are more prone to provide the depth of information required (Harrell & Bradley, 2009), surveying was not used. For example, with focus groups and interviews, it is possible to probe in on unclear aspects while evaluating. Surveys, on the other hand, are locked to a predetermined form. To understand the decision between interviews and focus groups, it is necessary to understand that it had to be assessed whether the senior managers understood the framework. Due to this, it is beneficial to understand how individual subjects perceived different parts of the framework. According to Harrell and Bradley (2009), focus groups are less suited to obtain this type of information, e.g., due to the participants moderating themselves because of the other participants in the group. Additionally, focus groups are less qualified to determine what issues individual managers had with different parts of the framework, as members of focus groups do not necessarily share the same perception (Harrell & Bradley, 2009). Resultingly, semi-structured interviews were used.

To summarize, the resulting evaluation method first adapts the framework constructed in Chapter 6 to the oil and gas industry (Chapter 7.2), whereafter senior managers in this industry are interviewed to provide qualitative feedback on the framework (Chapter 7.3). Based on this qualitative feedback, the frameworks ability to solve Karabin's problem is evaluated (Chapter 7.4).

7.2 Adapting the framework

In the following subchapter, the generic MMF designed in Chapter 6 is adapted to reflect the maintenance of larger oil and gas companies. This is done by first identifying some characteristic of maintenance in this industry. Subsequently, the framework is adapted.

7.2.1 Maintenance in the oil and gas industry

Maintenance is critical to companies engaged in oil and gas production, both to manage risk, reduce costs, increase availability, and increase productivity (Eyoh & Kalawsky, 2018).

Regarding risk, there are several examples of cases where faulty maintenance has contributed to catastrophic incidents in the industry, e.g., the famous Deepwater Horizon incident that claimed 11 lives and resulted in one of the largest oil spills in history (Norwegian Oil Industry Association et al., 2012). Incidents such as this have resulted in strict safety regulations, as exemplified by the European Union imposing Directive 2013/30/EU, which resulted in strict requirements to offshore oil and gas assets in response to the Deepwater Horizon incident (DNV GL, n.d.).

Knowing that efficient maintenance is essential to the oil and gas industry, what characterises the maintenance of this industry? First of all, it is a capital-intensive industry, meaning that large investments into fixed assets are typically required in order to engage in the production of oil and gas (Maverick, 2018). Not only does this result in a large number of assets in need of maintenance, but it does also result in a large number of spare parts and manufacturers of assets (Aoudia et al., 2008). This increases maintenance complexity, as the number of companies in the maintenance process increases, e.g., due to the original manufacturers having to perform the maintenance. Maintenance complexity is further complicated by the fact that assets are typically highly expensive, meaning that servicing is important, while a high asset complexity means that specialists are required to actually perform the maintenance (Christiansen, 2020).

Besides the large complexity and risks associated with maintenance in the oil and gas industry, high operating costs means that it is essential to a firm's profitability to increase availability (Eyoh & Kalawsky, 2018). For example, Aoudia et al. (2008) studied the economic impact of maintenance inefficiency in the facility of a larger oil and gas company and found that it resulted in large financial losses. This may explain why oil and gas companies are characterised by advanced maintenance technologies, such as predictive maintenance (GlobalData Thematic Research, 2019).

Ultimately, it may be summarized that for the oil and gas industry, it is essential for maintenance management to safeguard against human errors, ensure that staff have the correct training for their work tasks, documenting safe procedures, monitoring assets condition, controlling risk and compliance with safety regulations, managing the large complexity of maintenance planning and execution, and still ensuring the highest possible availability as efficiently as possible.

7.2.2 Adapting the framework

In this subchapter, the generic MMF designed in Chapter 6 is adapted to reflect the maintenance conducted in oil and gas companies.

The first step towards doing so is to make sure that the framework explains several types of maintenance. For less capital-intensive industries, it would likely be sufficient to limit the forms of maintenance to preventive and corrective maintenance. However, as seen above, the oil and gas industry typically employs innovative preventive maintenance technologies. Additionally, they conduct much maintenance, where minimizing risk is essential. Thus, while it is done at the expense of increased complexity, it was considered useful to explain more in-depth how the various elements of maintenance are seen in the MMF.

For tactical and strategic maintenance, it is essential to integrate the higher priorities of maintenance management in the oil and gas industry. This includes compliance with strict safety and environmental regulations, while still achieving customer satisfaction by having as high equipment availability as possible. Besides this, the same top-down approach is used to define maintenance objectives and requirements, which in turn are used on the operational level to define best-practice standards for different tasks in the maintenance value-chain. After this, besides the assessment made by staff on the operational level of whether they are complying with standards, the aggregated and historical data generated on the operational level will be analysed to assess whether work is performed so that maintenance objectives and requirements are met and if there are any possible improvements.

In a real setting, Karabin could have adapted the framework further, e.g., by altering the names of the various elements in the framework to reflect trivial names used by their customer. However, as this is not the case, the same terms as in the generic framework are used.

The outcome of this adaptation is seen in Figure 30 on the next page. Note that the conceptual models and the flowchart to explain the framework has not been altered and are therefore not included here.

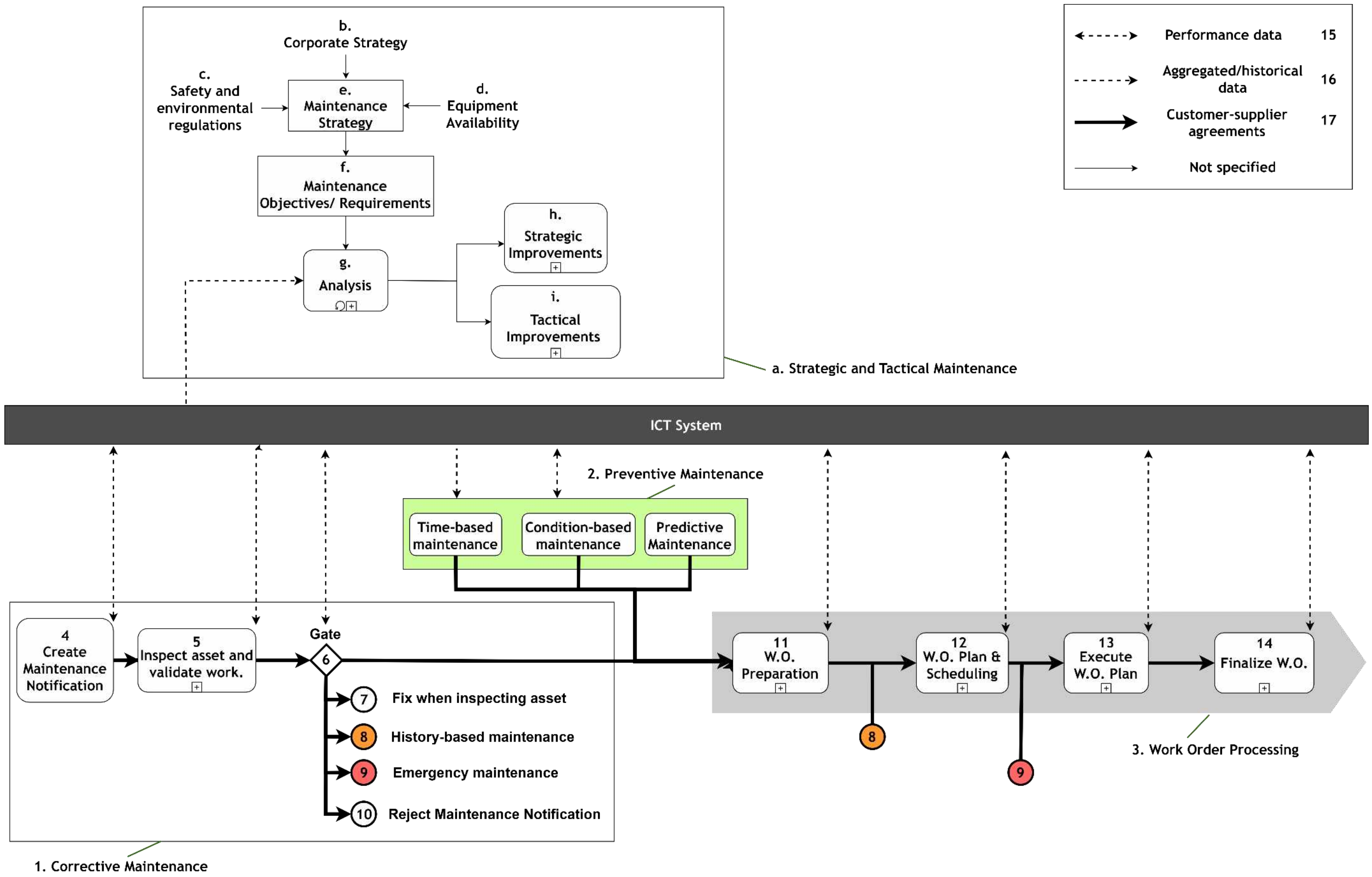

Figure 30: The MMF adapted to suit the oil and gas industry. Visualisation by author.

Table 22: Contents of the MMF adapted to suit the oil and gas industry.

#	Concept	Description
0	The Maintenance Process	The maintenance process describes the activities required to process a work order from it is created until it is finalized. This process is covered by concept [1] - [3]. This sequence of tasks utilizes best-practice standards, customer-supplier agreements, standardised task sequence, and performance measurements on time and quality to identify wastes in the maintenance process, to achieve continuous improvements in the maintenance process by increasing flow. The maintenance process can be considered as an imaginary assembly line, with predetermined procedures, staff responsible, etc. But instead of a physical item such as a car flowing on the assembly line, it is a work order being processed.
1	Corrective maintenance work orders	There are two potential sources of work orders, one being corrective maintenance. The unit of flow inside this box is maintenance notifications, not work orders. A notification is simply an alert submitted to say that an asset may be in need of maintenance. Qualified personnel then assess the validity of the notification, before deciding what to do with the notification, e.g., to create a work order. Inside this box, flow is not a priority. Here, the focus is on selecting work orders that generate value and eliminate those that do not.
2	Preventive maintenance work orders	Preventive maintenance is the second work order source. This type of maintenance may be based on, for example, time-based intervals, condition monitoring, or predictive maintenance. Once a criterion for the creation of a work order is met, e.g. if a time interval is met, a work order is created, and it enters the maintenance value-chain.
3	W.O. Processing	The four sub-processes within this grey arrow describes the four main sub-processes required to process a work order. For these sub-processes, flow is emphasised. That means that once a work order is created, it should be processed as quickly and efficiently as possible. The main idea behind this framework is that benefits are realised by avoiding unnecessary stops and preventing bottlenecks while processing work orders. This is done by measuring the performance of each task performed against the best-practice standard specifying objectives to time and quality. Note that time is tracked automatically as the work order flows between sub-processes, while quality-related measures are entered manually by those responsible. The measurements of time allow companies to identify possible efficiency-improving actions while leading quality-objectives ensure that quality maintenance is achieved.
4	Maintenance Notification	When staff observes an asset in need of maintenance, a maintenance notification is created. This notification is the unit of flow until concept [6].
5	Subprocess 1: Inspect and validate work	A maintenance notification may be created by anyone, even staff without knowledge of the asset in question. Subprocess 1 do, therefore, hold that competent staff should inspect and validate

		whether the maintenance notification is valid. This is based on the logic that a car mechanic does not simply change a gearbox when a customer points to the gearbox making weird sounds. It may simply be a bearing. This is done to increase the quality of input into the work order processing sequence.
6	Gate	After inspecting and validating corrective maintenance notifications in Subprocess 1, a decision is made about what to do with the notification. There are five different options. The “standard” option is that a work order is created. From here on, until concept [14], work orders are the unit of flow in the maintenance process.
7	Simplified maintenance	Simplified maintenance: The inspector simply fixes the asset while inspecting it.
8	History-based maintenance	History-based maintenance: Assets may also require maintenance after experiencing a previously experienced failure mode. In this case, the work order preparation from the last time may be used to process the work order, so it is sent straight to the plan and scheduling sub-process.
9	Emergency maintenance	Occasionally, assets critical to an organization may break down. In this case, the asset should not follow the “standard” W.O. sequence, as it should be prioritized over the other W.O.
10	Reject maintenance notification	The person inspecting the asset may see that the notification is unnecessary. In that case, the maintenance notification should be rejected. A key element of the framework is that the number of maintenance notifications should be strategically reduced by having qualified personnel determine what maintenance to do. By setting, for example, a goal of rejecting 20% of maintenance notifications, benefits are realised both due to savings from doing less non-value-adding maintenance, in addition to being able to focus on maintenance that actually results in value. Note that this assumes that the implementing company’s current maintenance practices processes at least 20% of non-value-adding corrective work orders, i.e., reducing the number by 20% will not affect the plant’s integrity but realise benefits. Note also that this rejection rate is measured by the ICT system.
11	Subprocess 2: W.O preparation	During this sub-process, the person/group responsible starts preparing for the executing of the work order. The input to this process is a description of what caused the work order, and the urgency of fixing it. The work order is sent to the person/group responsible for the asset. Note that if maintenance on the asset in question is outsourced, the work order is sent to this company. Examples of preparatory activities are an inspection of the work location, acquisition of required materials, and risk assessments.
12	Subprocess 3:	During the third sub-process, the responsible group schedules the work according to the priority, estimates the required time, and gain approval of the W.O. plan.

	W.O. Plan and Scheduling	
13	Subprocess 4: Execute W.O. Plan	During the fourth subprocess, the work planned is executed by the responsible person/group.
14	Subprocess 5: Finalize W.O.	To finalize a work order, assets are put back into operation and reports are submitted into the ICT system about the work done.
15	Performance data	For each sub-process/task in the maintenance value-chain, performance is measured by comparing the work done by comparing it to the best-practice standard.
16	Aggregated/ historical data	Aggregated and historical data is used to identify anomalies and performance gaps, in addition to ensuring that the maintenance process functions as intended.
17	Customer-supplier agreements	Customer Supplier Agreements standardise deliveries between sub-processes in the maintenance value-chain. In other words, when a sub-process is completed, there is a predetermined recipient and way to send the work performed to the next sub-process.
a.	Strategic and tactical maintenance	There are many requirements to companies maintenance processes. This box describes how these requirements are operationalised through maintenance objectives and requirements, and how data generated on the operational level of the company is aggregated and used to control and ensure whether the maintenance process achieves these goals. Additionally, concepts [h] and [i] provide two examples of strategic and tactical improvement efforts. Note that it is on the operational level that work orders are processed, i.e., under the concepts covered by concepts [1], [2], and [3].
b. c. d. e.	Determining the maintenance strategy	A maintenance process must satisfy various criteria. For example, it plays a large part in organizations reaching their corporate objectives by ensuring equipment availability and compliance with safety and environmental regulations. A company defines a maintenance strategy for how to reach these goals.
f.	Defining maintenance objectives and requirements	After determining the maintenance strategy, specific maintenance objectives and requirements are defined. These objectives/requirements are used to check whether the maintenance process satisfies the various criteria that the maintenance process needs to satisfy. Note that, as described in the flowchart, these objectives/requirements are also used on the operational level to define standards for each task that is used to measure the operational performance. This is not illustrated in the framework.
g.	Analysis	In [g], the company compares aggregated and historical performance data to assess whether the maintenance process is reaching the maintenance objectives/requirements defined, based on data generated on the operational level. Measures here may be the: • number of reworks per month, • critical assets downtime, • rate between preventive and corrective maintenance

		Also, besides assessing the state of the maintenance process, data is analysed to look for improvements not covered by the continuous improvements in the maintenance value-chain. Once an anomaly/ performance gap/ potential improvement is identified, the person or group responsible is notified and makes the improvement necessary.
h. i.	Strategic or Tactical Improvements	Depending on the type and amount of data analysed in the previous step, improvements may be strategic or tactical. Strategic improvements affect the conditions the maintenance happens under. Tactical improvements affect the day-to-day maintenance, such as optimizing the preventive maintenance schedule based on aggregated data.

7.3 Evaluation interviews

The procedure used to collect qualitative data for the evaluation was covered in Chapter 2.3.2. This subchapter reiterates this chapter's main points, as summarized in Table 24, and introduces the interviewed subjects. Note that the interview protocol used is seen in Appendix F and the interview summaries are found in Appendix G. For an overview of how the collected data was processed, see Chapter 2.3.3.

Table 24: Overview of the evaluation interviews.

Interview Set 2		
Purpose	Answer [RQ7] to evaluate the designed MMF's efficacy.	
Interview Length	45-50 min	
Sampling Technique	Opportunity sampling	
Subjects	Three senior managers from the oil and gas industry	
Data type	Qualitative	
Data analysis	Inductive	
Interview Procedure		
Introduction	Introduce the purpose of the interview. Establish ground rules.	5 min
Presentation	Present the designed MMF.	20 min
Interview	Interview to assess the framework's efficacy.	20 min
Conclusion	Conclude interview.	1 min

7.3.1 Interview subjects

Three senior managers from the oil and gas industry with decision-making power has been interviewed.

Subject 1 is the technical superintendent of an oil platform. He is responsible for all the maintenance on this platform, and that it satisfies the various requirements related to integrity and maintenance performance. He is the focal point of all technical project activities on the platform.

Subject 2 has previously been the technical superintendent of one of the world's largest oil and gas companies' fleet of oil platforms. Currently, he is the technical superintendent of the same company's fleet of oil platforms on the Norwegian Continental shelf. Here he is responsible for all technical operations such as maintenance, e.g., for mechanical and electrical assets. He has previous experience from several improvement projects related to maintenance.

Subject 3 has almost 20 years' worth of maintenance and maintenance management experience from the oil and gas industry. He is currently working as a technical superintendent for a smaller oil and gas company but has previously held the same position for larger firms. He has some experience with BPM.

7.3.2 Interview procedure

Each interview started with an introduction. Here, the interview's purpose was communicated, and the ground rules were established, i.e., anonymity was guaranteed, and it was asked for permission to record and publish the results of the interviews. Once permission had been given, the recording function of the software used was activated. Then, the subject was asked questions related to his/her background. Thereafter, the adapted version of the MMF from Chapter 7.2, and the conceptual models and flowchart from Chapter 6 was presented.

After the presentation concluded, the questioning started. While the subjects were asked whether they wanted a break, to avoid fatigue biasing their answers, this option was turned down by each subject. The questions asked were distributed in three categories, namely the framework's transferability, complexity, and compatibility. Recall that the interviews had to assess whether the constructed MMF could help Karabin solve their knowledge-based diffusion barrier. Also recall that The Maintenance Wheel, and therefore also the designed MMF, will be perceived by Karabin's customers as an innovation. This resulted in the review of diffusion research in Chapter 3.1, where different attributes of an innovation affecting diffusion were identified. Transferability, complexity, and compatibility were in Chapter 5.1 identified as the attributes of an innovation key to solve this problem.

In Chapter 3, it was explained that transferability is an attribute of an innovation, concerned with whether it is possible to communicate how the innovation works to potential adopters (Greenhalgh et al., 2007). It was also explained that complexity has to do with the difficulty of using and understanding an innovation (Rogers, 2003). Last, it was explained that compatibility refers to whether the managers assessing the framework potential adopter believes the innovation aligns with their values, experiences, and needs (Rogers, 2003). These attributes affect an innovations ability to diffuse. While other factors of an innovation affect diffusion, these three are directly connected to how The Maintenance Wheel is communicated, as explained in Chapter 5.1. Ultimately, by assessing these three categories, the framework's ability to sufficiently transfer knowledge on how The Maintenance Wheel work is answered.

Last, after the interviews were finished, each subject was thanked for participating and asked whether he/she had any questions. Each manager was also asked whether he/she wanted a copy of the master thesis.

7.4 Evaluating efficacy and suggestions for improvements

In the following subchapter, the designed MMF is evaluated. This answers [RQ7]:

- **[RQ7] Can the constructed MMF help Karabin overcome the knowledge-based diffusion barrier of The Maintenance Wheel?**

[RQ7] is answered by assessing the framework's transferability, complexity, and compatibility, which are attributes relevant to overcome such a knowledge-based diffusion barrier, as explained in Chapter 5.1. While these attributes are closely interlinked and do overlap somewhat, they are discussed separately for clarity.

7.4.1 Transferability

After presenting the framework, each manager was asked whether they had understood it, which they all confirmed. To validate this, each subject was asked to explain different parts of the framework in their own words. Given that they had only had a brief introduction to the framework, and limited experienced with BPM, the results were highly positive. The managers understood the framework presented to them well, and it was possible to have an in-depth discussion on how the framework worked.

However, one particular area of improvement was identified. Each manager requested more information to determine how the framework works in practice, which was expected. An MMF is theoretical, so it was expected to be difficult for the managers to obtain a complete picture of how the framework works in practice. Resultingly, it is a suggestion for future research to develop examples for the framework, to highlight how it works in practice. Karabin should have easy access to such examples from Equinor.

7.4.2 Complexity

After presenting the framework to the managers, they were all asked to judge the complexity of the framework. This was done by asking questions related to whether the relationships between the different elements of the framework was clear, and if it was easy to understand the framework. They all stated that the framework was easy to understand and follow. While it was difficult to test this, the fact that they were able to understand the framework validates their answers.

7.4.3 Compatibility

Last, each manager was asked whether they perceived the framework as practically relevant and if they thought it could be of value in their company. These questions tap into whether the framework has used terminology and concepts which are recognisable to the senior managers. The managers said that they recognised the terms used and the activities in the framework, albeit they used slightly different terminologies for different elements such as "maintenance notifications". But this should not be a problem for Karabin in a real pitch, given that they analyse the customer's process prior to presenting in, i.e., they can adapt the framework to reflect their customer's terminology. Effectively, the interviewed senior managers were able to recognize the different elements of the framework.

Each manager was also asked whether they thought it could be of value in their company, which they all answered yes to. As stated by Subject 1: "It is a smarter system, and we have to have as smart systems as possible" (see Appendix G). Nevertheless, despite the managers exerting a large interest in the framework, there was one particular concern, which is useful for Karabin to consider in their further pitches, which was out of this thesis scope. Both Subject 1 and 3 had concerns related to how the operational staff would feel about having their performance measured in detail. As seen in Chapter 4.2, facilitating the correct organizational environment where staff see the performance measures as a tool, and not a burden is indeed a critical barrier to the implementation of The Maintenance Wheel. However, as explained in Chapter 4.2.7, Equinor experienced an increase in employee satisfaction post-implementation of The Maintenance Wheel.

7.5 Conclusion

This chapter describes the fourth stage of the design process, namely, the evaluation stage. This was done to answer [RQ7]: "Can the constructed MMF help Karabin overcome the knowledge-based diffusion barrier of The Maintenance Wheel?"

When explaining the evaluation procedure in Chapter 7.1, it was explained that the framework is evaluated on efficacy and that the evaluation was summative. This means that it was assessed whether the framework achieved the research objective, and the results of the evaluation were not fed back into the design process. Furthermore, a naturalistic test, using real people, was used seeing that the constructed MMF is a socio-technical artefact which requires human interaction to prove its value (Venable et al., 2012). The specific evaluation method used is an illustrative scenario, seeing that it was not possible to evaluate the MMF in its intended setting, i.e., Karabin's benefits realisation process.

To evaluate the MMF, it first had to be applied in a suitable context. The selected "context" was senior managers from the oil and gas industry. Karabin has struggled to communicate the framework to senior managers, and the oil and gas industry makes up a large part of Karabin's customer base. Furthermore, the oil and gas industry is a capital intensive company with much to gain from efficiently managing maintenance (Maverick, 2018). Resultingly, evaluating in the oil and gas industry will both provide Karabin with a relevant indication of the designed MMF's efficacy, while the access to senior managers both interested in and with the required competence to evaluate the framework should be high. Thus, Chapter 7.2 first adapts the framework constructed in Chapter 6 to this context. Note that the reason for why this was necessary is discussed in Chapter 7.1.

After adapting the framework to reflect maintenance in the oil and gas industry, Chapter 7.3 explains how a semi-structured interview protocol was used to evaluate its efficacy. Here, three senior managers from three different firms with no prior knowledge of The Maintenance Wheel was first presented the constructed MMF, before asking them questions to evaluate the framework's transferability, complexity, and compatibility.

Ultimately, after processing the qualitative data, the framework's efficacy was evaluated in Chapter 7.4, thus answering [RQ7]: "Can the constructed MMF help Karabin overcome the knowledge-based diffusion barrier of The Maintenance Wheel?" The evaluation was highly positive. After a brief presentation, it was possible to have an in-depth discussion on The Maintenance Wheel, and the complexity judged to be low. However, one main suggestion for further improvements was identified: to provide more practical examples of how the different concepts of the MMF work.

"Wisdom.... comes not from age, but from education and learning."

Anton Chekhov

8. CONCLUSION AND DISCUSSION

This chapter concludes the thesis. Chapter 8.1 summarises the main findings of the thesis project and concludes on whether the designed MMF sufficiently achieved the thesis project's research objective. Thereafter, both the managerial and academic contributions of the thesis are discussed in Chapter 8.2. Third, Chapter 8.3 discusses prominent limitations of the thesis project. Fourth, a reflection on the research' quality is provided in Chapter 8.4 discussing the validity, reliability, and researcher independence. Fifth, Chapter 8.5 discusses the link of the master thesis project to the master programme it was written as a part of, "Management of Technology". Last, recommendations for future research and for Karabin are given in Chapter 8.6.

8.1 Main findings

In the following subchapter, the main findings of the thesis are summarised by answering the research subquestions defined in Chapter 2.2. The distribution of them over the design process is seen in Table 25. Note that it is concluded on whether the research objective defined in Chapter 1.4.1 has been achieved when answering the last subquestion, [RQ7].

Table 25: Research subquestions.

Design Stage	RQ #	Research Subquestions
Gathering Information	1	Which attributes of an organizational innovation can be influenced to solve a knowledge-based diffusion barrier?
	2	Why is there a gap between academic attempts to optimize maintenance and the application of these solutions in real-world organizations?
	3	What functions or elements should be in an MMF, and do the reviewed MFFs experience the same deficiencies identified in [RQ2]?
	4	What are the main elements of The Maintenance Wheel, and how do they combine to realize benefits?
Design Framework	5	What requirements does the MMF have to satisfy to provide a satisfactory solution, considering the research objective and gathered information?

	6	What does a satisfactory MMF from the design space look like?
Framework Evaluation	7	Can the constructed MMF help Karabin overcome the knowledge-based diffusion barrier of The Maintenance Wheel?

- **[RQ1]: Which attributes of an organizational innovation can be influenced to solve a knowledge-based diffusion barrier?**

Recall that The Maintenance Wheel, and thus also the designed MMF which communicates how it works, is perceived by Karabin's customers as an organizational innovation (see Chapter 1.3). Given this, [RQ1] provided insights on which attributes of an innovation that would affect the designed MMF's ability to overcome Karabin's knowledge-based diffusion problem, narrowing down on a set of relevant attributes.

The information required to answer this question was gathered in the conceptual review of the literature on the diffusion of innovations in Chapter 3.1. However, it was first discussed which of these attributes that could be integrated into the design in Chapter 5.1, when formulating design objectives. The findings are summarized in Table 26 on page 133.

A total of ten attributes influencing diffusion were identified in Chapter 3.1. First, Rogers (2003) identified six attributes, namely an innovation's relative advantage, compatibility, complexity, trialability, observability, and reinvention. Besides the characteristics identified by Rogers (2003), Greenhalgh et al. (2007) conducted a systematic review of diffusion research literature and identified four additional attributes with significant empirical evidence: task relevance and usefulness, implementation complexity, risk, and transferability. All of these are briefly explained in Table 26.

While each of the identified attributes generally affects an innovation's ability to diffuse, the relative importance of the various attributes depending on the context. This relative importance was assessed in a study by Vagnani and Volpe (2017). They found that for innovations not targeted at specific companies or where the adopter's characteristics were not known, such as in this thesis, particularly the relative advantage over available alternatives, compatibility, ease-of-use and understanding (complexity and transferability), and observability was important.

However, it was not a goal of the design process to affect how The Maintenance Wheel works in practice. This excluded a set of attributes. The focus was solely on attributes that could be directly affected by changing how The Maintenance Wheel was communicated to overcome the knowledge-based diffusion barrier. Ultimately, this meant that the attributes of transferability, complexity, and compatibility were focused on. Each of these attributes was also found to be particularly important by Vagnani and Volpe (2017). Below, these attributes and how they were integrated into the design process is discussed:

- Transferability refers to whether it is possible to communicate how an innovation works, both regarding aspects related to the innovation in-use and the innovation's underlying principles (Greenhalgh et al., 2007). In effect, it was essential to design an MMF effectively communicating how The Maintenance Wheel worked to overcome the knowledge-based diffusion barrier. To do so, Chapter 6.2 explains how the MMF is based on reductionism, seeing that this approach to explanation is well suited to explain how a complex system such as The Maintenance Wheel works (Nagel, 1998).

- Complexity refers to how difficult an invention is to use and understand (Rogers, 2003). Rogers describes that if an invention is difficult to use or understand, potential adopters are less likely to adopt it as it requires them to learn. Because of this, much was invested in illustrating the framework as easily and intuitively as possible. Nevertheless, a complex relationship between the desire to increase the transferability (informativity) of The Maintenance Wheel while also minimizing complexity was formed. Reductionism was key to balancing these two attributes.

- Compatibility refers to whether a potential company considering implementing an innovation believes the innovation aligns with its values, experiences, and needs (Rogers, 2003). In effect, compatibility refers to whether senior managers perceive the framework presented to them as relevant. While designing to achieve compatibility was complicated by the fact that Karabin required a generic framework, an effort was made to illustrate how it could be adapted to a specific context in Chapter 7.

Table 26: The innovation attributes, their relative importance, and whether they are improvable within the design scope.

Innovation Attribute	Description	Relative Importance	Improvable
Relative Advantage	The perceived advantage of one innovation, in comparison to its alternatives.	+	-
Complexity	The difficulty of using and understanding an innovation.	+	+
Compatibility	If a potential adopter believes the innovation aligns with its values, experiences, and needs.	+	+
Trialability	Whether potential adopters may experiment and try out an innovation before adopting it.	-	-
Observability	Whether the benefits of a given innovation is visible to others.	+	-
Reinvention	Whether potential adopters may adapt the innovation to suit their own business context.	-	-
Task Relevance and Usefulness	If the innovation is relevant and will help increase the performance of tasks in the organization.	-	-
Implementation Complexity	The more complex an innovation is to implement, the less likely it is that organizations will adopt it.	-	-
Risk	The higher the uncertainty and undesired consequences associated with the implementation of an innovation, the less likely is adoption.	-	-
Transferability	Whether it is possible to communicate how the innovation works, both in-use and the underlying principles, to potential adopters.	+	+

- **[RQ2]: Why is there a gap between academic attempts to optimize maintenance and the application of these solutions in real-world organizations?**

This subquestion was formulated to investigate why there is a gap between academic attempts to optimize maintenance and their adoption by real-world organizations, as explained in Chapter 1.1, seeing that simply designing an MMF might not be enough to overcome Karabin's diffusion problem.

In Chapter 3.2.3, three studies were found in which it was assessed why academic solutions to maintenance issues generally fail to be spread to real-world organizations. The first study, by Dekker (1996), points to (1) academic attempts to optimize maintenance generally being difficult to understand and interpret for practitioners, (2) most solutions tend to focus only on mathematical optimization and not real practical problems, (3) companies with successful approaches to managing maintenance are not interested in their practices being publicised, (4) maintenance is a very broad concept affected by many aspects meaning there is no automatic reason that a framework working in one context is applicable to another, and (5) older attempts to optimize maintenance relies on maintenance techniques which have fallen out of favour (pp. 235–236). The second study, by Van Horenbeek et al. (2010), points to similar reasons, stating that the solutions fail to recognize and discuss how they will be applied in practice. The last study examined, by Fraser et al. (2015), points to two main reasons: a lack of empirical proof from real-world applications and a lack of practical focus.

Overall, the studies point to the same class of issues. Solutions developed in academia to optimize maintenance generally fails to provide the practical relevance to convince organizations to implement them. This is interesting, given the backdrop of the MMF designed in this thesis. By developing an MMF based on The Maintenance Wheel, which has proven benefits from a real-world organization, the designed MMF should have an advantage in convincing senior managers.

- **[RQ3]: What functions or elements should be in an MMF, and do the reviewed MFFs experience the same deficiencies identified in [RQ2]?**

Having answered [RQ1] and [RQ2], the considerations necessary to overcome the knowledge-based diffusion barrier standpoint had been identified. [RQ3] is the first of two subquestions researching how to indeed construct the MMF itself, to communicate how The Maintenance Wheel works. Answering this subquestion identified how to construct a generic MMF, i.e., a theoretical framework of an approach to maintenance management. Furthermore, it investigated what elements to avoid, considering the gap between academic solutions to maintenance issues investigated in [RQ2].

The literature review in Chapter 3.2 found and analysed nine MMFs. It found that there is no standardised style or specification of what elements to include in an MMF. For example, Campbell and Reyes-Picknell (2015) and Wireman (2005) present abstract frameworks and rely on in-depth textual explanations. On the other hand, Hassanain et al. (2003) and Campos and Crespo Márquez (2011) describe in-depth, descriptive maintenance processes with detailed task-sequences and information flows. The five remaining frameworks lay somewhere in between these two examples.

Despite the different MMF styles, a list of reoccurring elements was identified, as explained in Chapter 3.2.14. This list helped identify what aspects of maintenance management to focus on while creating the MMF. These elements include strategic maintenance activities, the control function (e.g. performance measurements), maintenance planning, maintenance execution, and some form of way to continuously improve. Furthermore, the relationship between all of these elements needed to be explicit. However, note that the latter characteristic stems from the literature review focusing on process-oriented MMFs, as defined by Campos and Crespo Márquez (2009). The other MMF type identified by Campos and Crespo Márquez (2009), declarative frameworks, do not make interrelationships between concepts explicit. As The Maintenance Wheel is based on BPM, it would be necessary to link its different concepts together when ultimately designing the MMF. Thus explicit interconnections between a framework's concepts was a selection criterion while identifying MMFs for the review.

The review also found that the MMFs suffer from the same type of deficiencies which cause a gap between academic solutions to maintenance issues, as discussed in [RQ1]. By answering the [RQ1], it was found that solutions developed in academia to optimize maintenance generally fails to provide the practical relevance to convince organizations to implement them. For the reviewed MMFs, the lack of demonstrations or empirical evidence from real-life applications is concerning. Only Pramod et al. (2006) provides empirical evidence that their framework works in practice. Söderholm et al. (2007) provide a demonstration of how their generic framework may be utilised in a paper mill, but they provide no empirical evidence that it works in practice.

- **[RQ4]: What are the main elements of The Maintenance Wheel, and how do they combine to realize benefits?**

By answering [RQ3], it was researched how to construct a theoretical framework to communicate an approach to maintenance management, i.e., an MMF. By answering [RQ4], it was effectively identified what approach that such an MMF had to communicate.

Unfortunately, little had been written about The Maintenance Wheel prior to this thesis, meaning that desk research of existing documents would not be sufficient to answer [RQ4]. Resultingly, an in-depth analysis of The Maintenance Wheel was required. For this, Chapter 4.1 explains how five semi-structured interviews with three key experts on The Maintenance Wheel were conducted. Additionally, desk research of the internal documents of Equinor and Karabin provided additional information. But, the use of desk research was restricted as these documents were not given permission to be included in full as appendixes.

Processing the gathered information to answer [RQ4] was highly challenging. The Maintenance Wheel is based on concepts from the literature, while the knowledge on how to combine these concepts comes from the Equinor. Effectively, a complex iteration between the review of knowledge bases in Chapter 3 and the information was required to analyse The Maintenance Wheel. The result of the analysis is the in-depth description of The Maintenance Wheel found in Chapter 4.2. Below, a brief summary of its contents is given, albeit it is recommended to read Chapter 4.2 for a complete overview. Alternatively, see the constructed MMF in Chapter 6 to get a more intuitive explanation based on visualisations.

The Maintenance Wheel is a maintenance management approach based on BPM and performance management that covers both corrective and predictive maintenance. In simple terms, it provides a way to standardise an organization's maintenance process, spanned by the tasks from once a maintenance notification is created, until a work order has been processed. It also provides a simple way to generate actionable data to manage this process as an actual process, in particular for the operational level. However, through the aggregation of the operational process performance data, data is also made available for the tactical and strategic organizational level. The ultimate goal of the management approach is to maximize the flow in the work order processing to realise benefits, while also ensuring the correct work quality.

There are four main elements to ensure this is: (1) the standardisation of tasks in the maintenance process through best-practice standards, (2) the standardisation of task sequences by the flow of a work order, (3) the standardisation of interfaces between sub-processes in the overarching maintenance process through customer-supplier agreements, and (4) continuous improvements based on performance management.

The first three elements describe how to standardise the maintenance process. By standardising the maintenance process with best-practice standards, the best way to execute each task is codified. In these best-practice standards, there are also performance metrics for the expected quality and estimated time when following this best practice. Note that quality may be very simple aspects such as having the right person filling out the right scheme, i.e., leading performance indicators. Thus, when measuring the actual performance of each task by tracking the time it takes for a work order to be processed (by simply using the ICT system) and having staff submitting the actual quality performance into the organization's ICT system, performance gaps are easily identified. Note that this performance is measured for each single work order that is processed. By tracking the time it takes for each work order to be sent between the various tasks in the maintenance process, and comparing these against the time objectives specified in the standards, it is possible for the organization to easily identify areas of improvement from an efficiency standpoint. For example, if a task systematically takes longer than expected, this is easily identifiable from the performance analyses. Regarding the quality objectives, these safeguard the quality of the work being done, and as each task of the maintenance process is completed, those who completed that tasks need to enter the quality measures manually into the ICT system. Resultingly, it is also easy to identify gaps in the quality of the work being performed by comparing the actual quality against the quality objectives.

However, besides the standardisation of the maintenance process to achieve regularity and higher quality of work, continuous improvements are also essential. First, they may be realised by closing the performance gaps identified in the previous paragraph. Second, whenever new best-practices are identified, the constructed MMF provides a simple way to ensuring that all staff follow the same best practice by codifying the new best-practice and using the updated performance metrics to ensure that staff complies with it. In effect, the constructed MMF shows how to effectively organize and manage human efforts using technologies.

- **[RQ5]: What requirements does the MMF have to satisfy to provide a satisfactory solution, considering the research objective, scope, and gathered information?**

This question was answered in Chapter 5. After answering [RQ1]-[RQ4], both knowledge of the problem and how to solve it had been gathered. Consequently, the third stage of the research process could be initiated, i.e., the design stage itself. The third stage was made up of two sequential steps, where answering [RQ5] to identify design requirements was the first step.

Design requirements specify the outer boundaries of what a satisfactory design has to do to reach a research objective. The requirements identified in Chapter 5 were based on the information gathered in the second stage of the design process, i.e., in Chapter 3 and 4. Recall that Chapter 3 identified how to design an MMF, how to solve the diffusion problem of Karabin, and provided the theoretical foundation to analyse The Maintenance Wheel. Also recall that Chapter 4 identified how The Maintenance Wheel worked, i.e., what the MMF has to communicate.

The design requirements were identified in Chapter 5.2. The categories of requirements identified were based on Verschuren and Doorewaard (2010), who propose three types of requirements for design-oriented research projects: functional, contextual, and user requirements. However, seeing that reality of the design project resulted in the line between contextual and user requirements being blurred, these requirements were simply combined under the name "contextual requirements". Seeing that the rationale of the different requirements is discussed, this should not affect the thesis' procedural transparency significantly. Functional requirements describe what the designed framework should do. Contextual requirements are requirements to design based on the environment that the framework will be used in. In total, 17 functional requirements and three contextual requirements were defined.

Overarchingly, the design requirements specify how to construct an MMF, based on The Maintenance Wheel, which could overcome the knowledge-based diffusion barrier. Additionally, requirements ensuring that the designed MMF aligned with Karabin's benefits specialization process were identified (see the thesis' scope in Chapter 1.5).

- **[RQ6]: What does a satisfactory MMF from the design space look like?**

By answering this question, the last of two steps in Stage 3 of the design process was completed. After answering [RQ5], the external boundaries of a satisfactory MMF was defined. In effect, [RQ6] could be answered. However, moving from these requirements to a satisfactory design was not straightforward, due to the complex nature of the design required. Ultimately, a design technique called a "morphological chart" was applied to help answer [RQ6] (Dym et al., 2014).

According to Dym et al. (2014), the first step towards producing a final design is to establish the design space. The design space is an imaginary intellectual region of design alternatives that contains all of the potential solutions to the design problem at hand, based on the design requirements (Dym et al., 2014, p. 92). A morphological chart is a design technique that provides a formal procedure to establish the design space. Resultingly, Chapter 6.1 took the design requirements defined in Chapter 5.2 as inputs and used a morphological chart to convert them into the design space. This is done through a matrix listing the design requirements on the vertical axis before the author came up with different propositions for how to realise each of these requirements on the horizontal axis (Dym et al., 2014).

After establishing the design space, Chapter 6.2 created the final design, thus answering [RQ6]: "What does a satisfactory MMF from the design space look like?" This was done by selecting from the various propositions in the morphological chart, and then synthesizing them.

To create a satisfactory MMF, which satisfied the design requirements, reductionism was used. This is the idea that any complex phenomena may be explained by reducing it into simpler parts (Nagel, 1998). In other words, the most important dynamics of the larger framework is explained by first describing its underlying components. The opposite approach, holism, would be to see the framework as a whole not possible to reduce due to synergies between parts (Østreng, 2007). The reason for applying reductionism on the designed MMF is that it had to be understandable for senior managers even with limited BPM knowledge. Resultingly, it was necessary to be as pedagogic as possible. Resultingly, two simpler conceptual models and a flowchart were made first, with explanations, to communicate how the framework work conceptually. Thereafter, the framework itself was presented.

The first two conceptual models focused on how the framework worked on the lowest possible level. The flowchart was made to illustrate the measurement, analysis, and improvement activities of the to-be-designed framework. Initially, this flowchart was not included, but it was considered purposeful to include it as the jump from the conceptual models to the designed framework was perceived to be too large. The flowchart is based on Campos and Crespo Márquez (2011, p. 814) MMF framework, who uses a similar top-down approach to identify maintenance objectives and a similar down-up aggregation of data for controlling the maintenance process as that used in The Maintenance Wheel (see Appendix D). This flowchart is seen on page 108, in Figure 26.

The framework itself is displayed on page 110 in Figure 27, with an explanation of its contents on the subsequent pages. Designing this was a challenge since it was necessary to strike a balance between information richness and minimal complexity due to the design objectives in Chapter 5.1. Ultimately, it was prioritized to make the framework simpler and rather describe in-depth how the framework works. This is based on Karabin having to adapt the framework to different business contexts. By rather aggregating activities under larger sub-processes such as "make improvements", Karabin can alter the description of these sub-processes to describe activities relevant to their customers business contexts while pitching it. This is shown in Chapter 7, where the framework is adapted to suit the oil and gas industry.

- **[RQ7] Can the constructed MMF help Karabin overcome the knowledge-based diffusion barrier of The Maintenance Wheel?**

By answering [RQ6] in Chapter 6, an MMF was constructed, completing the thesis project's design stage. Subsequently, the last stage of the thesis project's design process was initiated in Chapter 7, namely, the framework evaluation. This evaluation was a summative test of the designed MMF's efficacy, which was performed by answering [RQ7]. Effectively, the last research subquestion concludes on whether the designed MMF was able to reach its research objective, to *design an MMF aimed at supporting Karabin in communicating how The Maintenance Wheel works to help cope with the knowledge-based diffusion barrier.* Recall how Chapter 1.3 explained that this knowledge-based diffusion barrier was caused by Karabin struggling to effectively transfer knowledge on how The Maintenance Wheel to their customer's senior managers.

Chapter 7.1 explains the evaluation procedure used. To answer [RQ7], an illustrative scenario was applied, which is the "[…] application of an artefact to a synthetic or real-world situation aimed at illustrating suitability or utility of the artefact" (Peffers et al., 2012, p. 402). Specifically, the framework was first adapted to reflect maintenance in the oil and gas industry. Then, it was presented to three senior managers in this industry with no prior knowledge of The Maintenance Wheel, before using a semi-structured interview protocol to gather qualitative data. The interviews gathered qualitative data on the designed MMF's transferability, complexity, and compatibility. Seeing that the MMF will be perceived by the customers of Karabin as an innovation, these three attributes were found to be particularly important to overcome the knowledge-based diffusion barrier when answering [RQ1]. Thus, by assessing how well the constructed MMF scored in these attributes, the ability to positively influence the knowledge-based diffusion barrier could be determined.

To determine the MMF's transferability, each manager was asked questions to test their understanding. They all stated that they had understood the framework. To validate these answers, each subject was asked to explain different parts of the framework in their own words. Given that they had only had a brief introduction to the framework, and limited experienced with BPM, the results were highly positive. The managers understood the framework presented to them well, and it was possible to have an in-depth discussion of how the framework works.

After presenting the framework to the managers, they were also asked to judge the complexity of the framework. This was done by asking questions related to whether the relationships between the different elements of the framework was clear, and if it was easy to understand the framework. They all stated that the framework was easy to understand and follow. While it was difficult to test this, the fact that they were able to understand the framework validates their answers.

Last, each manager was asked whether they perceived the framework as practically relevant and if they thought it could be of value in their company. These questions tap into whether the framework has used terminology and concepts which are recognisable to the senior managers. The managers said that they recognised the terms used and the activities in the framework, albeit they used slightly different terminologies for different elements such as "maintenance notifications". But this should not be a problem for Karabin in a real pitch, given that they analyse the customer's process prior to presenting in, i.e., they can adapt the framework to reflect their customer's terminology.

Ultimately, each manager was also asked whether they thought it could be of value in their company, which they all answered yes to. As stated by Subject 1: "It is a smarter system, and we have to have as smart systems as possible" (see Appendix G).

However, one particular area of improvement was identified in connection to transferability. Each manager requested more information to determine how the framework works in practice, which was expected. An MMF is theoretical, so it was expected to be difficult for the managers to obtain a complete picture of how the framework works in practice. Resultingly, the framework is ready for a next phase development, where examples for the different concepts of the framework are constructed to further explain how it works in practice. Karabin should have easy access to such examples from Equinor.

To conclude, the framework did score positively in attributes which are important to overcome a knowledge-based diffusion barrier. Effectively, the research objective has been completed. Nevertheless, a next phase development with a larger focus on practical examples is suggested, to further improve transferability.

8.2 Contributions

The following subchapter discusses both the managerial and scientific relevance of the thesis. Note that the managerial relevance is split into two parts: for Karabin and for companies in general.

8.2.1 Practical contributions

Karabin

The thesis was initiated based on Karabin having a practical problem, as explained in depth in Chapter 1.3. Karabin had access to a highly successful approach to maintenance management called The Maintenance Wheel, developed by Equinor. However, Karabin struggled to communicate it to their customers. In turn, Karabin struggled to convince its customers to implement it.

The maintenance management approach was developed in-house by Equinor. There, spreading it to other companies was not a priority when it was developed. Effectively, the information base which the management approach was built on was fuzzy, with no clear description of what the main concepts were, or how they combined to realise benefits. This resulted in there not being any conceptual description of how the management approach worked that Karabin could use while in contact with their customers.

Recognising both that the management approach is perceived as an organizational innovation by Karabin's customers, and that customers not understanding how the management approach works is a barrier to the diffusion of innovations (Ortt et al., 2013), this thesis constructed an MMF to help Karabin overcome the knowledge-based diffusion barrier. This MMF has identified the main elements of The Maintenance Wheel and their interconnections and provides a conceptual description of how they combine to realise benefits when applied on a maintenance process.

The MMF's ability to solve Karabin's problem was evaluated in a real setting, with real senior managers. The senior managers used in the evaluation had no prior knowledge of how the framework worked, and limited knowledge of BPM. However, after a brief pitch, they were all able to have in-depth discussions of how the management approach developed worked. In effect, the constructed MMF should be able to help Karabin overcome the knowledge-based diffusion problem.

Organizations in general

In a world where companies rely increasingly on machines and automated production lines to deliver customer value, asset availability is a becoming a larger driver of companies' productivity and thus also their performance (Fordal et al., 2019). In effect, where maintenance was historically perceived as a cost-centre, it is generally treated as a value-adding business element that must be effectively managed today. However, while increased use of automation and new technologies have resulted in increased maintenance importance, the cost and complexity of maintenance have risen too (Han & Yang, 2006). Simply put, as the number of assets and the complexity of them increases, it becomes more difficult to effectively conducting maintenance. For example, it is much more challenging to fix a three-phase induction motor than to replace a simple pump, as it requires both specialized tools and competence. Coupling this growing portfolio of complex assets with factors such as maintenance being a cross-functional activity, stricter HSE requirements, a stochastic maintenance demand, the complexity of maintenance management has also increased drastically (Crespo Márquez, 2007). The result is a reality where maintenance is, on the one hand, becoming more critical to companies' performance. Simultaneously, it is also a large and growing source of operational issues and costs that is highly challenging to improve.

Current maintenance operations are generally characterized by several issues caused by faulty maintenance management (Phogat & Gupta, 2017). A literature review by Crespo Márquez (2007) identified seven barriers to efficient maintenance management: (1) a lack of models to improve the underlying understanding of maintenance, (2) a lack of plant and process knowledge and data to help staff make suitable improvements, (3) a lack of time to analyse the data available, (4) a lack of top management support, (5) increased safety and environmental requirements have increased maintenance management complexity, (6) the broad span of maintenance activities makes it difficult to create a system to facilitate improvements, and (7) the increased use of advanced manufacturing technologies has increased maintenance complexity (pp. 11–13).

While the thesis found that many solutions have been developed by academia to cope with the challenges of maintenance management, few of them are adopted by real-world organisations (Van Horenbeek & Pintelon, 2014). Chapter 3.2.3 investigated why this was, and found that Dekker (1996), Van Horenbeek et al. (2010), and Fraser et al. (2015) all points to the same class of issues. The academic solutions fail to diffuse because of deficiencies lowering their practical relevance, such as the lack of empirical benefits or a focus on complex mathematical modelling that is challenging for practitioners to understand. This trend was also observed in this thesis while reviewing different approaches to maintenance management in Chapter 3.2-3.3.

The designed MMF, on the other hand, communicates a way to manage the maintenance process based on BPM and performance management, which has massive empirical benefits from two large, real facilities. Ultimately, given that the importance of maintenance is increasing, and that there is a lack of efficient maintenance management solutions relevant for practitioners, the MMF can have a large potential value for managers in the real-world. It provides practitioners with a proven way of dealing with the many challenges of maintenance management. In fact, Dekker (1996) and Van Horenbeek et al. (2010) both discuss generalizing knowledge from successful facilities as a way to solve the gap discussed between academia and practitioners in maintenance management. This being said, the MMF was designed for Karabin. External practitioners are, therefore, advised to take a proactive approach while examining the designed MMF, to interpret and make the necessary changes in order to make the MMF reflect maintenance in their particular business context.

Chapter 4.2 explains how The Maintenance Wheel is a maintenance management approach based on BPM and performance management that covers both corrective and predictive maintenance. In simple terms, it provides a way to standardise an organization's maintenance process, spanned by the tasks from once a maintenance notification is created, until a work order has been processed. It also provides a way to continuously improve this process. The ultimate goal is to increase the flow of the work order processing, by eliminating waste across the entire process, while also ensuring the correct maintenance quality. For a further discussion of how The Maintenance Wheel works, either see a brief explanation in [RQ4] in Chapter 8.1 or an in-depth explanation in Chapter 4.2.

The designed MMF provides a direct solution to three of the seven barriers to efficient maintenance management identified by Crespo Márquez (2007), discussed above. The designed MMF provides an easy way to gather process data (barrier 2), which is easy to analyse to identify performance gaps (barrier 3), in turn also provides a way to continuously improve all of the maintenance activities collectively (barrier 6). Then, one can also discuss the positive ripple effects the excess capacity realised by this way of managing maintenance, allowing companies to focus on the increasing maintenance complexity (barrier 5 and 7).

To summarize, it is believed that the framework has a large potential value for companies who are looking to improve their maintenance performance. It, directly and indirectly, addresses most of the current barriers to efficient maintenance management, as identified by Crespo Márquez (2007). At the same time, it does not suffer from the issues which have caused the gap between academic solutions to maintenance issues and their diffusion into real-world organisations. In the discussion of the theoretical relevance below, it will be further explained how the MMF realises improvements. Pay particular attention to the latter part of this section, where it is explained how the designed MMF can fuel further research which can have large implications for practitioners' ability to improve maintenance performance.

8.2.2 Theoretical contributions

In the following section, the implications of this thesis to academia are discussed. Four fields of literature were reviewed in Chapter 3, namely, diffusion of innovations, BPM, MMFs, and maintenance performance measurement. However, the contribution of this thesis lays mainly in the domain of MMFs and maintenance performance measurements, as is explained next.

Diffusion of innovations

While diffusion research has played a big role in this thesis, it has mainly been applied to solve the problem at hand. Resultingly, diffusion research is not expected to be affected significantly by this thesis.

BPM

By comparing the results of the analysis of The Maintenance Wheel (Chapter 4.2), and the literature review on BPM (Chapter 3.4), one sees that the approach to management developed by Equinor is based on BPM. While the review of maintenance management literature (Chapter 3.2 and 3.3) found that BPM has been applied in maintenance management previously, it is an underexplored topic. The Maintenance Wheel applies BPM on maintenance activities in a novel way. But, the MMF explaining how this was done is not a contribution to BPM literature, but to the body of literature on maintenance management discussed next.

MMFs and maintenance performance measurement

The thesis project delivers a significant academic contribution to the body of knowledge on maintenance management (reviewed in Chapter 3.2 and 3.3), effectively closing a large knowledge gap.

Maintenance encompasses activities from a broad array of functional departments. Seeing that maintenance is perceived as a strategic, value-adding activity today, it is important to facilitate for continuous improvements in all of these activities (Simões et al., 2011). However, while publications discussing the application of BPM to manage maintenance activities were identified, which in itself appears to be an underexplored topic, none of them discusses how to effectively manage maintenance as an end-to-end business process with BPM and performance management. For example, none of the reviewed approaches to maintenance performance measurement in Chapter 3.3 discuss performance measures similar to those in the designed MMF, as discussed in Chapter 4.3.2.

In other words, prior research on maintenance management has primarily focused on measuring the performance for one and one maintenance activity, and not on the collective and overarching process' performance. Thus, the corresponding maintenance management has been accordingly, with silo-based management and thus performance improvements.

None of the publications reviewed for this thesis provides a way to measure the process performance of the end-to-end maintenance value-chain based on time. Even less, none of the articles discusses how to actually set up the maintenance process to enable this way of measuring performance. Thus, by creating the MMF, a new way of managing maintenance based on BPM is introduced to the body of knowledge on maintenance management. In effect, a considerable knowledge gap is closed.

By closing this gap, the thesis opens up for future research on the application of BPM in the end-to-end management of a maintenance process based on process performance measurements. Discussed further under Chapter 8.6, this opens for studies on process-based improvements such as the elimination of waste between activities in the entire maintenance process.

8.3 Limitations

In the following section, prominent limitations of the thesis are discussed. These can and have affected the thesis project.

8.3.1 Research scope

The thesis' initial scope was too vague. First, the problem of Karabin was vaguely defined. Second, both maintenance management and BPM literature is fragmented and suffer from the lack of standardised terminologies. The initial research proposal was therefore too broad, and much time had to be put into iterating the research scope, even after the thesis' kick-off meeting. This has had a negative effect, as there was limited time to complete the thesis project. With a clearer scope from the beginning, it could have been possible to construct an MMF more accurately describing how The Maintenance Wheel works. Additionally, it could have been possible to perform a more extensive evaluation, with more senior managers to improve the evaluation's validity.

Second, the design process integrated research on the diffusion of innovations. From this field, factors positively influencing diffusion was integrated into the design process. However, the scope of factors considered was restrictive. First, it only focused on the attributes of the innovation (The Maintenance Wheel). Second, of the innovation's attributes, it only focused on attributes which could aid in effectively transferring knowledge on how The Maintenance Wheel works. Resultingly, several other important factors for diffusion were not considered. First, there are other attributes of an innovation which affects diffusion, such as the relative advantage it provides, as explained in Chapter 3.1 and Chapter 5.1. Second, there are variables not directly related to the innovation, e.g., the knowledge of the senior managers assessing the framework. Ultimately, this means that the thesis has not explored the full range of possible improvements to Karabin's problem. This is thus a recommendation for future research.

8.3.2 Design science research

It is important to acknowledge that subjectivity is inherent in DSR (Reubens, 2016). The designed MMF is the result of the thesis' author perception of how to best solve Karabin's problem.

Different researchers approach the same problem contexts differently, particularly in problem contexts with poorly defined problem areas, ultimately resulting in different artefacts being made (Drechsler, 2015). Given this, the thesis has attempted to provide the highest possible procedural transparency to improve reliability, e.g., resulting in the DSR process of Peffers et al. (2007) applied in this thesis being modified in Chapter 2.1.2.

Second, while it is possible to discuss whether this is a limitation, no "proof" may be found in prescription-based design projects (Van Aken, 2004). Instead, supporting evidence is accumulated through the application and evaluation of artefacts in different contexts, after which a state of saturated evidence may be reached (Eisenhardt & Graebner, 2007). As this thesis only evaluates the designed MMFs efficacy in one industry, testing it in other industries is a suggestion for future research.

8.3.3 Literature reviews

First, the fields of literature included in the thesis were selected based on the author's subjective opinion on how to achieve Karabin's problem the best way. While much literature was explored while defining the research scope, resulting in the reviewed disciplines, it is assumed that other fields of literature could also have helped solve Karabin's problem.

Additionally, the fields of literature that were ultimately reviewed are broad. Resultingly, strict selection criteria had to be employed. While much time went into searching through literature in each field, it is not possible to guarantee that all of the most relevant publications were included. This is particularly influenced by non-standardized terminology in the BPM and maintenance management literature. Terminology-based limitations are discussed as a separate limitation below.

8.3.4 Semi-structured interviews

The interview setting may introduce a bias. Due to Covid-19, each interview was performed remotely, via video calls. By not interviewing in person, an interviewer may miss out on non-verbal communication, impairing the interview's quality. For example, this may have resulted in an issue with the designed MMF not being picked up on while evaluating it. Second, by not being able to control the setting in which the interview subject sat, external factors influencing the interview subject could not be controlled.

Second, a bias may be introduced by the interviewer and his (or her) questions. While a manual on how to conduct interviews was used to reduce bias in questions, not all questions are prepared in semi-structured interviews, making it difficult to guarantee unproblematic questions. The only method to improve this aspect is through training. Therefore, leading up to the interviews, several publications on how to successfully conduct interviews were reviewed, such as Harrell and Bradley's (2009), Sekaran and Bougie's (2016), and Adams' (2015).

The interview subjects may also introduce biases. As relatively few interviews were held, bias can have been introduced by, for example, external factors or the interview subject having a bad day. Consequently, an interview subject may have simply forgotten essential information during the interviews. This is considered a larger problem for the set of evaluation interviews, as these focused on the interview subjects' personal perception. In other words, this may have influenced the findings of the evaluation's validity. The other set of interviews all focused on The Maintenance Wheel, i.e., the risk of all interview subjects failing to provide essential information across five interviews on the same topic is considered low. Additionally, in this set, two interview subjects were interviewed twice.

8.3.5 Limitations of the evaluation procedure

The evaluation is naturalistic, i.e., real people were interviewed in a real setting. Because of this, the evaluation is plagued confounding factors and possible misinterpretations, meaning that the internal validity is influenced negatively.

The MMF was not evaluated in its intended setting, as it was not possible to apply it in Karabin's benefits realisation process. This required Karabin to have a customer, with maintenance issues, where the constructed MMF could have been applied. This was not the case. Resultingly, the managers interviewed are not truly evaluating the framework as a possible multi-million EUR investment. It is natural to assume that the managers would have been more critical in a real setting.

Additionally, few senior managers were interviewed. To strengthen the external validity of the evaluation, more managers would have ideally been interviewed. However, this was not possible due to time constraints.

A presentation was used to introduce the framework to the senior managers. Senior managers have busy time schedules, so having them read and study the framework prior to the interviews were not seen as feasible. Ultimately, this means that the evaluation was influenced by the author's presentation skills.

8.3.6 Problems with terminology

Most of the disciplines which this thesis is based on suffer from non-standardized terminologies. This can have affected the thesis negatively. First, it can have affected the review of literature in Chapter 3. For example, it can have resulted in relevant publications being overlooked. It can also have affected the interpretation of the publications reviewed. To mitigate the influence of this affecting the thesis, much time was spent on reviewing and consulting books and literature reviews on the reviewed topics prior to, during, and after the literature reviews to build an understanding of the terms used. Additionally, much time went into selecting and analysing each article.

Second, the non-standardized terminologies can have affected the semi-structured interviews. The subjects interviewed operate in companies with their own sets of terminologies. Resultingly, aspects such as how subjects interpret questions, or how the author's interpretation of their answers can have been biased. Thus, much time went into carefully considering which questions to ask and to analyse the qualitative data gathered. However, note that since semi-structured interviews were conducted, not all questions asked were subject to the same careful formulations.

8.4 Research quality

In the following subchapter, the quality of the DSR project is discussed. This is done by discussing the research' validity, reliability, and researcher independence.

8.4.1 Validity

Pries-Heje and Baskerville (2008) state that the validity of DSR projects comes from the evaluation of developed artefacts. In effect, it must be demonstrated that artefacts achieve their expected functions, to ultimately achieve the defined research objective (Pries-Heje & Baskerville, 2008).

First of all, the evaluation was naturalistic. In this type of evaluation where the artefact is evaluated in a real setting with real people, the external validity is highest (Venable et al., 2012). According to Venable et al., this type of evaluation is plagued confounding factors and misinterpretations, meaning that the validity of the evaluation of efficacy may not be accurate (i.e. lower internal validity). However, Venable et al. also explain that in contrast to the alternative, artificial evaluation, naturalistic evaluation offers higher face validity.

This being said, this thesis used an illustrative scenario to evaluate the framework. This is a weaker form of evaluation than the ideal method of evaluation, i.e., to test the designed framework in the actual benefits realisation process of Karabin to conduct a case study (Peffers et al., 2012).

Last, the outcome of the evaluation was highly indicative of the designed MMF achieving the research objective. However, had more time been available, more interviews would have been conducted during the evaluation to improve the validity.

8.4.2 Reliability

Reliability may be defined as "[…] the consistency of the analytical procedures, including accounting for personal and research method biases that may have influenced the findings" (Noble & Smith, 2015, p. 34). In a DSR project, reliability thus translates to that a rigorous process should be employed to construct and evaluate an artefact to ensure the reliability of a design process' results (Hevner & Chatterjee, 2010).

The reliability of a DSR project is exposed by providing the highest possible procedural transparency (Dresch et al., 2015), which this thesis has strived for continuously. First, in Chapter 2, an in-depth explanation was given of the thesis project methodology. There, aspects such as how and why different data collection methods were applied, how the collected data was analyzed, and biases influencing the collected data, was discussed in-depth. This was also the case in the remaining chapters.

However, it is recognized that this thesis will not have the highest reliability. There are two main reasons. First, "[…] because human behaviour is never static, no study can be replicated exactly, regardless of the methods and design employed" (LeCompte & Goetz, 1982, p. 35). In effect, this means that because of subjective perceptions, it is not guaranteed that other researchers would arrive at the same conclusions by following the procedure used in this thesis. Second, it is difficult to develop a rigorous design procedure. It has been particularly challenging to clearly explain how this thesis moved from the design space generated with the morphological chart to a design alternative, in addition to how the design requirements were identified. However, measures have been taken to provide transparency here by explaining the rationale behind each design requirement and the main decisions made while creating the final design.

8.4.3 Researcher independence

The independence of a researcher in a DSR project is defined by the researcher's dependence on a person or group who has an incentive for a certain outcome of the research project (Verschuren & Hartog, 2005).

The group with the largest incentive or interest in the project, besides the thesis' author, is Karabin. The contact with them has been very limited, and the thesis has effectively been conducted in isolation from them, much due to the Covid-19 pandemic. While there were some meetings with them around the thesis' kick-off meeting, since then the contact has been limited to two semi-structured interviews on The Maintenance Wheel. In effect, the influence of Karabin on the thesis has been minimal.

The thesis committee members from TU Delft has influenced the research project occasionally. However, this committee had no interest in a particular outcome. Instead, this group acted as a useful and neutral party in discussing decisions made, as well as the way forward.

The last group which could have influenced the researcher independence is the senior managers used in the evaluation of the designed MMF. However, none of the managers used in the evaluation had any incentive in the research project. They had no direct connection to Karabin or Equinor, no prior knowledge of The Maintenance Wheel, and no direct connection to the researcher. Additionally, each manager was guaranteed anonymity, and it was emphasized in the introduction of the evaluation that this thesis project would not be affected negatively by them not understanding parts of the framework presented to them. Resultingly, they had no particular interest in the outcome of the research project.

To conclude, the researcher has not been influenced by a person or group with a particular incentive for a certain outcome of the research project.

8.5 Management of Technology relevance

The overarching objective of Management of Technology (MoT), the master programme that this thesis was written for, is to teach its graduates to become technology managers. In effect, its graduates should learn to critically assess technologies analytically, and understand how they could best be integrated into organizations, considering the interface between human resources and technologies. In effect, its graduates should build an understanding of how to continuously improve companies' performance, to cope with an ever-changing environment caused by factors such as technological developments.

In this subchapter, it is reflected on why this thesis complies with the programme objective. This is done based on three criteria for what a typical MoT thesis should contain, as defined by MoT's Study Programme Administration (SPA).

> "The work shows an understanding of technology as a corporate resource or is done from a corporate perspective" (SPA TBM, 2019, p. 3).

The thesis project has been conducted from a corporate perspective (Karabin) and understanding the potential value of a technology (The Maintenance Wheel) as a corporate resource is at the centre of it.

The Maintenance Wheel is a perfect example of how the clever use of relatively simple technologies can be used as a corporate resource to manage and continuously improve companies' performance, in this case through improving maintenance efficiency. Being a consulting firm, Karabin had realised the potential value of this technology and wanted to use it to improve its customers' maintenance efficiency. However, when Karabin communicated that they had struggled to communicate and thus convince organizations to implement the technology in the preliminary stage of this thesis project, understanding the behaviour of technologies was crucial to identify and subsequently designing the prescriptive solution. Seeing how companies evaluate and judge potential innovative technologies for implementation, this thesis is based on the notion that a lack of knowledge is a barrier to the diffusion of innovations. Thus, an MMF providing the knowledge on how this technology works was constructed, which Karabin could apply in their customer interactions. Additionally, the thesis also illustrated how the MMF has a large potential value for companies in general, seeing both the growing importance and simultaneous challenge of maintenance management, thus highlighting the potential of the technology as a corporate resource.

> "The work reports on a scientific study in a technological context" (SPA TBM, 2019, p. 3).

While understanding the behaviour of innovative technologies in a corporate context was essential to the thesis, understanding the technology itself was a crucial prerequisite to solving the problem. The constructed MMF is the result of an extensive scientific study, based on scientific methods taught by the MoT programme. Prior to this thesis, there were no complete descriptions of how The Maintenance Wheel worked. A DSR project, using both desk research and semi-structured interviewing, both made it possible to identify the main elements of the technology and how they combine to realise benefits, before constructing the MMF to communicate how this technology works when used in a maintenance process. The elective "SEN1622 – I and C Service Design" and the course "MOT2312– Research Methods" was essential to developing the thesis project methodology. Note that the elective introduces students to DSR, while the latter course taught how to apply different research methods.

> "Students [of the programme] use scientific methods and techniques to analyse a problem as put forward in the MoT curriculum" (SPA TBM, 2019, p. 3).

As explained under the previous criterion, the foundation provided by the MoT programme on different scientific methods and techniques was crucial to completing this thesis. Below, other key courses from the MoT programme is listed.

The course "MOT 1531 - Business Process Management and Technology" taught how companies can use process management as a tool to realise performance improvements by better organizing human resources and applying novel technologies. In effect, the course was essential to understand The Maintenance Wheel. "MOT2421 - Emerging and Breakthrough Technologies" taught about diffusion research, and explicitly discussed how missing knowledge is a barrier to diffusion of innovations. Thus, it was crucial in the problem analysis and research objective definition in Chapter 1. The elective "SPM5931 – Internship" allowed the author to work in a real company, and be responsible for a project where the maintenance schedule of a critical production line of an aluminium plant was optimized by a failure mode and effects analysis (FMEA). This internship taught the author about the potential value of efficient maintenance management, and how integral maintenance is to companies' performance. This understanding was expanded on in the elective "SEN 9720 – Logistics and Supply Chain Innovation", which taught the author more about the complexities of maintenance and asset management. Last, the course "MOT1524 – Leadership and Technology Management" taught about knowledge as a corporate resource that should be effectively managed. The constructed MMF integrates this, organizing staff by their competencies in the maintenance process, to effectively improve maintenance performance.

8.6 Recommendations for future research

Over the course of the project, some prominent potential avenues of future research emerged.

First of all, Chapter 8.2 explains how the thesis opens up for future research on the application of BPM in the end-to-end management of a maintenance process based on process performance measurements. New studies could either validate or criticize this thesis project's findings or identify new use cases. There are two particularly interesting avenues here. First, a study researching in-depth different use-cases for how time-based performance measures may be applied to the maintenance process is suggested, seeing that these performance measures are an underexplored topic in maintenance management. Furthermore, the framework designed in this thesis emphasizes process flow, i.e., it was designed with a focus on increasing the efficiency of the maintenance process. However, because of the performance management abilities of the framework, where the performance of each single task used to service an asset is monitored, it is recommended to conduct a research project on whether the framework could be used in industries where maintenance quality management is prioritized. An example of such an industry is the pharmaceutical industry, where strict regulations imposed on companies' production processes makes it essential to ensure the highest quality of the conducted maintenance.

Second, a next phase development for the MMF is suggested. An MMF is theoretical, so it was expected to be difficult for the managers to obtain a complete picture of how the framework works in practice. The evaluation in Chapter 7 confirmed this. Resultingly, it is a suggestion for future research to develop examples for the framework, to highlight how it works in practice. Karabin should have easy access to such examples from Equinor.

Third, an important recommendation for future research is to evaluate the constructed framework in its intended setting, namely, Karabin's benefits realisation process. Since Karabin did not have a customer looking to improve maintenance performance, at the stage where they pitch solutions, it was not possible to use it in a real setting to conduct a case study. There were several factors from the MMF's intended setting, which were not possible to replicate in the evaluation. Thus, it is not given that the evaluation's findings are generalizable to Karabin's setting. Thus, the MMF should be evaluated in its intended setting.

Fourth, the framework was only evaluated in one industry. As explained in Chapter 2, no "proof" may be found in prescription-based design projects. Instead, supporting evidence is accumulated through the application and evaluation of artefacts in different contexts (Van Aken, 2004). Resultingly, the evaluation could have yielded another result in another industry. Thus, the only way to "prove" that the framework is able to explain to and convince senior managers from every industry is to apply the designed framework in enough and different contexts to gather enough supporting evidence to reach this so-called saturation. As the framework was only employed in a single industry, it is therefore recommended that it is tested in other industries.

Fifth, the integrated research on the diffusion of innovations was restrictive, focusing only on the attributes of the innovation itself directly influencing the knowledge-based diffusion barrier. There are other attributes of an innovation which affects diffusion, such as the relative advantage it provides, as explained in Chapter 3.1 and Chapter 5.1. Second, there are variables not directly related to the innovation, e.g., the knowledge of the senior managers assessing the framework. Ultimately, this means that the thesis has not explored the full range of possible improvements to Karabin's problem. A broader focus on how to improve the knowledge-based diffusion barrier is thus a recommendation for future research.

Sixth, the interviews with three key experts of The Maintenance Wheel (see Chapter 4.1 and Appendix C) found that implementing The Maintenance Wheel is a substantial challenge. However, this thesis focused solely on the initial implementation decision, i.e., implementation was out of the thesis project's scope. Thus, it is a recommendation for future research to identify and analyse the critical success factors of The Maintenance Wheel's implementation, to be better able to cope with the implementation.

Last, Chapter 1.5 explains how the MMF was designed to provide a theoretical framework for how to manage maintenance based on The Maintenance Wheel. In other words, the designed MMF is simply a tool to transfer knowledge on how The Maintenance Wheel works. This means that the thesis did not attempt to make any type of improvements to how The Maintenance Wheel works. But researching whether it is possible to improve the structure or elements in The Maintenance Wheel is a recommendation for future research.

BIBLIOGRAPHY

Adams, W. C. (2015). Conducting Semi-Structured Interviews. In K. E. Newcomer, H. P. Hatry, & J. S. Wholey (Eds.), *Handbook of Practical Program Evaluation* (Fourth Edi, pp. 492–505). John Wiley & Sons, Inc. https://doi.org/10.1002/9781119171386.ch19

Ahuja, I. P. S., & Khamba, J. S. (2008). Total productive maintenance: Literature review and directions. *International Journal of Quality and Reliability Management*, *25*(7), 709–756. https://doi.org/10.1108/02656710810890890

Al-Najjar, B., & Alsyouf, I. (2003). Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making. *International Journal of Production Economics*, *84*(1), 85–100. https://doi.org/10.1016/S0925-5273(02)00380-8

Al-Najjar, B., & Alsyouf, I. (2004). Enhancing a company's profitability and competitiveness using integrated vibration-based maintenance: A case study. *European Journal of Operational Research*, *157*(3), 643–657. https://doi.org/10.1016/S0377-2217(03)00258-3

Al-Turki, U. M. (2009). Maintenance planning and scheduling. In *Handbook of Maintenance Management and Engineering* (pp. 237–262). Springer London. https://doi.org/10.1007/978-1-84882-472-0_11

Alsyouf, I. (2006). Measuring maintenance performance using a balanced scorecard approach. *Journal of Quality in Maintenance Engineering*, *12*(2), 133–149. https://doi.org/10.1108/13552510610667165

Alsyouf, I. (2007). The role of maintenance in improving companies' productivity and profitability. *International Journal of Production Economics*, *105*(1), 70–78. https://doi.org/10.1016/j.ijpe.2004.06.057

Aoudia, M., Belmokhtar, O., & Zwingelstein, G. (2008). Economic impact of maintenance management ineffectiveness of an oil and gas company. *Journal of Quality in Maintenance Engineering*, *14*(3), 237–261. https://doi.org/10.1108/13552510810899454

Barberá, L., Crespo Márquez, A., Viveros, P., & Stegmaier, R. (2012). Advanced model for maintenance management in a continuous improvement cycle: Integration into the business strategy. *International Journal of Systems Assurance Engineering and Management*, *3*(1), 47–63. https://doi.org/10.1007/s13198-012-0092-y

Baskarada, S., Gao, J., & Koronios, A. (2006). Agile maturity model approach to assessing and enhancing the quality of asset information in engineering asset management information systems. In W. Abramowicz (Ed.), *Lecture Notes in Informatics (LNI), Proceedings - Series of the Gesellschaft fur Informatik (GI)* (pp. 486–500). https://www.researchgate.net/publication/221281598_Agile_Maturity_Model_Approach_to_Assessing_and_Enhancing_the_Quality_of_Asset_Information_in_Engineering_Asset_Management_Information_Systems

Beasley, J. E. (n.d.). *Data envelopment analysis*. Retrieved April 12, 2020, from http://people.brunel.ac.uk/~mastjjb/jeb/or/dea.html

Bevilacqua, M., & Braglia, M. (2000). Analytic hierarchy process applied to maintenance strategy selection. *Reliability Engineering and System Safety*, *70*(1), 71–83. https://doi.org/10.1016/S0951-8320(00)00047-8

Brennhovd, Ø., & Flatebø, E. L. (2017). *Prosessledelse i Norge - En kvantitativ studie av organisasjoners prosessmodenhet og forholdet mellom motivasjon, prosessmodenhet og effekter*.

Campbell, J. D., & Reyes-Picknell, J. V. (2015). *Uptime: Strategies for Excellence in Maintenance Management* (3rd ed.). Crc Press.

Campos, M. L., & Crespo Márquez, A. (2009). Review, Classification and Comparative Analysis of Maintenance Management Models. *Journal of Automation Mobile Robotics and Intelligent Systems*, *3*(3), 110–115.

Campos, M. L., & Crespo Márquez, A. (2011). Modelling a maintenance management framework based on PAS 55 standard. *Quality and Reliability Engineering International*, *27*(6), 805–820. https://doi.org/10.1002/qre.1168

Caulfield, J. (2019). *How to Do Thematic Analysis | A Step-by-Step Guide & Examples*. https://www.scribbr.com/methodology/thematic-analysis/

Christiansen, B. (2020). *How to Solve the Biggest Maintenance Challenges in the Oil & Gas Industry*. https://blog.isa.org/maintenance-management-increase-productivity-minimize-production-costs-oil-gas-industry

Cloutier, M., & Renard, L. (2018). Design Science Research: Issues, Debates and Contributions. *Projectics / Proyéctica / Projectique*, *20*(2), 16. https://doi.org/10.3917/proj.020.0011

Crespo Márquez, A. (2007). The Maintenance Management Framework. In *The Maintenance Management Framework*. Springer. https://doi.org/10.1007/978-1-84628-821-0

Crespo Márquez, A., De León, P. M., Fernandez, J. F. G., Márquez, C. P., & Campos, M. L. (2009). The maintenance management framework: A practical view to maintenance management. *Journal of Quality in Maintenance Engineering*, *15*(2), 167–178. https://doi.org/10.1108/13552510910961110

Crespo Márquez, A., & Gupta, J. N. D. (2006). Contemporary maintenance management: Process, framework and supporting pillars. *Omega*, *34*(3), 313–326. https://doi.org/10.1016/j.omega.2004.11.003

Dahlgaard, J. J., & Dahlgaard-Park, S. M. (2006). Lean production, six sigma quality, TQM and company culture. *TQM Magazine*, *18*(3), 263–281. https://doi.org/10.1108/09544780610659998

Davenport, T. H., & Short, J. (1990). The New Industrial Engineering: Information Technology And Business Process Redesign. *Sloan Management Review*, *summer 1990*, 11–27.

Dekker, R. (1996). Applications of maintenance optimization models: A review and analysis. *Reliability Engineering and System Safety*, *51*(3), 229–240. https://doi.org/10.1016/0951-8320(95)00076-3

DNV GL. (n.d.). *Adding value to compliance - EU Offshore Safety Directive*. Retrieved August 12, 2020, from https://www.dnvgl.com/oilgas/offshore-safety-directive/index.html

Drechsler, A. (2015). A postmodern perspective on socio-technical design science research in information systems. *DESRIST 2015: Proceedings of the 10th International Conference on New Horizons in Design Science: Broadening the Research Agenda - Volume 9073*, *9073*, 152–167. https://doi.org/10.1007/978-3-319-18714-3_10

Dresch, A., Lacerda, D. P., & Antunes, J. A. V. (2015). Design science research: A method for science and technology advancement. In *Design Science Research: A Method for Science and Technology Advancement*. Springer International Publishing. https://doi.org/10.1007/978-3-319-07374-3

Duffuaa, S. O., & Haroun, A. E. (2009). Maintenance control. In M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, & D. Ait-Kadi (Eds.), *Handbook of Maintenance Management and Engineering* (pp. 93–113). Springer. https://doi.org/10.1007/978-1-84882-472-0_5

Dumas, M., La Rosa, M., Mendling, J., & Reijers, H. A. (2018). Fundamentals of Business Process Management. In *Fundamentals of Business Process Management: Second Edition* (2nd ed.). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-56509-4

Dym, C. L., Little, P., & Orwin, E. J. (2014). *Engineering Design: A Project-Based Introduction* (D. Sayre (ed.); 4th ed.). Wiley.

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. In *The Academy of Management Review* (Vol. 14, Issue 4).

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, *50*(1), 25–32. https://doi.org/10.5465/AMJ.2007.24160888

Equinor. (n.d.-a). *About us*. Retrieved February 15, 2020, from https://www.equinor.com/en/about-us.html#our-values

Equinor. (n.d.-b). *Kårstø processing plant*. Retrieved June 30, 2020, from https://www.equinor.com/en/what-we-do/terminals-and-refineries/kaarstoe.html

European Committee for Standardization. (2017). *BS EN 1306 : Maintenance - Maintenance terminology* (p. 98). BSI Standards Limited.

Eyoh, J., & Kalawsky, R. S. (2018). Evolution of Maintenance Strategies in oil and Gas Industries: The Present Achievements and Future Trends. *FEAST International Conference on Engineering Managemen*. https://pdfs.semanticscholar.org/64fa/d217ef7de8fdb7a439d9dcf0eb523bcbad2e.pdf

Fisher, J. (1992). Use of non-financial performance measures. *Journal of Cost Management*, *6*(Spring), 31–38.

Fordal, J. M., Rødseth, H., & Schjølberg, P. (2019). Initiating industrie 4.0 by implementing sensor management – Improving operational availability. *Lecture Notes in Electrical Engineering*, *484*, 200–207. https://doi.org/10.1007/978-981-13-2375-1_26

Fraser, K. (2014). Facilities management: the strategic selection of a maintenance system. *Journal of Facilities Management*, *12*(1), 18–37. https://doi.org/10.1108/JFM-02-2013-0010

Fraser, K., Hvolby, H. H., & Tseng, T. L. B. (2015). Maintenance management models: A study of the published literature to identify empirical evidence a greater practical focus is needed. *International Journal of Quality and Reliability Management*, *32*(6), 635–664. https://doi.org/10.1108/IJQRM-11-2013-0185

Garg, A., & Deshmukh, S. G. (2006). Maintenance management: literature review and directions. *Journal of Quality in Maintenance Engineering*, *12*(3), 205–238. https://doi.org/10.1108/13552510610685075

Ghalayini, A. M., & Noble, J. S. (1996). The changing basis of performance measurement. In *International Journal of Operations and Production Management* (Vol. 16, Issue 8, pp. 63–80). MCB UP Ltd. https://doi.org/10.1108/01443579610125787

Gleasure, R., Feller, J., & O'Flaherty, B. (2012). Procedurally transparent Design Science Research: A design process model. *International Conference on Information Systems, ICIS 2012*, *3*, 2686–2704. https://aisel.aisnet.org/icis2012/proceedings/ResearchMethods/10

GlobalData Thematic Research. (2019). *Predictive maintenance in oil and gas: Key trends revealed*. https://www.offshore-technology.com/comment/predictive-maintenance-oil-gas/

Gomes, C. F., Yasin, M. M., & Lisboa, J. V. (2004). A literature review of manufacturing performance measures and measurement in an organizational context: A framework and direction for future research. In *Journal of Manufacturing Technology Management* (Vol. 15, Issue 6, pp. 511–530). Emerald Group Publishing Limited. https://doi.org/10.1108/17410380410547906

Greenhalgh, T., Robert, G., Bate, P., Macfarlane, F., & Kyriakidou, O. (2007). Diffusion of Innovations in Health Service Organisations: A Systematic Literature Review. In *Diffusion of Innovations in Health Service Organisations: A Systematic Literature Review*. BMJ Books. https://doi.org/10.1002/9780470987407

Greenhalgh, T., Robert, G., Macfarlane, F., Bate, P., & Kyriakidou, O. (2004). Diffusion of innovations in service organizations: Systematic review and recommendations. In *Milbank Quarterly* (Vol. 82, Issue 4, pp. 581–629). Milbank Memorial Fund. https://doi.org/10.1111/j.0887-378X.2004.00325.x

Grover, V., Jeong, S. R., Kettinger, W. J., & Teng, J. T. C. (1995). The implementation of business process reengineering. *Journal of Management Information Systems*, *12*(1), 109–144. https://doi.org/10.1080/07421222.1995.11518072

Haarman, M., & Delahay, G. (2004). *Value driven maintenance : new faith in maintenance*. Mainnovation.

Hammer, M. (2010). What is Business Process Management? In J. vom Brocke & M. Rosemann (Eds.), *Handbook on Business Process Management 1: Introduction, Methods, and Information Systems* (pp. 3–16). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-00416-2_1

Hammer, M., & Stanton, S. (1999). How process enterprises really work. *Harvard Business Review*, *77*(6). www.hbr.org

Han, T., & Yang, B. S. (2006). Development of an e-maintenance system integrating advanced techniques. *Computers in Industry*, *57*(6), 569–580. https://doi.org/10.1016/j.compind.2006.02.009

Hansen, H. (2006). *Picture: Boat at Sture facility*. http://bit.ly/2v3tF4R

Harmon, P. (2010). The Scope and Evolution of Business Process Management. In J. vom Brocke & M. Rosemann (Eds.), *Handbook on Business Process Management 1: Introduction, Methods, and Information Systems* (pp. 37–81). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-00416-2_3

Harmon, P., & Garcia, J. (2020). *The State of Business Process Management*.

Harrell, M. C., & Bradley, M. A. (2009). *Data Collection Methods. Semi-Structured Interviews and Focus Groups*. https://apps.dtic.mil/dtic/tr/fulltext/u2/a512853.pdf

Hart, C. (1998). *Doing a Literature Review*. SAGE Publications.

Hassanain, M. A., Froese, T. M., & Vanier, D. J. (2003). Framework model for asset maintenance management. In *Journal of Performance of Constructed Facilities* (Vol. 17, Issue 1, pp. 51–64). https://doi.org/10.1061/(ASCE)0887-3828(2003)17:1(51)

Hayes, R. H., & Garvin, D. A. (1982). Managing as if tomorrow mattered. *Harvard Business Review*, *60*(3), 70–79.

Hayes, R. H., Wheelwright, S. C., & Clark, K. B. (1988). *Dynamic Manufacturing: Creating the Learning Organization*. Free Press.

Hevner, A. R., & Chatterjee, S. (2010). *Design research in information systems: theory and practice*. Springer Publishing.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 105.

Iden, J. (2011). Fører investeringe i kvalitetsystem til prosessledelse? *MAGMA*, *1*, 49–57. www.kvalex.no

Iden, J. (2018). *Prosessledelse - Ledelse og Utvikling av Prosesser* (2nd ed.). Fagbokforlaget.

IELTS. (n.d.). *What does your IELTS band score mean?* Retrieved August 29, 2020, from https://www.ielts.com/results/scores

INOSA. (2018). *One Point Lesson (OPL)*. https://inosa.no/en/insight/one-point-lesson-opl/

International Organization for Standardization. (2014). ISO 55000:2014 Asset management - Overview, principles and terminology. In *International Organization for Standardization* (Vol. 1, p. 18).

Jesson, J., Matheson, L., & Lacey, F. M. (2011). *Doing Your Literature Review : Traditional and Systematic Techniques.* SAGE Publications.

Johannesson, P., & Perjons, E. (2014). An Introduction to Design Science. In *An Introduction to Design Science*. Springer International Publishing. https://doi.org/DOI 10.1007/978-3-319-10632-8_6

Kaplan, R. S. (1983). Measuring Manufacturing Performance: A New Challenge for Management Accounting Research. *Accounting Review*, *58*(4), 686–705.

Kaplan, R. S. (1984). Yesterday's accounting undermines production. *Harvard Business Review*, *62*(4), 95–101. https://doi.org/10.1225/84406

Khan Academy. (n.d.). *Sampling methods review*. Retrieved June 13, 2020, from https://www.khanacademy.org/math/statistics-probability/designing-studies/sampling-methods-stats/a/sampling-methods-review

Kohlbacher, M., & Reijers, H. A. (2013). The effects of process-oriented organizational design on firm performance. *Business Process Management Journal*, *19*(2), 245–262. https://doi.org/10.1108/14637151311308303

Kumar, U., Galar, D., Parida, A., Stenström, C., & Berges, L. (2013). Maintenance performance metrics: A state-of-the-art review. In *Journal of Quality in Maintenance Engineering* (Vol. 19, Issue 3, pp. 233–277). https://doi.org/10.1108/JQME-05-2013-0029

Kutucuoglu, K. Y., Hamali, J., Irani, Z., & Sharp, J. M. (2001). A framework for managing maintenance using performance measurement systems. *International Journal of Operations & Production Management*, *21*(1–2), 173–194. https://doi.org/10.1108/01443570110358521

LeCompte, M. D., & Goetz, J. P. (1982). Problems of Reliability and Validity in Ethnographic Research. *Review of Educational Research*, *52*(1), 31–60. https://doi.org/10.3102/00346543052001031

Linnéusson, G. (2018). *Towards strategic development of maintenance and its effects on production performance: A hybrid simulation-based optimization framework*. University of Skövde.

Liyanage, J. P., & Kumar, U. (2003). Towards a value-based view on operations and maintenance performance management. *Journal of Quality in Maintenance Engineering*, *9*(4), 333–350. https://doi.org/10.1108/13552510310503213

Lundquist, C. H., Vickery, S. K., & Droge, C. (2000). The effects of information system infrastructure and process improvements on supply-chain time performance Jayanth Jayaram. In *International Journal of Physical Distribution & Logistics Management* (Vol. 30, Issue 3). # MCB University Press. http://www.emerald-library.com

Lusk, S., Paley, S., & Spanyi, A. (2005). The Evolution of Business Process Management as a Professional Discipline. *BP Trends*, *June*, 1–9. https://www.bptrends.com/publicationfiles/06-05 WP ABPMP Activities - Lusk et al2.pdf

Maddern, H., Smart, P. A., Maull, R. S., & Childe, S. (2014). End-to-end process management: implications for theory and practice. *Production Planning & Control*, *25*(16), 1303–1321. https://doi.org/10.1080/09537287.2013.832821

Mapes, J. (2000). Process variability and its effect on plant performance. *International Journal of Operations and Production Management*, *20*(7), 792–808. https://doi.org/10.1108/01443570010330775

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*(4), 251–266. https://doi.org/10.1016/0167-9236(94)00041-2

Marshall, C., & Rossman, G. B. (2014). *Designing Qualitative Research* (6th ed.). SAGE Publications.

Math Open Reference. (2011). *Sector definition*. https://www.mathopenref.com/arcsector.html

Maverick, J. B. (2018, September 10). *Which types of industries have the largest capital expenditures?* Investopedia. https://www.investopedia.com/ask/answers/020915/which-types-industries-have-largest-capital-expenditures.asp

Muchiri, P., Pintelon, L., Gelders, L., & Martin, H. (2011). Development of maintenance function performance measurement framework and indicators. *International Journal of Production Economics*, *131*(1), 295–302. https://doi.org/10.1016/j.ijpe.2010.04.039

Muchiri, P., Pintelon, L., Martin, H., & De Meyer, A. M. (2010). Empirical analysis of maintenance performance measurement in Belgian industries. *International Journal of Production Research*, *48*(20), 5905–5924. https://doi.org/10.1080/00207540903160766

Münstermann, B., Eckhardt, A., & Weitzel, T. (2010). The performance impact of business process standardization: An empirical evaluation of the recruitment process. *Business Process Management Journal*, *16*(1), 29–56. https://doi.org/10.1108/14637151011017930

Nagel, T. (1998). Reductionism and Antireductionism. In Novartis Foundation (Ed.), *The Limits of Reductionism in Biology* (pp. 3–14). Wiley.

Neely, A., Gregory, M., & Platts, K. (1995). Performance measurement system design - A literature review and research agenda. *International Journal of Operations & Production Management*, *15*(4), 80–116.

Noble, H., & Smith, J. (2015). Issues of validity and reliability in qualitative research. In *Evidence-Based Nursing* (Vol. 18, Issue 2, pp. 34–35). BMJ Publishing Group. https://doi.org/10.1136/eb-2015-102054

Norwegian Oil Industry Association, Norwegian Clean Seas Association for Operating Companies, & Norwegian Shipowners' Association. (2012). *Deepwater Horizon - Lessons learned and follow-up*.

NPD. (1998). *Maintenance baseline study: A method for self-assessment of maintenance management systems*. https://www.ptil.no/contentassets/9fdd4648b19747aca09c0abd82830c8b/engelsk-basisstudie-vedlikeholdsstyring-revisjon-0-281098.pdf

Ortt, J. R., Langley, D. J., & Pals, N. (2013). Ten niche strategies to commercialize new high-tech products. *19th International Conference on Engineering, Technology and Innovation*. https://doi.org/10.1109/ITMC.2013.7352687

Östlund, C. (2017). *Design for e-training*. Copenhagen Business School.

Østreng, W. (2007). Reductionism versus Holism – Contrasting Approaches ? In W. Østreng (Ed.), *Consilience. Interdisciplinary Communication* (Issue May, pp. 11–14). http://www.cas.uio.no/Publications/Seminar/Consilience_Ostreng.pdf

Ouertani, M. Z., Parlikad, A. K., & McFarlane, D. (2008). Towards an approach to select an asset information management strategy. *International Journal of Computer Science and Applications*, *5*(3b), 25–44.

Palmberg, K. (2009). Exploring process management: are there any widespread models and definitions? *The TQM Journal*, *21*(2), 203–215. https://doi.org/10.1108/17542730910938182

Palmberg, K. (2010). Experiences of implementing process management: A multiple-case study. *Business Process Management Journal*, *16*(1), 93–113. https://doi.org/10.1108/14637151011017967

Parida, A. (2006a). *Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM)*. https://doi.org/10.1108/13552510710780276

Parida, A. (2006b). Maintenance performance measurement system: Application of ICT and e-Maintenance Concepts. *International Journal of Condition Monitoring and Diagnostic Engineering Management*, *9*(4), 30–34.

Parida, A., & Chattopadhyay, G. (2007). Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM). *Journal of Quality in Maintenance Engineering*, *13*(3), 241–258. https://doi.org/10.1108/13552510710780276

Parida, A., & Kumar, U. (2006). Maintenance performance measurement (MPM): Issues and challenges. *Article in Journal of Quality in Maintenance Engineering*, *12*(3), 239–251. https://doi.org/10.1108/13552510610685084

Parida, A., Kumar, U., Galar, D., & Stenström, C. (2015). Performance measurement and management for maintenance: a literature review. *Journal of Quality in Maintenance Engineering*, *21*(1), 2–33. https://doi.org/10.1108/JQME-10-2013-0067

PCMS ENG Group. (2016). *Design Out Maintenance (DM) - PCMS Engineering*. https://pcmseng.co.uk/bwl-knowledge-base/design-maintenance-dm/

Peffers, K., Rothenberger, M. A., Tuunanen, T., & Vaezi, R. (2012). Design Science Research Evaluation. In K. Peffers, M. A.

Rothenberger, & B. Kuechler (Eds.), *Design Science Research in Information Systems - Advances in Theory and Practice* (pp. 398–410). Springer Berlin Heidelberg.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45–77. https://doi.org/10.2753/MIS0742-1222240302

Phogat, S., & Gupta, A. K. (2017). Identification of problems in maintenance operations and comparison with manufacturing operations: A review. In *Journal of Quality in Maintenance Engineering* (Vol. 23, Issue 2, pp. 226–238). Emerald Group Publishing Ltd. https://doi.org/10.1108/JQME-06-2016-0027

Plomp, T., & Nieveen, N. (2013). Introduction to the collection of illustrative cases of educational design research. In T. Plomp & N. Nieveen (Eds.), *Educational design research Part B: Illustrative cases* (pp. V–XVI).

Porter, M. E. (1985). *Competitive Advantage: Creating and Sustaining Superior Performance* (1st ed.). Free Press.

Pramod, V. R., Devadasan, S. R., Muthu, S., Jagathyraj, V. P., & Moorthy, G. D. (2006). Integrating TPM and QFD for improving quality in maintenance engineering. *Journal of Quality in Maintenance Engineering*, *12*(2), 150–171. https://doi.org/10.1108/13552510610667174

Prat, N., Comyn-Wattiau, I., & Akoka, J. (2014). Artifact evaluation in information systems design-science research - A holistic view. *PACIS 2014 Proceedings*. http://aisel.aisnet.org/pacis2014/23

Pries-Heje, J., & Baskerville, R. (2008). The design theory nexus. *MIS Quarterly: Management Information Systems*, *32*(4), 731–755. https://doi.org/10.2307/25148870

Procurement Executives' Association. (1999). *Guide to the Balanced Scorecard Performance Management Methodology*.

RAND. (n.d.). *About the RAND Corporation*. Retrieved June 15, 2020, from https://www.rand.org/about.html

Reubens, R. (2016). To craft, by design, for sustainability Towards. In *TU Delft University*. https://doi.org/10.4233/uuid:0c2c14c8-9550-449d-b1ff-7e0588ccd6c2

Rogers, E. M. (2003). *Diffusion of Innovations* (5th ed.). Free Press.

Rosemann, M. (2015). The service portfolio of a BPM center of excellence. In J. vom Brocke & M. Rosemann (Eds.), *Handbook on Business Process Management 2: Strategic Alignment, Governance, People and Culture* (2nd ed., pp. 381–398). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-45103-4_16

Rosemann, M., & vom Brocke, J. (2010). The six core elements of business process management. In J. vom Brocke & M. Rosemann (Eds.), *Handbook on Business Process Management 1: Introduction, Methods, and Information Systems* (pp. 105–122). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-45100-3_5

Rudden, J. (2007). *Making the Case for BPM: A Benefits Checklist*. http://www.bptrends.com/publicationfiles/01-07-ART-MakingtheCaseforBPM-BenefitsChecklist-Rudden.pdf

Sekaran, U., & Bougie, R. (2016). *Research methods for business : a skill-building approach* (Seventh ed). Wiley.

Shafiee, M. (2015). Maintenance strategy selection problem: an MCDM overview. *Journal of Quality in Maintenance Engineering*, *21*(4), 378–402. https://doi.org/10.1108/JQME-09-2013-0063

Shafiee, M., Finkelstein, M., & Chukova, S. (2011). Burn-in and imperfect preventive maintenance strategies for warranted products. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*, *225*(2), 211–218. https://doi.org/10.1177/1748006X11398584

Simões, J. M., Gomes, C. F., & Yasin, M. M. (2011). A literature review of maintenance performance measurement: A conceptual framework and directions for future research. *Journal of Quality in Maintenance Engineering*, *17*(2), 116–137. https://doi.org/10.1108/13552511111134565

Simon, H. A. (1996). *The sciences of the artificial* (3rd ed.). MIT Press.

Simonofski, A. (2019). *Citizen Participation in e-Government: Management Tools Development*. KU Leuven.

Söderholm, P., Holmgren, M., & Klefsjö, B. (2007). A process view of maintenance and its stakeholders. *Journal of Quality in Maintenance Engineering*, *13*(1), 19–32. https://doi.org/10.1108/13552510710735096

Sonnenberg, C., & Vom Brocke, J. (2012). Evaluations in the science of the artificial - Reconsidering the build-evaluate pattern in design science research. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *7286 LNCS*, 381–397. https://doi.org/10.1007/978-3-642-29863-9_28

SPA TBM. (2019). *Final Assessment Form: MSc Thesis Project CoSEM | EPA | MOT*. https://tinyurl.com/y4alxnz4%0A

Spear, S., & Bowen, H. (1999). Decoding the DNA of the Toyota Production System. *Harvard Business Review*, *77*(5), 96–106. www.hbrreprints.org

Stenström, C., Parida, A., Kumar, U., & Galar, D. (2013). Performance indicators and terminology for value driven maintenance. *Journal of Quality in Maintenance Engineering*, *19*(3), 222–232. https://doi.org/10.1108/JQME-05-2013-0024

Suh, N. P. (1998). Axiomatic Design Theory for Systems. *Research in Engineering Design - Theory, Applications, and Concurrent Engineering*, *10*(4), 189–209. https://doi.org/10.1007/s001639870001

Swanson, L. (2001). Linking maintenance strategies to performance. *International Journal of Production Economics*, *70*(1), 237–244.

Trefis. (2014). *Q2 2014 Integrated Oil and Gas Round-Up: Capital Expenditures*. Forbes. https://www.forbes.com/sites/greatspeculations/2014/08/29/q2-2014-integrated-oil-and-gas-round-up-capital-expenditures/#6d5244ea4f17

Tsang, A. H. C. (1998). A strategic approach to managing maintenance performance. *Journal of Quality in Maintenance Engineering*, *4*(2), 87–94.

Tsang, A. H. C., Jardine, A. K. S., & Kolodny, H. (1999). Measuring maintenance performance: a holistic approach. In *International Journal of Operations & Production Management* (Vol. 19, Issue 7). # MCB University Press. http://www.emerald-library.com

Vagnani, G., & Volpe, L. (2017). Innovation attributes and managers' decisions about the adoption of innovations in organizations: A meta-analytical review. *International Journal of Innovation Studies*, *1*(2), 107–133. https://doi.org/10.1016/j.ijis.2017.10.001

Vaishnavi, V. K., & Kuechler, W. (2007). *Design Science Research Methods and Patterns: Innovating Information and Communication Technology*. CRC Press. https://doi.org/10.1201/9781420059335

Van Aken, J. E. (2004). Management Research Based on the Paradigm of the Design Sciences: The Quest for Field-Tested and Grounded Technological Rules. *Journal of Management Studies*, *41*(2), 219–246. https://doi.org/10.1111/j.1467-6486.2004.00430.x

Van Aken, J. E., & Romme, G. (2009). Reinventing the future: Adding design science to the repertoire of organization and management studies. *Organisation Management Journal*, *6*(1), 5–12. https://doi.org/10.1057/omj.2009.1

van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). Introducing educational design research. In J. van den Akker, K. Gravemeijer, S. McKenney, & N. Nieveen (Eds.), *Educational Design Research* (1st ed., pp. 3–7). Routledge.

Van Horenbeek, A., & Pintelon, L. (2014). Development of a maintenance performance measurement framework-using the analytic network process (ANP) for maintenance performance indicator selection. *Omega - International Journal of Management Science*, *42*(1), 33–46. https://doi.org/10.1016/j.omega.2013.02.006

Van Horenbeek, A., Pintelon, L., & Muchiri, P. (2010). Maintenance optimization models and criteria. *International Journal of Systems Assurance Engineering and Management*, *1*(3), 189–200. https://doi.org/10.1007/s13198-011-0045-x

Venable, J., Pries-Heje, J., & Baskerville, R. (2012). A comprehensive framework for evaluation in design science research. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *7286 LNCS*, 423–438. https://doi.org/10.1007/978-3-642-29863-9_31

Verschuren, P., & Doorewaard, H. (2010). *Designing a Research Project*. Eleven International Publishing.

Verschuren, P., & Hartog, R. (2005). Evaluation in design-oriented research. *Quality and Quantity*, *39*(6), 733–762. https://doi.org/10.1007/s11135-005-3150-6

vom Brocke, J., Schmiedel, T., Recker, J., Trkman, P., Mertens, W., & Viaene, S. (2014). Ten principles of good business process management. *Business Process Management Journal*, *20*(4), 530–548. https://doi.org/10.1108/BPMJ-06-2013-0074

Wireman, T. (1997). How to calculate return on investment for maintenance improvement projects. *ASME 1997 Citrus Engineering Conference*, *74*(3), 27–43. https://doi.org/10.1115/cec1997-4303

Wireman, T. (2005). *Developing Performance Indicators for Managing Maintenance* (2nd ed.). Industrial Press.

APPENDIX A

MEETING MINUTES: MASTER THESIS KICK-OFF MEETING

Present at the meeting:

M.Sc. Student: Henrik Talleraas
Chair: Prof.dr.ir. Z. Lukszo
First Supervisor: Ir. M.W. Ludema
Second Supervisor: Dr.ir. Z. Roosenboom-Kwee,
External Supervisor: Are Jaastad, Vice-President of Karabin AS

Time of Meeting:

The meeting was set up in Delft on 02.03.2020, from 11.00-12.00, with two of the committee members calling in through Skype.

Purpose of Meeting:

Present the (proposed) broader lines of the thesis' research design, as well as signing the kick-off form.

Presented Material:

The material presented was based on a thesis proposal submitted to all the committee members in the week prior to the meeting. In this proposal, Henrik proposed to conduct design science research, using qualitative data.

It was presented that, in its current form, The Maintenance Wheel is too context-specific. This makes it challenging to introduce new people to the framework, as well as making them aware of how it works. To rectify this, making a conceptual model of The Maintenance Wheel was suggested. It was also suggested to possibly examine different forms of customer journeys, as well as making different versions of The Maintenance Wheel following talks with Ir. Ludema.

Feedback:

The feedback given indicated that some changes were necessary. It has been categorized according to the thesis' content and the structure of the thesis.

Content: Firstly, a common denominator in the feedback was that the scope should be more clearly defined. Secondly, the final deliverable should also be stated more clearly. Thirdly, the research design should be "compressed" to reduce the steps of the research design. Common reasons for these suggestions were time concerns. One suggestion was, for example, to not focus on both redesigning The Maintenance Wheel, as well as diving into the sales process of it through customer journeys. As was also stated by Are, Karabin is able to sell the framework, but the process of doing so would be easier with a conceptual model of The Maintenance Wheel. It would also increase the current understanding of The Maintenance Wheel, which is desirable. Other feedback also suggested that the document should be simplified. The thesis proposal had been challenging to understand for some of the committee members, a clear indicator that the readability of the document should be improved.

Structure: Regarding the structure of the thesis proposal itself, it was suggested to alter how the chapters are structured. It was, for example, mentioned that the research subquestions should be mentioned after the research design had been presented.

The outcome of the meeting:

- The kick-off form was signed and has since been approved by the Study Programme Administration (SPA).
- The research design will be compressed and made more explicit.
- The research plan will be made more comprehensive. It will be examined where it is possible to conduct steps of the research design in parallel, to avoid wasting time.
- Following a discussion in the meeting (after Marcel had to leave for another meeting), it was also agreed to not focus on specific industries. A framework that works for one company in an industry will not necessarily work similarly for another company in the same industry.
- The final deliverable will not focus on the implementation process. As mentioned by Are, Karabin is able to do this. What they want is a conceptual "model", where it has been analysed what is actually the core concepts of the model, and how these combines to realize benefits. This should help them explain to, and convince, senior managers to implement the framework.
- The number of research subquestions will be reduced, and the research subquestions will be rewritten to fit the changes made following the kick-off meeting's feedback (such as solely focusing on creating a conceptual model).

Meeting minutes submitted by:

Henrik Talleraas

APPENDIX B

LITERATURE REVIEW PROCEDURE

Four literature reviews, each in their respective fields, are conducted in the thesis (see Chapter 3). The topics reviewed are MMFs, maintenance performance measurement, BPM, and diffusion research. However, as the reviews of BPM and diffusion research literature was conceptual, no particular procedure was used, besides using credible sources that were cross-checked.

Review Purpose and Scope

The first step in conduction the literature review was to decide what goals we had for each literature review.

For the first review, we wanted to assess various MMFs, to establish benchmarks for The Maintenance Wheel.

For the second review, we wanted to assess various approaches to maintenance performance measurement, to establish benchmarks for the performance measurement approach used in The Maintenance Wheel.

Strategy

Searches were primarily conducted in the database Web of Science. Google Scholar was also used, albeit in a reduced capacity. This is based on its reliability issues. Search results are customized based on search history in Scholar, meaning that different author's using the same search string get different results. Concludingly, Scholar was mostly used in a supplementary role, to gain access to articles discovered in Web of Science where the full-text document was not available. However, in some cases, it was also used to identify literature reviews for MMFs, as this was difficult. In Web of Science, searches were conducted in the "Topic" category (i.e. title, abstract, and author keywords). If a search is conducted in another search category, it is specified in the search string.

The overarching search strategy for this section was to find literature reviews or books already conducted in the respective fields. Then, these reviews were then examined before new searches were conducted. This was done to get an overview of the fields, and a grasp of the terminology used. The second step was to use these reviews to define the subsequent search strings by using the information of the literature reviews. Lastly, if interesting articles were found in the identified literature reviews or articles which were not identified during the search process, these were included if found relevant.

Search Strings and Results

Search strings provide detailed information of a search, enabling the replication. These strings are now presented.

The first review, on MMFs, used the following search strings, with the subsequent amount of results:

1. Google Scholar: “Maintenance Management” AND (“framework” OR “model”) AND “review” – 71 results
2. TITLE: “Maintenance Management” AND (“framework” OR “model”) – 64 results in Web of Science
3. TITLE: “Maintenance Management” – 742 results in Web of Science

The second literature review used the following search strings, with the subsequent amount of results:

1. "Maintenance Performance" AND ("Literature Review" OR "Review") – 37 results in Web of Science
2. “Maintenance Performance Measurement” – 36 results in Web of Science
3. TITLE: (“Maintenance” AND “Performance” AND (“Measurement” OR “Measuring”)) – 36 results in Web of Science
4. “Maintenance” AND “Performance” AND (“Measurement” OR “Measuring”) - Web of Science Categories: (*“Engineering Industrial” OR “Engineering Multidisciplinary” OR “Management” OR “Operations Research Management Science” OR “Engineering Manufacturing”)* - 507 results in Web of Science

Selection Criteria

Selecting credible and influential articles was desired to increase the reliability of the reviews. Additionally, most search strings initially returned to many articles to possibly consider for the review. Consequently, the selection criteria were defined. Note that attempts of restricting the number of articles were already made in the search strings, by restricting some searches to only show results from relevant disciplinary categories. This was done when the initial search yielded more than 100 publications.

For the maintenance management framework review, only frameworks considering maintenance as value-adding was considered. Additionally, due to the importance of ICT-based solutions in contemporary maintenance management, frameworks accounting for the integration of systems such as ERP and computerized maintenance management systems (CMMS) were used. Based on this, only frameworks from 1985 forward were reviewed. Furthermore, no industry-specific frameworks were included due to the diverse customer base of Karabin, and an attempt to only review frameworks from peer-reviewed journals was made. However, note that due to the influence of two frameworks presented in two independent books, an exception was made to include them. Additionally, since established papers in the field were desired and there were many hits, a minimum number of 15 citations was used. Last, inspired by the review of Campos & Crespo Márquez (2009), only global MMFs, meaning frameworks covering all maintenance management activities were reviewed. Resulting from this is the nine frameworks seen in Table 27 were reviewed.

For the second review, publications included were limited to articles from peer-reviewed journals, except for Parida’s (2006) doctoral thesis. This thesis was included on the grounds of its influence on the field of maintenance performance measurement. The second criteria defined was that influential articles in the field were desired. Being influential increases credibility and shows that the examined frameworks have contributed to the field of knowledge. Therefore, a minimum amount of citations was initially specified, but as the field is relatively mature, it was not needed to identify the leading articles. Additionally, only articles considering maintenance as value-adding was desired. Therefore, the review was restricted to articles from 1995 forward. Last, only generic performance measurements were desired, i.e., no industry-specific frameworks were selected.

Results

See the next page.

Table 27: Results from the literature search.

Search String \ Topic	Maintenance Management Frameworks	Maintenance Performance Measurement
1	1. (Campos & Crespo Márquez, 2009) – Google 2. (Garg & Deshmukh, 2006) 3. (Hassanain et al., 2003) 4. (Crespo Márquez et al., 2009)	1. (Parida et al., 2015) 2. (Kumar et al., 2013) 3. (Simões et al., 2011)
2	5. (Crespo Márquez & Gupta, 2006) 6. (Barberá et al., 2012) 7. (Campos & Crespo Márquez, 2011)	4. (Van Horenbeek & Pintelon, 2014) 5. (Parida & Chattopadhyay, 2007) 6. (Parida & Kumar, 2006) 7. (Alsyouf, 2006)
3	No new results.	8. (Muchiri et al., 2011) 9. (Muchiri et al., 2010) 10. (Kutucuoglu et al., 2001) 11. (Tsang et al., 1999)
4		12. (Stenström et al., 2013)
Found in the previous articles' references.	8. (Campbell & Reyes-Picknell, 2015) 9. (Wireman, 2005) 10. (Pramod et al., 2006) 11. (Söderholm et al., 2007)	13. (Garg & Deshmukh, 2006) 14. (Parida, 2006a) – Doctoral Thesis 15. (Parida, 2006b) 16. (Liyanage & Kumar, 2003) 17. (Tsang, 1998)

APPENDIX C

INTERVIEW SUMMARIES: THE MAINTENANCE WHEEL

Subject 1, Interview 1:

Background information: Subject 1 has many years of experience as a maintenance manager from Equinor. He is responsible for the creation of The Maintenance Wheel, of which he made a prototype in 2007, while he was the head of maintenance at Kårstø. Here, he struggled with coordinating his staff, so he created it to communicate with his staff how to work. In 2010 he joined an internal improvement initiative by Equinor, where The Maintenance Wheel as we know it today, was created. Then, in 2013, he was appointed as the head of maintenance at Sture and Kollsnes, tasked with implementing The Maintenance Wheel.

Sture and Kollsnes:

- **Before implementing The Maintenance Wheel**:
  - Organized with a functional organization, which caused a lot of idle time and frustration among staff and obstructed the flow of work orders—focused on individuals, and the training of them, but not on how to improve the maintenance value-chain. Additionally, Equinor did too much maintenance, too expensive. They did therefore want to establish a new way of conducting maintenance, critically determining what maintenance work orders that were actually necessary. He uses the term input. Furthermore, they wanted to adjust the amount of effort going into maintenance, as they did more thorough maintenance than required.

They set a goal to reduce all maintenance inputs by 20%, without affecting the regularity, HSE, or plant integrity.

- **Implementation (Sture and Kollsnes):**
    - They started by developing an understanding of BPM among the workers. In other words, capacity building, to ensure that all workers were prepared for the new way of working. They built an understanding among the staff that all activities are important in an end-to-end value chain.
    - After doing so, they started distributing roles and responsibilities in the value chain (process) and established new performance measures.
    - They started standardizing the overarching value-chain first and then defined the in-depth activities later.
    - They focused on end-to-end value chain improvements, not cost-reductions.
- How it works:
    - The maintenance work is standardized in a company-wide process, incorporating all functional departments contributing to maintenance. This process is further subdivided into two processes. In the first process, you decide whether a maintenance notification needs to become a work order. In the second process, there are all the various activities needed to fix the asset (plan, schedule, execute, analyse, etc.). Between each stage, there are customer-supplier agreements, specifying what constitutes delivery of quality. Based on these, performance can be measured. Then, as maintenance tasks are conducted, this leads to data. This data can be used to continuously improve maintenance activities.
    - The Maintenance wheel is adapted to the computer system of Equinor. The innermost "layers" of The Maintenance Wheel represent different ERP-codes.
    - It is essential to capture data. This is to assess the performance of the value chain. This is, for example, done with customer-supplier agreements and SOPs'. Documents like this standardize the interfaces between the most critical interfaces in the value chain. These documents are highly defined lists of sequenced activities, describing what must be done to deliver according to the predefined time and quality objectives. These standards are created by those responsible for the deliveries. Through continuous improvement, the best-practice changes, and so should the standards. Furthermore, standards are between functional departments. Therefore, improving standards is a cross-functional job.
    - It is important to have managers with the power, and willingness to make cross-functional improvements.
    - The Maintenance Wheel draws and mixes several approaches to BPM. For example, lean is about making work-orders flow at a predetermined (consistent) rate. Quality management is about removing errors in the process. But to remove an error, you need to know what an error is, which is where the standards come into the picture. And the standards do also define what quality is. Last, Six Sigma is to have consistent trend measurements of quality.
    - There is not a specific list of tools or techniques to be used. What is important is to use tools or techniques which allows you to follow your set plan. "So, with the speed of improvements, if you have a SCRUM improvement or if you use a SCRUM master as a project manager, you use the same approach but achieve it quicker. And this is where your plan enters. If you want an optimal timeline, you have to make a good plan which you follow."

  - The Maintenance Wheel is flexible. If you, for example, only want to improve the quality of the maintenance process, there is nothing preventing this. However, then you will not reap the same benefits, as you only focus on a section of The Maintenance Wheel.
  - Four principles highly important in The Maintenance Wheel is (1) standardisation, (2) customer-supplier relationships, (3) flow, and (4) continuous improvement. If you are not able to make these four principles "connect", you will not reap the full benefits of The Maintenance Wheel.
    - Standardization: Distribution of tasks, roles, and responsibilities. Of the contents of deliveries. And the set-up of tasks.
    - Customer-supplier agreements: A means to establish measures of what constitutes quality and time of process deliveries.
    - Flow is what generates results. By increasing flow, you improve efficiency, lower the lead time, and more. So by standardizing and establishing customer-supplier agreements, you should be able to improve the flow.
    - Continuous improvement: To continuously improve entails increasing the competitiveness of the organization, by improving its performance.
- Benefits:
  - Able to do 40% more maintenance for the same input. They achieved better inputs, meaning that the rate of value-adding maintenance increased. Less time was spent per work order. Improved employee satisfaction. More or less eliminated HSE incidents (standardized how to work + better planning). Better cross-functional communication.
- Disadvantages:
  - Difficult to motivate for change, as managers will have to radically alter the way they are working.
  - You need to spend a lot of time on motivating and building commitment among managers, on all hierarchical levels and in all functional departments, unfamiliar with this way of working. Furthermore, continuous improvements are driven by those responsible for each step/standard. Therefore, if they are not committed, it will be difficult to reap benefits from The Maintenance Wheel.
  - All the functional departments involved need to commit to this way of working.

<u>Subject 1, Interview 2:</u>

The Maintenance Wheel:

- How it works:
  - The Maintenance Wheel visualizes a complex value-chain. It organizes human efforts, illustrating their flow in sequence.
  - It is important to note that the flow unit is a maintenance work-order.
  - An important aspect of managing maintenance value-chain is to have competent workers. The wheel provides an easy way of making staff aware of their cross-functional dependencies, to build competency.
  - The wheel is based on the concept that removing waste categories results in better performance and lower costs per unit produced.
  - Performance measurements

    - Performance measurements inside the wheel are based around quality and time. Time is easy to measure and is extracted directly from the backing ERP system. However, since quality is subjective, and is submitted by staff, it must be defined what quality in fact is. This happens through standardized interfaces between the deliveries among different departments, referred to as customer-supplier agreements. This agreement standardizes what the delivery between different departments needs to achieve in order to be deemed sufficient. Based on this standard, you can then perform a gap analysis if the quality delivered is less than the objective. These are process measurements, in contrast to KPI's.
    - The customer decides which measure to use in order to measure quality.
    - There are also overarching, aggregated KPI's, per "functional department" and for the process. These measure variables such as the need for work, the need for correcting an issue, and the total amount of resources which may be used for corrective maintenance. The same applies to the plan, acquisition, and more.
    - For strategic performance measurements, you can aggregate the lower-level performance measurements, e.g. over the span of a week or a month.
    - Most indicators are leading.
    - Measurements are connected to other departments through customer value. The customer is essentially the plant in which the maintenance happens. So by maximizing customer value, you improve plant integrity, regularity, and so on.
    - In total, Equinor set a goal of 20% less input, 20% better flow, and a 20% reduction of costs. When you improve flow and reduce inputs, you can decide how to reap the benefits; more maintenance or reducing the bottom-line expenditures.
    - Most performance indicators are leading. Only 20% of the indicators are lagging, the KPI's. Whether you have leading or lagging indicators depend on where you are in the maintenance value-chain.
  - Continuous improvements: "You cannot really improve something which is not standardized."
  - Organizing: Use a functional organization. Competency building, sick leave, and similar tasks are coordinated by the functional departments.
  - The structure of the wheel, of how to work, is given by the senior management. Then you use actors in the organization, regardless of their location in the organizational structure, in The Maintenance Wheel. You use them based on their competency. They are then responsible for continuously improving maintenance.
  - He states that the main concepts of the wheel are BPM, end-to-end value-chains, continuous improvement and performance management.
  - "You cannot deliver a budget version of maintenance, but you can deliver a good maintenance product efficiently". The focus was, therefore not on cutting costs.
  - Risk management: Risk is accounted for in the partial deliveries of quality. Equinor has also implemented a risk-assessment step in its value-chain.
  - ICT is a must, as this allows you to easily track time-based measurements, create reports, remain in control of assets history, and similar. Note that one of the fundamental principles of the quality-movement was to make a decision based on facts. An ICT system allows you to do so.

- The ICT system allows you to focus on the value-adding activities, instead of administrative tasks such as retrieving documents to assess an asset's history. "Digitalization is […] used to meet the needs of […] standards, not the other way around."
- You must not complete a full-round around The Maintenance Wheel. Cases where you do not complete all the steps:
  - Faulty notification, no need for maintenance
  - The wear is normal, complete the maintenance based on history.
  - Emergency maintenance (Drop planning and scheduling?)
  - Simplified maintenance, upon asset inspection, simply fix it.
- Regarding the selection process of work-orders: After a maintenance notification is submitted, a worker competent to assess whether the asset is in need of servicing determines whether to proceed with the maintenance. The standards decide whom that makes these decisions.
- Shift-based maintenance is not covered by the wheel. This form of maintenance is not governed by The Maintenance Wheel.
- All types of maintenance are covered by the wheel, but preventive maintenance enters after the first process.

- Benefits:
  - If there is no standard, there will be uncertainty and no stable deliveries. This is caused by different perceptions of the same problem. The Maintenance Wheel provides predictability.
  - The standards are highly useful to build competency, as it depicts the best-practice. You, therefore, close knowledge gaps by on-the-job training, which is cheaper than seminars and similar events.

Subject 2, Interview 1

Interview subject's background: A leading consultant and manager of Karabin AS. Experience with management consulting, as a line manager of a maintenance department, and as a plant director of a plant with more than 600 employees. He quit working at this plant and started working as an independent consultant. While doing this, he was hired due to his experience and reputation as a lean expert to assess whether The Maintenance Wheel was a lean-based approach to maintenance management. This was in late 2013, until 2015. He found that The Maintenance Wheel provided a "cutting-edge" method of managing maintenance according to lean. His earlier experiences with maintenance were that it was difficult to find a way to think of flow in maintenance, due to the stochastic nature of maintenance. Or how to think of standardisation when every job is different.

The Maintenance Wheel:

- The Maintenance Wheel is like an imaginary assembly line, on which the flow unit is the various work orders.
- The Maintenance Wheel incorporates other silos, improving the coordination between the various functionalities, which contributes to the maintenance process. This breaks

away from the standard approach to maintenance, namely, to think of it as its own functional department, isolated from other departments.

- He describes The Maintenance Wheel by referring to the article published in the Harvard Business Review in 1999, called "Decoding the DNA of the Toyota Production System", written by Steven Spear and Kent Bowen. They summarize lean as standardising work, using customer-supplier agreements, continuous flow, and continuous improvements.
- The Maintenance Wheel is a typically relevant measure for companies wanting to improve their profitability, lower their expenditures, and improving equipment availability.
- The value chain which The Maintenance Wheel illustrates is more or less universal.
- The Maintenance Wheel is more useful for companies that are asset and capital intensive.
- Since The Maintenance Wheel provides a way of standardising maintenance, it is not necessarily only useful for those companies with strict requirements to the reliability of their internal processes, e.g. companies producing medicine.

Subject 2, Interview 2:

- **Integration with Karabin's benefits realisation process:** Karabin scopes and adapts their benefits realisation process to each specific customer. They experience that the knowledge of BPM is lacking and that it is usually necessary to gradually introduce some of the concepts used in The Maintenance Wheel.
- Although most customers have some form of a maintenance process in their computer systems, there is usually little coherency and contents to these processes. This is usually due to a lack of competency of their customer staff related to BPM.
- In addition to a lack of knowledge, a challenge is that managers question The Maintenance Wheel's compatibility with their own business context and want to know what concepts The Maintenance Wheel is based on.
- Karabin has no specific customer profile and serves all companies which want it. It is, therefore, important that the designed framework is generalized.

Subject 3, Interview 1:

Interview subject's background: Background from Equinor and is a lean coach. She has worked with BPM for multiple years and was hired by her current company, a large capital-intensive company (market worth >5.5 Billion Eur) to improve its maintenance department. She has a unique insight into what challenges The Maintenance Wheel can be used to solve, and she is able to speak to the qualities of The Maintenance Wheel from the perspective of a customer. She is currently responsible for implementing the wheel in more than 15 facilities (>700 people) at the same time.

They are currently working with the inputs to The Maintenance Wheel, having more than 30000 notifications submitted per year. And, of these, roughly 50% is corrective maintenance. These 15000 thousand tasks need to enter the same maintenance process. So, they are currently focused on controlling the inputs to their maintenance process, and they expect to be there for a long time. "If I am not able to control the quality of those work-orders which enter the maintenance process, I will never be able to improve the latter parts of the process".

- **Difference between the previous way of managing maintenance and The Maintenance Wheel:**
  - Continuous improvements: Previously, they chased cost reductions and increasing availability based on "symptoms" of larger issues. With The Maintenance Wheel, on the other hand, performance measurements of the process identify the root-cause of issues, resulting in larger, realized benefits. Instead of chasing project-based improvements without lasting benefits, they are now chasing lasting improvements for the entire value chain.
- **Critical success factors:** You need competent managers who understand what this way of working means. You need a team of managers who act as champions for this way of working, that are willing to make changes. If the managers are not motivated, you will never be able to implement the wheel, as such a large number of people needs to change the way they think and work.
- **Motivation:** They want to cut maintenance costs by roughly 95 Million EUR per year. They also want to train their organization to continuously improve in order to reap lasting benefits. Last, an important aspect is to increased employee satisfaction. "There are so large benefits from working this way that not doing it is not an option."
- **Challenges:**
  - The Maintenance Wheel entails a completely different way of working than what is normal, at least for the Norwegian industry, e.g. due to continuous performance measurements and a different way of thinking about work.
  - Differing knowledge levels pose a challenge while introducing The Maintenance Wheel.
  - The Maintenance Wheel is based on concepts which takes time to understand. It is necessary to understand that nobody will commit to The Maintenance Wheel based on one conversation.
  - The Maintenance Wheel is not complete. It only covers corrective maintenance. She argues that preventive maintenance is also essential. For example, The Maintenance Wheel does not cover "Analysis", "Actions/Improvements", "Goals" and Accept Criteria, and "Maintenance Program alterations". Also, design-out maintenance is not covered. Currently, they only analyse preventive maintenance. However, she mentions that they have a narrower scope today, and they are not able to do everything at once. Eventually, they will be able to use their loop to also analyse corrective maintenance.
  - Some people refuse to adopt the new way of working since it is drastically different than how they have been working previously. This is particularly true for older staff. This is a large problem, as they will ultimately be the ones realizing and driving continuous improvements.

APPENDIX D

TRANSCRIBED INTERVIEWS: THE MAINTENANCE WHEEL'S CREATOR

This appendix contains the transcripts of two interviews conducted with the creator of The Maintenance Wheel. Before the interviews were conducted, he was presented with the interview's intent, which he accepted. This agreement covered confidentiality, and the publication of the transcripts was accepted. The full transcripts are included due to their potential value to someone looking to implement The Maintenance Wheel. Note that the interviews have been transcribed and translated from Norwegian.

Interview 1

[Interviewer (H.T.)]: Could you describe your role in the creation and implementation of The Maintenance Wheel?

[Maintenance Wheel Creator (MWC)]: we have to go all the way back to around 2006-2007 when the first version was created.

[H.T.]: Oh, so you started with it so long ago?

[MWC]: Yes. I have a [early] version which I made to train the employees of my division. I was the head of maintenance at Kårstø [the biggest Gas processing plant in Europe], in the mechanical department, region west. I was the manager of a large department and needed to create a shared understanding among my staff of how we had to work, which is how the wheel was first created. I then found out, through my role as the department manager, that it was very easy to communicate it [The Maintenance Wheel] to the workers, as an image is usually easier to communicate as opposed to a lot of factual documents. So, it quickly became part of the way we thought of work and how we worked. Until 2010, we used it internally [within Kårstø], and spread it where we could, including suppliers at Kårstø. However, in 2010, I started working in an improvement initiative of all the land facilities of Equinor that was started. This lasted from 2010 until 2013. There, The Maintenance Wheel was brought in as one initiative, and it was visualized in a better way.
Additionally, a new and improved [maintenance] process was defined, and the wheel was adapted to it, resulting in it looking the way it looks today. From December 2013, this wheel was then put into operation at Sture and Kollsnes. As this happened, I went from a position in the improvement initiative to becoming the head of maintenance in the facilities Sture and Kollsnes.

[H.T.]: Ok, so then, if we must summarize briefly, you created the first version of the wheel. The wheel was spread internally after that before you were tasked with implementing it at Sture and Kollsnes from December 2013.

[MWC]: Yes.

[H.T.]: So, can you tell a bit about the implementation of the wheel, and how long it took? At Sture and Kollsnes, specifically.

[MWC]: Yes. It started with creating an understanding of business process management [among workers] to understand The Maintenance Wheel. Also, it was done to build an understanding that all activities are equally important in an end-to-end value chain. That everybody is responsible for the continuous improvement of their deliveries. And more. So, it started with a lot of capacity building. After that, it was mapped *whom* that had to do *what*, and who that was responsible for each part of the delivery. Performance management based on time and quality was implemented. It took roughly two years before we started seeing significant effects of the work.

[H.T.]: Yeah. So, The Maintenance Wheel was created with a purpose. I am thus curious which problems The Maintenance Wheel was made to solve? The purpose of this question is to examine which problems The Maintenance Wheel can help solve [for other companies looking to implement the wheel].

[MWC]: Yeah, so there is a set of theories connected to what these sorts of thoughts and setups can help solve. It is mainly related to input and to flow. Concerning inputs, we did way too much maintenance, way too expensive. This means that we wanted to look at what criteria were used to determine what maintenance we had to do. The form of maintenance which is affected by The Maintenance Wheel here is corrective and preventive maintenance. If you think of the wheel as connected to lean, and then towards the [seven] categories of waste, you may say that the categories related to input are the categories of inappropriate processing and overproduction. By this, I mean that we did too much, which did not give customer value. And when we did something that did, we used to many resources [too expensive]. We conducted maintenance better than what was required, which becomes an expense [overprocessing]. So, these are the two categories which are related to the input. So, what we then did is to look at whether it would be possible to reduce inputs by 20%, without this affecting the regularity, "health, safety and environment", and integrity [of the plant]. These are the three most important factors which you have to manage, as they are the regulatory conditions. 0 incidents, 0 integrity which means 0 failures in equipment that you do not have control over and barriers in place, and of course that you produce the set production objective, meaning the requirements of the customer at any given time. And then, you can say that when you have controlled the input, you wish that the work-orders which has been put in on the assembly line, or The Maintenance Wheel if you want to use that terminology, you need a good flow. You want to avoid excessive processing, lack of competency resulting in activities taking too long, and it is all the categories which result in waste entering the value chain. We know that, in general, to do a task, it is typically done, if you have zero waste categories with you, around 30% of the time spent is on doing it and around 15 % necessary administrative time, so you are at approximately at

50% of the time spent. The rest of the time, 50%, is waste. This is where the benefits could be realized. We only wished to realize 20% of this 50 %, and we achieved this relatively quickly.

[H.T.]: Okay, so the next question I was planning to ask is related to what you ended with now. When you implemented this wheel, you realized some benefits. Which benefits were realized quickly, and which emerged as you engaged in continuous improvement?

[MWC]: Yes. We did relatively quickly say that we did not want to have a focus on the economy. The economy is possibly the most common driver behind such an improvement [project], but we did not want to cut costs by reducing maintenance work, we wanted to improve the value chain, end-to-end. So, all the deliveries in the maintenance process. So, we focused on the work environment and HSE. Work environment and HSE is often the same, so we wanted to improve employee satisfaction. Good deliveries are often connected to employee satisfaction, so we measured that for each employee. This increased. For those who were absolutely opposed to The Maintenance Wheel, they were probably down in a slump, to begin with. However, as they began to understand this is the way we worked, and this is sensible, more employees started applauding the new way of working. So, employee satisfaction was important. That which is connected to HSE was also improved; we had as good as zero incidents. To conduct a task more precisely, to follow standards more precisely, to develop best-practice documents which engage in cross-functionality capacity building contributes to achieving deliveries within the set objectives of time and quality, that contributes to achieving zero deviations related to [HSE] incidents. This showed promising effects.
Additionally, we saw that way less time was spent on work orders, because we decided on better inputs, so better ways of servicing equipment, alternative ways of servicing equipment to what was decided, better routines related to putting equipment back into production and so on, with every factor related to the seven categories of waste, we saw on the bottom line. We conducted more maintenance using the same amount of resources. We achieved an increase in maintenance of approximately 40%, with the same amount of input as previously.

[H.T.]: That is a very impressive result. Something which I also want to ask about, if we go back to before The Maintenance Wheel was implemented at Sture and Kollsnes, is performance management. How was the maintenance department managed before The Maintenance Wheel?

[MWC]: It is important to think about autonomy. In a traditional organisation, you usually develop human resources [capacity building]. After that, you employ these people to conduct tasks, and it is these employees who find the best way to conduct maintenance. Often, the interface between [different] tasks is not as coordinated as they should be, so that you may have a lot of idle time and frustration, which lowers flow or is detrimental to the work environment, and so on. So, this is the traditional way of working. And people do enjoy being autonomous. However, this [The Maintenance Wheel] does not compromise competency; it becomes more important to have the correct competency to solve the tasks. Nevertheless, some tasks are more important than others. Moreover, some interfaces are more important than others. So, when you implement the wheel, you identify these areas, and the way you mitigate or make it possible to identify the waste categories is usually through best-practice. So, it is best-practice documents, connected to what I said, and the documents which are used are SOP's, EPL's, and customer-supplier agreements. It is the person responsible for each task which establishes these documents and is responsible for continuously improving. Furthermore, you measure these deliveries, which is where performance management comes into play, on the level which each delivery is made. You are not measured as an individual, but as an actor, on whether a delivery is within the set objectives. If it fails to meet the objectives, you must come with concrete measures to remove the root cause of why an issue arises. This is where performance management is connected to the value chain or The Maintenance Wheel in our case.

[H.T.]: So, if I understand correctly, you went from being centred on individuals, to [focusing on] measuring the deliveries made in the value chain?

[MWC]: Yes. And you can say that it is impossible to measure if you do not manage to capture data. And quality is often measured according to a standard, so you must construct some standards to be able to measure. And here is the connection between software, or the computer program, which is part of the workflow. It is so that when an employee puts in data in a computer program, he presses the wrong box, or in general, just inserts the wrong information. Then we need to ensure that the information, which is put into the computer program and is extracted as reports to, for example, look after issues, is of the necessary quality. Thus, we had to move a bit away from being autonomous to becoming more specific.

[H.T.]: Yeah. When you began with the implementation, I am wondering how you started to define the processes? Did you start broadly, or did you start with highly specific processes? In other words, did you derive the processes top-down or down-up, if that makes more sense?

[MWC]: Yes, you could say that the experience is that if you make it simple, it is simpler to implement. If you try to bureaucratise it and make it more complicated than it is, you will face resistance, particularly from the operational level of the organisation. Because, if there is one thing the operational level does not enjoy, it is lengthy PowerPoints and a lot of theory. They wish to know why you are implementing something, whereas what they have to focus on is not something they have an interest in. So, they want to have examples of how you do it in real life. And therefore, if you have developed a "how-to", which The Maintenance Wheel is on the highest organisation level, it is the entire value chain from end-to-end, it is a picture of how a large and complex process with hundreds of employees and deliveries. An acknowledged scientist said that "A picture says more than a thousand words", and this is precisely what The Maintenance Wheel is. It is easy to explain input. It is easy to explain the flow. It is easy to explain the most critical tasks in a sequence. It is easy to see the connection between the computer program, such as the ERP codes and the most important actors, and the most critical activities. So, you have a form of a 3D SIPOC, is what The Maintenance Wheel is.

[H.T.]: A 3D SIPOC, that is a term I have to say I am not familiar with. Could you explain it?

[MWC]: Yeah, so it is not a formal expression. But The Maintenance Wheel is adapted to the software we use in Equinor. It is adapted to the most important roles who conduct the most important activities. So, if you look at the wheel, and try to understand it like it was intended to be understood, the innermost circle described a notification and a work order. The next ring contains the ERP-codes which you find in the computer software, so when you want to extract a report and select [the code] "PREP", you know the status. The third ring is the most important task [activity] done in that delivery. And then the outermost ring describes who in the ring which is responsible for this task being done. So, this gives a picture of the sequence and the time. And then you have to develop the documents I talked about earlier, as standards between the interfaces, such as the handing over the [relay] baton between important activities. It could be important best-practice documents related to standardized documents of critical deliveries, where you have to engage in cross-functional capacity building, where you have to go from being autonomous to be more specific. Here we are not discussing long factual texts of how to do something, but a highly defined list of sequenced activities describing what you have to do to deliver within the set time and quality objectives.

[30:00]: [MWC]: This is what I am referring to when I am discussing that the wheel considers both computer software, whom that is working, and what you are working with. These are the three dimensions I was referring to. What makes it so easy to communicate [to employees], is that when you are presenting, you only have to use a single picture on the wall. You do not need factual documents; you use a single picture to communicate the entire story.

[H.T.]: Okay. So, when I am referring to whether a top-down or down-up approach was taken, I am referring to the to the process of deriving the wheel itself. Because, I would assume, to take an example, the first activity [of the wheel] is "need for maintenance", and "quality control" [is the second]. And you said that the third ring of the wheel describes the most important activity of that sequence. What is implied is that all of these activities are part of "sub-processes", if I understand correctly? So, take quality control [as an example], there are other activities done within this "box". Are these activities also defined as "sub-processes"?

[MWC]: Yes. You could say that an overarching process has a set of activities. If, using your example, submitting notifications to say that maintenance is needed is something everyone can do. However, that being said, there is no guarantee that the notification is of quality. The notifier may have, for example, have made an observation which is not correct, despite him having described the need for maintenance well. So, as there needs to be a good foundation for decision-making, quality control is done. In the quality control, there is also a process, because what should you actually quality control? That is a sub-process, right? So, you have sub-processes in each of the black boxes in the third ring of The Maintenance Wheel.

[H.T.]: Yes, okay. That is what I was thinking of. Because, when you created the wheel, you have a very broad overview of the wheel, which is easy to understand, in addition to sub-processes. So, when you created the wheel, did you start defining the overarching value-chain first, or the sub-processes found in, for example, quality control?

[MWC]: Well, you begin with, you talked about different levels. You start with The Maintenance Wheel as a picture of the assembly line that is needed to conduct maintenance in a facility. It is not possible to conduct maintenance in a facility without going through these steps. And you cannot necessarily jump between these steps; you need the outputs from of each step. And you may say, for example, that making coffee is a process. So, if the description of the work said that you had to make coffee, it is easy to describe how you actually make coffee. And then you have to ask yourself, what flavour does the customer want? And here we start talking about all sorts of varieties [that the sub-processes] need to consider, such as the ratio between water and coffee. And this is how you work with each of the "black" boxes [the third ring in The Maintenance Wheel], right? But the problem is that somebody else has said something, or they have said something about how they work. But, autonomy… everyone is allowed to be different. But in the organisation, we say that only a select few people are allowed, maybe 2% of the organisation, work with the description of the need for maintenance. Or maybe not describing the need of maintenance, everyone can do that, but to quality control to check whether the notification satisfies the criteria to become a part of the process [i.e. to be fixed]. So here, you pose the question to those in the organisation, independent of their place in the organizational structure, how will the customer in the next step want their delivery, and what do you [in your task] have to do to ensure that these [customer] expectations are met. So, then you have to do some research, such as how to do you, in fact, conduct quality control to ensure that you avoid inappropriate processing and overproduction [2 of the seven wastes]. You have to have what the customer needs, and the customer is the facility, it is not any particular person: it is availability, it is integrity, and HSE. And these have to be at a satisfactory level. And you do this throughout the entire wheel, where you end up with a value chain composed of many processes, which acts together to deliver the value which is desired from the end-to-end value chain.

[H.T.]: Okay. The reason why I am tasking this is that you defined four improvement principles relatively early in the implementation of the wheel at Sture and Kollsnes, one of these being to standardize. Due to this, I am wondering how standardized these sub-processes are, the third ring of The Maintenance Wheel? This is to understand how other companies have to adapt The Maintenance Wheel themselves. And whether these sub-processes then were defined before the value-chain [The Maintenance Wheel] was illustrated?

[MWC]: Yes, the standardization of the sub-processes are created after you have established and built an understanding among the staff of The Maintenance Wheel, you have identified those in the organisation which do the tasks related to the most important activities, and then you start asking the questions. Because you start mapping the current situation of, for example, how they currently work with M2's [maintenance notifications], and from there, you start to build an image of how they work. And then you start asking the question: "How should we be working?". And the answer is that we will still be autonomous, we will still engage in capacity building, but we will become a bit like the aviation industry where we have some pre-take-off check-lists, to check that we actually have done the things we have said that we would do [in each step] and delivered it according to the set objectives of quality [and time]. So we have said that we need a customer-supplier agreement, we need a standard, but we say to the people responsible for each task that it is their responsibility to make a best-practice document. Still, first, you need to identify the way you work today, and then develop it from there into infinity so that we achieve deliveries within the set objectives of time and quality. So, the standards come in the end.

[H.T.]: Okay. That is also something which is discussed in Iden's (2018) book. He discusses how to implement business process management in a company, where he starts with creating an overview of the entire value-chain, then you start standardizing, and as this has been established, you start working with continuous improvements. So, it is good to have that clarified, that that was, in fact, the way you worked.

[MWC]: Yes, and what is interesting is that if you go to any other company, in the entire world in fact, and look at maintenance. Maintenance is possibly the largest industry in the entire world, whether you are talking about maintenance on buildings, facilities, roads, and so on, and everyone who works with the maintenance of assets in a facility with 24/7 production, need to deal with the same wheel. So, if you have done it in one [facility], you can copy it to any other facility, that is how generic it actually is.

[H.T.]: Okay, so if you first develop an understanding in a company of how to implement it [business process management], you will say that it is possible to implement it?

[MWC]: Yes, because it is like you are making a washing machine or a car, or whatever need be, where you have to have specific input and convert it to a certain finished product, which needs a given quality that is defined. The steps you need to take to conduct maintenance is generally like what you see here. The Maintenance Wheel will always be a helping tool for everyone who needs to adapt this way of thinking because it is not that many ways to do it. It is only who that actually does it [maintenance tasks], and which computer program you use to aid the way of working that captures data as you progress through the various steps. So, the black boxes [third ring of The Maintenance Wheel], will always be relatively similar [in other companies], I have at least not seen any other who approach it very differently.

[H.T.]: No, it is possibly a lack of control in other companies in comparison to you [Equinor]. At least, it seems as if you have a good hold of the entire process with the standardization you conducted. Many other companies do not think about maintenance as a process, they do only think [, for example,] "oh, this filter is broken, I need to fix it", without involving anyone else, in effect very autonomous as you were talking about earlier.

[MWC]: Yes, and that is one of the big things to take notice of, also in respect to Iden [author of the recommended book discussed previously] about business process management, of managing in a process versus managing in a functional organisation. Many other companies build up their organisations according to their functions, and not according to their value chains, right? And to manage in a value chain is commonly done irrespective of the organisational affiliation. And to have a manager who has the power and authority related to business process management includes management of suppliers, other departments, consultants, in effect you do not care about the functional department [that each employee is part of]. Still, you use the staff in the value chain where they have the competency, and you need resources. And this is one of the good things about Jon Iden's book, because he visualizes it in a very good way, and makes it understandable for anyone interested. And when you understand this, it is simpler to translate it into real-life regardless of the value chain in question, which is why I am delighted with Jon Iden's approach, since he has researched it. But I was not aware of Jon Iden before I had developed this [wheel], it was only a couple of years ago since I first read his book. I was benefitted by this book, as it gave my own theories support, which I have used in practice, through research.

[H.T.]: What I am a bit curious about, is whether there are any negative aspects to implementing the wheel? Were there any issues which were more prominent than others?

[MWC]: What I am able to say about that, and which I have experienced, is that if you do not spend enough time on "anchoring" The Maintenance Wheel to establish the steps of the process which we discussed previously, if you do not understand this image as a manager, and are not capable of communicating the picture to your employees, there will be a lot of issues. It is an entirely new way of thinking for a lot of people, but if you can spend enough time on anchoring, to mobilize the managers, and I am talking about all managers regardless of their location in the organizational structure, as said. All decisions of going for a business process management process is anchored high up in the organisation, that there is no alternative to going for that approach, that the only alternative is to improve the structure and the standards. The structure is determined by the way the wheel is set up, and the standard is the content of the type of documents done to make this work in real life. With this, I am talking about the contents of these standards is based on those who are delivering something, as nobody should tell you how you should do a task. You should describe how you do this task today. Then you should identify gaps in the best-practice approach, after which you should start measuring your performance concerning continuous improvement. And this insight, this summary, is what we refer to as "mobilizing for commitment". I think the documents I sent you to discuss this quite a bit, that if you are not able to do this, which is possibly the hardest job, you will not be successful.

[H.T.]: No, okay. Now you said something interesting, which I did not expect. But I was referring to when The Maintenance Wheel is implemented, so, in effect how the organisation responded to it? Were there any unexpected consequences which had undesirable effects? Possibly, for example, through increased expenditures. You mentioned earlier that the economic aspect was something you did not focus on initially. Did this then, for example, increase in expenses increasing during implementation?

[MWC]: No, benefits were realized relatively quickly after implementing the wheel, and this has been proven multiple times internally, so this is something we have quite a lot of experience with too. The negative aspects are usually related to management. If the management is not engaged, and the planned change is not anchored in the higher hierarchical levels, if it is not part of the strategy, there is no purpose for a single department to start working with an end-to-end value chain. And we know a lot about what happens then: if one delivery in the wheel, for example, quality control, as we discussed that previously if one department decides "let us do a better quality control", this will not work. This is caused by it being a collaboration between production, maintenance, and technicians to decide what is "good-enough" quality control. This means that you cannot do it as a single department or employee; you need to do it cross-departmental. And this is when you start thinking that we need to mobilize the entire organisation, we need to anchor it on in the higher hierarchical levels, on the top management's level, that this is the change we are going to do. And when we have done this, we have not experienced any particular issues with regards to the resources you need. For example, the resourced required to conduct capacity building, the resources required to develop structures, the resources you need to develop standards, the method of measuring, of the continuous improvement, and so on. All of these aspects are relatively simple to achieve. The biggest challenge is to make the manager, who start [with the change process] first and is the most impatient since he knows and understands the most to be patient. You know of sine waves, right?

[H.T.]: Yes, of course.

[MWC]: Where somebody is on the highest point, somebody else is on the bottom, and as somebody else reaches the top, somebody else is still on the bottom, right? So, it is sort of the manager's job to make everyone reach the top of this sine wave, and he needs to be careful of not becoming too impatient and too engaged, which can result in the exhaustion of staff or the staff becoming tired of nagging. So you have to allocate quite a lot of time to conduct the implementation, and here the plans are essential, you can not achieve this if you do not have a milestone plan, you need a detailed governance plan. This plan should not be too ambitious, but "on-the-job", right? You do not need to spend many resources on this [besides time], you do it as part of the daily work assignments. And, therefore, the staff, or the [human] resources, will not feel as if it is a burden, but a way of improving their own work environment. And what is also implied by mobilizing for commitment, is to focus on, for the management, on different [hierarchical] levels, to describe the change history of why we are doing it. So, by focusing on the fact that if we do this change, then we will improve, for example, the quality which will give a better availability, a better work environment, a lot of positive results for the employees, and possibly other positive aspects for the management and the owners, the society. So, mobilizing for commitment is the most important step before we start. And from there, the milestone plan determines who will be involved when, and when the various sequences should be run.

[H.T.]: Yes, okay. So, what I am thinking of then … there is a lot of [importance] related to the implementation, where you must be very thorough. This could, possibly, for companies which want rapid results to be seen as a barrier. They would need to spend quite a lot of time on it [implementing The Maintenance Wheel], despite the overwhelming set of benefits and the lack of resources needed for the employees and so on because it is quite a change to alter the way the entire organization thinks. Despite the benefits possibly indicating that it would actually be the wisest decision.

[MWC]: Yes, and it is not necessarily a discussion of changing so much about the way you work, as most people work this way, you need to achieve more precise deliveries according to time and quality, right? So, you identify those in the organisation who does a task today. Then you challenge them on how this task could be done in optimally, with the "best-practice" documents, in effect standardizing critical tasks.

[H.T.]: Ok. Regarding the philosophy behind The Maintenance Wheel, there is lean which we have discussed previously. When I examined the book of Iden, he writes a bit about quality management. Is this something which was discussed? Because he discusses three different approaches to business process management, namely lean, six sigma, and quality management, so I am wondering if you have been inspired by these two other approaches? Because you talk a bit about quality in deliveries and other elements which are common in quality management, and so on.

[MWC]: Yes, it is nice that you bring up those three approaches. Because, in my mind, lean is about making things flow at a predetermined rate. And quality management is when you measure 0 errors, but to measure 0 errors, you need a standard, right? And you may have a standard, such as Ryanair having their standard, and Scandinavian Airlines have their own too, as an example. So, you pay for what you receive, but you are measured against the standard you decide on. And it is like this in maintenance too. So, when we have decided which quality we need on the input, we have decided on the content of the quality control, right? But we cannot deliver quality in the quality control without having defined what in fact quality is for this task. So, this is where quality management enters the picture, which is measured according to time and quality. And how to conduct this measurement is done according to a reference, to identify an improvement area, and then you have continuous improvement to act on this possible improvement. And six sigma is, when you measure, in particular trend measurements, you deliver for example 40% quality today, but desire to deliver 100% quality, the possible improvement is 60%. Then, you have to do some specific actions to act on the possible improvement. And then to measure whether the actions you have done have succeeded in meeting the 100% quality objective if you have a positive trend. If you have large deviations in this trend, you may say that the actions taken do not work because the variation is as large as before, we are not able to achieve a variation within the desired objective. **[60:00]:** In effect that we do not deliver something having a quality variation like a yoyo. And this is where six sigma becomes relevant. So, there are a lot of theories that we use, including those three that you mention, which are of course particularly important.

[H.T.]: Yes. You say that there are a lot of theories used. Are there any other theories which you would emphasize?

[MWC]: You could say that I am not as interested in which theories that explain what, I am interested in getting results from the tools which have been created by the theories. So, with the speed of improvements, if you have a SCRUM improvement or if you use a SCRUM master as a project manager, you use the same approach but achieve it quicker. And this is where your plan enters. If you want an optimal timeline, you have to make a good plan which you follow.

[H.T.]: Yes. That is also the impression I have, that the results are the most important. I felt I had to ask because I need to explain the framework's theoretical foundation. But would you then agree that lean, six sigma, and quality management are the most important aspects?

[MWC]: Those are the three most important theories I have used. But that does not mean that I am not using other theories or other approaches.

[H.T.]: Yes, okay. But finding the main theories used is what is most important, right? As there will be quite a lot of flexibility for each potential company [to adapt The Maintenance Wheel], depending on how they want to adopt it themselves.

[MWC]: You could say that lean suits The Maintenance Wheel well, as it is a standardized process which does not change a lot. The innovation that you need is actually found in the deliveries, right? You may say that the deliveries are made simpler. But it is not like you must develop a new product. Lean is not as suited for product innovation, but for something stable [e.g. a process] that you wish to improve continuously. So, therefore, I have a particular emphasis on lean. But this does not mean that only lean is used throughout the wheel.

[H.T.]: No, okay, that is nice to hear. It is a bit important to discuss this, because it relates to how the wheel can be adapted to different types of companies, depending on, for example, the company size and the type of industry.

[MWC]: Yes. But there is no need for it to be as complex as it is today. When you are integrating The Maintenance Wheel in an organization, you can do it step-by-step. If you, for example, decide on solely focusing on quality control, to improve only this input, nothing is preventing this. But then, everybody working with this quality control must develop a standard irrespective of their organisational affiliation. This is so that you avoid resistance within the organisation, with an example being that one manager is in support of the project, whereas another is against it. That he does not want to use resources on it. That he does not want to motivate his staff to work in this way. In effect, we are then discussing mobilizing for commitment in a smaller section of The Maintenance Wheel. Or whether you attempt to do it for the entire Maintenance Wheel, you have to identify anyone who is involved, independent of the organisational affiliation and to anchor is so high in the organizational hierarchy that the decision-maker has power and authority over everyone which will work with it.

[H.T.]: Okay. So, then I would like to move on to the four improvement principles that we have already discussed in brief earlier [in the interview]. There is standardization, customer-supplier relationships, flow, and improvement. We have discussed a bit about each of these principles in themselves. But is it possible to hear about how these four principles work together to realize benefits?

[MWC]: Yes, you could say that it is difficult to look at one of the principles without seeing its connection [to the other principles], right? And there is a sequence of how to approach these principles. Standardization, customer-supplier relationships, flow, and improvement is principles which are interconnected. You cannot really look at one of them in isolation, and you need The Maintenance Wheel before you can think about the approach because when you look at each of the activities in a sequence, or in parallel, you need to be very careful with some of the interfaces. And if you are not able to make these interfaces connect, you will not be able to achieve a steady flow, meaning that you will generate waste such as idle time, deviations from the set quality objectives, frustration, and so on. So, there are a lot of negative consequences of not coordinating appropriately. And thus, there is a need of looking at the end-to-end value chain, on the activities, to look at where there are interfaces between deliveries, what form of interface it is, does it require standardization, who will make the standards, and so on. So, the first thing in the sequence is The Maintenance Wheel, if you are using that terminology, or the value chain if you will. And then, you have standardization, which means that you have to identify who does what, the content of the deliveries, so all the of the deliveries needs a customer, a relay baton, and then you need a customer-supplier agreement standard related to how to deliver according to time and quality. And then flow is the product, where the results are. If you can increase the flow, you can reap the benefits from eliminating the seven waste categories, you increase the efficiency, you lower production costs per unit, you get a lower lead time, so this is where the results are. And continuous improvement is what you need to increase the competitiveness of the organization to a higher level. I do not know whether this was a good enough explanation, but you cannot look at each of the principles in itself.

[H.T.]: No, the explanation was clear. So, I think we should wrap up for today.

[Remaining parts omitted due to relevance.]

Interview 2

[H.T.]: In our last meeting, I was planning on asking you a question which I think is a nice place to start today. Could you please describe The Maintenance Wheel, by only using a couple of sentences where you describe what you find to be the most important aspects? So, in effect a very simple explanation of it.

[MWC]: Mhm. If I have to summarize it briefly, it is a visualization of a complex value-chain. It is a picture of activities in sequence, or parallel, which is about the deliveries of humans, or resources if you will. So, to achieve quality throughout the different stages of the wheel, you need to have competent workers that submit these. And you need a standardized way of working, to coordinate the critical interfaces, and the critical deliveries. This is the backdrop for understanding maintenance. And by describing this history through a picture, it is easier to understand the interactions, such as what the product is and how our assembly line is structured [the maintenance value-chain]. You do not need to use and switch between a lot of PowerPoints. The discussions are based on this picture. And in this picture, it is visualized what software, what form of a computer program which is built into the value-chain to support administrative tasks such as capturing information, extracting information (reports), analysing information, and to learn from this. So, I think that last time, I told you that there are 3 or 4 dimensions, such as what type of document, what status (how far have you come in the document, in the computer program), and the most important actors in the organization, and the most important tasks. So, there is a lot to discuss time and quality in the wheel, regardless of where you are in it.

[H.T.]: Yes, OK. That was a good explanation. But what you ended with now, about time and quality, is what performance measurements are based on. I was wondering if you could explain why exactly the indicators time and quality is? Because there is a lot of approaches to approach performance measurements within maintenance, and it is something which I find to be one of the most exciting aspects of The Maintenance Wheel.

[MWC]: Mhm. You know, if you take a computer program, software, that supports a value-chain, it is mainly the people who are performing the different tasks that are inserting data into the program. So, the data that is inserted into the computer program, that is subjective data which is based on the competency of each individual worker. So, the variance in the data set, which is the foundation of the reports [used by managers to assess the performance], will be challenging to trust and come to conclusions with. An example, if you have a factory, where you bring in data from sensors, such as temperature and flow, these are objective and absolute measures. They are plotted continuously, and you will have a continuous assessment of the plant's condition. But it is not like this in a value chain which covers the deliveries of resources. Of humans that are allowed to be 100% autonomous, more or less. They get trained, and then they have to put information into the software which results in the capture of data, based on their [the resources] experiences. If you take one of the inputs to this process, what is that? It is an error condition or the need for some sort of work…
[Connection issues]

What I was discussing now, was that you have a variance in the data quality of the data gathered, which serves as the foundation of reports that are used in the analysis to engage in continuous improvements. So, among quality and time, the time you are able to measure directly in the computer program, but the quality is difficult to measure based on the input data. So, you need to standardize the interfaces within the value chain by creating customer-supplier agreements. On the critical deliveries, such a safety [risk] and efficiency, there is established a standard with regards to how delivery is made. And this makes it possible to measure quality, as you have established a standard for all the deliveries. Then you can conduct a gap analysis of the data gathered versus the standard which you have set as the best-practice. And then you have given those you who are responsible for each task to improve their deliveries by asking themselves a set of questions, such as why is the quality of the delivery less than the standard? Is it because we do not follow the standard? Or is it because we have a faulty standard? So, this is the foundation of a gap analysis, which serves as the tool to identify why the quality is not at the desired level. And then it is the person responsible for each task to improve it continuously. So, this is the way you approach quality measurements. It is not easy to measure quality if you do not have a standard.
I could shed light on it. Take an utterly random task in society. Say that for this task, there are 10, 100 or 1000 who deliver something to it. For this task, there may be the same amount of delivery varieties. This is because there are so few [tasks] that are standardized, and it is difficult to measure before you reach the end product. And when you have a final product, you can measure the quality of the final delivery, but it is difficult to measure within and among the different steps of the wheel if you do not have a standard.

[H.T.]: Yes, that is something which I have seen hints of in my literature reviews. However, there is another form of measurement which I have seen in my review, which is financial measurements through, for example, the balanced scorecard. I am a bit curious about how financial performance is measured?

[MWC]: Yeah, so you mentioned the balanced scorecard. The approach taken in The Maintenance Wheel is balanced measurements, meaning that you do not look at measurements in isolation, but you compare the various measurements holistically. And when you have measured, you may for example use economy as one measurement, and you can use financial measurements as one measurement, you can use safety as one measurement, you can use quality as one measurement so that you can use a lot of different measurements. But none of these can be used in isolation if you do not look at the customer value. And we do mainly measure per delivery, so if the deliveries have become more efficient, better decisions have been made. And the hypothesis is that if you deliver according to the standards, you will be better at making decisions and in terms of efficiency, as you remove the waste categories [of lean]. And this will result in lower costs per unit produced. And from there, you can decide to produce more units for the same resources or to realize it through saved expenditures on the bottom line by conducting the same task with fewer resources. So, there are a lot of opportunities to make both operative and strategic decisions.

[H.T.]: Okay. So, within the wheel, about the operative measurements, between the various steps of the wheel, how are these measurements connected to the strategic aspects in the wheel?

[MWC]: we have measurements all the way down to the individual deliveries required to complete a lap around the wheel. And these are a form of process indicators. But then we also have a form of reactive measurements related to the main deliveries on a strategic level. If you think that a process is composed of an input, a flow, and an output, and then we have divided different sections of the wheel into the input of corrective maintenance, and then you can think of indicators such as the number of input and hours invested. You can think of "one-piece flow", how much per unit, the average per unit, it may be the average per week, and so on. So, you can have both process indicators and reactive measurements such as KPIs for the central part of the wheel. For example, we have KPIs for decisions regarding the need for work, for the need of correcting an issue, KPIs related to the total amount of resources needed for corrective maintenance. We have measurements related to preparation, so work order planning, such as determining the needed resources and required tasks. And we have measurements for acquisition. So, there are quite a lot of measurements related to different levels of the wheel. And these things are identified at the different levels of the wheel. They are identified in the different "sections" of the wheel, where it is written what they measure, why they measure, and what activities that should be done in order to improve a measurement which is outside of the predefined objective per delivery.
So, you can say that the wheel is one-piece flow, but the aggregate sum per week will be what you want on the strategic level. And when you set the objectives, the target measures, for each of these measurements, they are balanced and interconnected. So, for the entire value chain, end-to-end maintenance, The Maintenance Wheel in total, there is set a strategic goal for 20% less input, for 20% better flow, and for 20% reduction in costs. This is connected to you having a decision to make when you have realized benefits such as less input and increased flow. This benefit is something you use on, for example, more maintenance for the same amount of resources or a reduction in the bottom-line expenditures. So, the connection between the strategy and the operative, this connection where you have the strategic direction set top-down, whereas the improvements come down-up, as in the lean terminology.

[H.T.]: Yes, okay. Something which I am also interested in regarding performance measurements is whether there are any particular points of measurements used? For example, you can take measurements about the inputs to a process, during the process, or after the process has concluded.

[MWC]: You could say that, as I mentioned earlier, each delivery within The Maintenance Wheel has a type of measurement. And these measurements are taken all the way down on the task level [the operational level]. And this measurement is concerned with this delivery. So, if you take the need for work or the need for corrective maintenance, there are typically measurements connected to the unit of flow. So, these activities flow is measured through, for example, time, resources spent, whether the plan has been achieved, and so on for each of section [of the wheel].
But we also have an additional measurement related to the quality of a deliverance, what we discussed about autonomy, about having a certain standard that we measure towards. This makes it possible for us to measure how good the competency of the "suppliers" is if the delivery is of good quality so that a good end-product is achieved. And for each of these deliveries, there are specified target measures that determined the best-practice which those that perform a certain task is measured against. So, whether there are meetings every morning, every afternoon, once a week, and so on, is determined by the person responsible for a task to decide. And the sum of this can

be measured on the end-product, through customer satisfaction, how many end-products that were delivered as planned, how many that was faulty, how many that needed "rework", how many were stopped mid-process, and so on. These are various measurements that are related to the end-product that we can improve. But this is more or less analysis on the aggregate sum, all the activities that are needed to deliver the end-product. But in theory, we should be able to identify each deviation before they enter the next step of the wheel.

[H.T.]: Yeah, okay, because that is something which is quite interesting. In the performance measurement literature, two forms of indicators are commonly defined: leading and lagging indicators. So, either a measurement which can be used to steer [lead] a process to a predefined goal or a measurement is taken afterwards, which defines whether this goal was achieved. When I listen to your answer, it sounds a bit like measurements are mostly lagging? With regards to what you said about measurements being discussed in the afternoon.

[MWC]: No, in fact, 80% of the indicators are leading indicators. It is only a few which are lagging, which are KPIs. These are usually weekly or monthly measurements. But every measurement is set up with regards to sequence, with regards to how often, with regards to the speed of the work. And there is no need to measure often if it takes a long time to change something or to stop a product. So you have daily, and in fact, hourly, you have weekly, you have twice a day, you have monthly, you have quarterly, it all depends on where you are in the delivery sequence if there are proactive or reactive measurements. But in principle, we should be able to stop all the work which is not of the required quality before you have a deviation in quality.

[H.T.]: Okay. So, the second problem often discussed in the literature is about deriving these measurements. Did they emerge when you standardized the processes, or are they derived from the company's strategy? In effect, whether a top-down or down-up approach was taken.

[MWC]: Well, it is strategic to set up an assembly line for a delivery [to set up a value-chain]. And it is strategic how the assembly line is structured, how the various deliveries are to be made, so whether they should happen in sequence or in parallel. If they are the main processes of the value chain, or if they are supporting processes, such as acquisition. So, the way the assembly line is structured is strategic. And it is also strategic to identify the need for a customer-supplier agreement, or a form of standard for critical deliveries, or to deal with risk in a sufficient way. And then you are done with the strategy. The structure is set up.
And then you identify actors in the organization, independent of their location in the organizational structure. And then you ask questions from the strategy to the person who is responsible for a given task. They should determine the contents of the standards, and the cooperation between two steps of the process should be standardized. So, the pyramid is flipped. We [the management] then say that "we have determined how we want it strategically". But the contents of the work, such as the best-practice documents, needs to be determined on the operational level. And it is up to the person responsible for a given task to continuously improve these deliveries. So, it is according to the strategic approach top-down, and the continuous improvement and involvement from down-up with regards to the task.

[H.T.]: Yes, that was clear. Something I am also wondering about with regards to the performance measurements, is if you have connected them to other performance measurements in the organization? Because this is an assembly line for [the department] maintenance. So, have you, for example, connected these measurements up towards manufacturing.

[MWC]: Yes. This is sort of the balanced scorecard again. If you look at what the customer value of maintenance is. This is a safer plant, better integrity of the plant, a higher regularity, better earnings, and so on—[Connection timed out].
So, I think that I mentioned [before the connection timed out] that everything is interconnected, and that there is a customer value from conducting maintenance. So, all of these approaches are on the strategic level. But you also mentioned organization. And in the wheel, we are not talking about the organization. We are talking about a value-chain set up independent of the organizational affiliation of the actors in it. So, in all the segments of the wheel, you will have deliveries which move between different functional departments of the organization, such as operation, technical, modification [different functional departments]. So, everyone is involved in some sort of delivery. And everyone is measured with regards to how they deliver according to a standard. So, if you think of maintenance, potentially, only 30% of the [human] resources are employed in the plant's maintenance department. 30% will be suppliers who are external, from large companies such as Aker and Aibel, and smaller subcontractors. And then you have possibly 10-15% of resources coming from the acquisition process. And you have planning and similar work from operations which may account for around 20%. And possibly 10 or 15% from technicians. And all of these deliveries are measured according to the same indicators, time and quality.

[H.T.]: Yeah, when I think about it, it is related to the process map which is discussed in Iden's book, where people are a part of the process irrespective of their role in the organization. So, in effect, it is wrong to ask how maintenance is connected to other functional departments because such departments are already a part of the wheel.

[MWC]: Yes, you are absolutely correct. Often, those who manage business processes such as this have a matrix-shaped organizational structure, where people are treated according to their competency with things like sick leave and similar needs. And then they are placed in the value-chain independent from their location in the organizational structure. Thus, the matrix shape.

[H.T.]: Yeah, that was more or less what I had to ask about performance measurements. So, the purpose of the thesis I am working on is to help Karabin in their sales process. To make it easier to explain and make it easier to interpret it. So, I would like you to hear from the person who has the longest experience with the wheel, how you would adapt the wheel to sell it to other companies? What would you emphasize, looking at companies of both different sizes and that operate in different industries?

[MWC]: What I would use as selling points, and what I have used as sales arguments, is to see one delivery as made up of several partial deliveries, either in sequence or in parallel. So, regardless of whether you are making coffee or whatever example you decide on, you need to have some technical equipment, you need some resources, and you have some people who are conducting tasks. And to standardize value-chains in this way, to standardize deliveries in the value chain according to a quality standard which is possible to measure towards, and connecting this to a computer program, you can look at the value chain according to multiple dimensions. You need to mention the uncertainty if you do not have standards, and only autonomy, you will have a lot of different deliveries being made [from the same task], since people have different behavioural patterns, different understandings of the same problem, which will make it challenging to produce a good end-product. So, it [standards] provides a degree of predictability for the employees; everybody knows what they need to deliver. These types of standards are incredibly useful in continuous improvement, not to mention to build competency. You close a gap in the competency by providing a best practice. And additionally, you educate "on-the-job", which is much cheaper. So, there are a lot of aspects which you can mention which are beneficial. Not to mention to provide a better product for the customer by increasing the flow and removing waste. So, there are not a lot of alternatives to this type of production. And then this approach has shown that you can possibly achieve 30-40% in increased efficiency, in comparison to other approaches. And it is essential to know that this is not the solution to all your problems. There can be a lot of things that need to be improved. You set up the current situation, but in the long run, you will need to improve it. But this way of thinking makes it possible to identify whether the process is set up the wrong way, or whatever that is actually the cause behind the desired end-product, or partial deliveries, not being achieved. You cannot really improve something which is not standardized.

[H.T.]: Yes, okay. Something which I am also wondering about is, if you think of the maintenance as something modular, as something composed of different components, is whether there is room for improvement within The Maintenance Wheel itself? If you think of The Maintenance Wheel, is there anything you would remove, or add.

[40:00]:
[MWC]: Well, this is connected to continuous improvements. But you must remember that The Maintenance Wheel is a picture of a complex end-to-end value-chain. And the sum of activities is, more or less, standardized in all companies which engage in maintenance. There is naturally some variation, for example, if you are working on a live facility or on one that is not in production. But, more or less, the trick is to go through all the steps. And we have found, over many years, that these steps are standardized. But there are some steps which were previously more challenging to pass through, which we have now simplified and built-in an improved flow by improving the standards, the measurements, the root-cause analyses, better computer programs and digitalization. So each step, if you call each step a task, the main tasks, the number of tasks in each step has been reduced due to some form of efficiency improvement, which has been identified by the person responsible for each task. But else wise, it is a picture of a complex value-chain, where you only need one PowerPoint slide to explain everything for the operational level of the organization. Because, you know that in the operative environments, they do generally not like long PowerPoints, which is one good selling point. And it is generalizable; you can use it on anything you want. The visualization discusses four different dimensions; it explains more than a thousand words. So, the overarching selling point is that everybody can see what we are talking about immediately.

[H.T.]: Ok. When I look at it, if you think of it as a computer, as something which is to be sold, a computer has a lot of different specifications. And I think of the maintenance as something like this, as something which has a set of specifications that can be sold to different companies, if they want these specifications. But then you could look at another computer, which has a lot of similar specifications, but has maybe, since we discussed it previously, a different set of indicators used in performance measurements than time and quality. For example, instead of using time, you could use the wear rate of the equipment, or similar. So, in effect, whether you have experienced any room for improvement in of the wheel's specifications given this type of modularity?

[MWC]: I think that you need to think of this Maintenance Wheel, or the plant wheel, that is the picture of a complex process. And when you want to sell this picture, you cannot sell it without the theories of an end-to-end value-chain, performance management, and continuous improvements. Because that is what the wheel illustrates, that you need business process management, you need performance management, and you need to illustrate the value chain end-to-end. This means that if you are in a traditional company, with a functional hierarchy, which often leads to a silo mentality among the staff, and makes it challenging to understand end-to-end value-chains and performance management, and where performance management is done in the organization and not in the value-chain, you will end up with a sub-optimization and with incremental improvements which do not result in increased customer value. It will be challenging to engage in improvement work that actually improves the end-product. You need to argue with all of these aspects that I mentioned. Otherwise, it will be of little purpose.

I think that if I were to write a book, The Maintenance Wheel would be a picture on the front page of the book. And inside the book, there would be all the aspects we have discussed, like different chapters. But the main chapters would likely be structured according to business process management, in end-to-end value chains, and in continuous improvements, which are some chapters you would not be able to avoid. And of course, also performance management. And then you would elaborate a bit on other aspects related to these main topics.

[H.T.]: Yes, definitely. Up until now, in the thesis, I have focused a lot on how others have approached performance management and measurements of maintenance. And something which I see as a common denominator is that they more or less always try to connect it to financial aspects, everything should be measured in return on investments. But only one of the articles I have reviewed up until today discusses some of the terms related to business process management.

[MWC]: Well, this is something you also see in the book of Jon Iden. He talks about organizational hierarchies, about functional departments, where managers today struggle to understand that they are producing something as part of a value-chain. So they continue to manage as if they are in a functional organization, with the adverse effects this has for lack of coordination, silo-based improvements, incremental improvements that do not have an effect for the end-product, so all of these things that we are trying to improve are difficult to improve with a functional approach. And this is something Iden discusses a lot, and it is also my experience, and I have worked with this for many years, that you need to mobilize the managers for a form of commitment for change. You need to make managers realize that they need to change their behaviour a bit and that they need to look at strategic and operational activities as interconnected, where the economy is not as essential as the customer's value. You could say that you could travel with Ryanair, and pay for many services that you are capable of yourself, that you do not need to pay for, and you do not receive them for free either. Or you could go for Scandinavian Airlines, which is a bit more expensive, and you get a bit more services that you pay for, that in sum becomes a bit more expensive. So, everything boils down to what standard you should provide to your customer.

[H.T.]: Yes, all right, so in effect, which value you want to provide [to your customers]?

[MWC]: Yes. And with regards to maintenance of a plant, you have integrity requirements which you are not able to avoid. You cannot conduct maintenance with quality less than the requirements to integrity, because then you start to face safety-related issues and governmental interventions. So, you cannot deliver a budget version, but you could deliver a good product efficiently. A product which satisfies the requirements which are predefined [in the standards]. And that is what we are working with continuously, to remove the waste categories. To optimize inputs to avoid over-processing and overproduction based on a good foundation for decision-making, which is standardized and a little less autonomous than the traditional approach but ensures a good quality throughout the value chain.

[H.T.]: Yes. You mentioned something now which I planned on asking you about, so now is a good time to ask you. How did you account for risk when you created and implemented The Maintenance Wheel? Because, it is, especially for the oil and gas industry essential to have high integrity. So, by reducing the inputs to maintenance, I am curious about how risk was accounted for?

[MWC]: Well, that is relatively easy to answer actually. Because a value-chain, as The Maintenance Wheel - end-to-end with performance management - has two purposes. The first is that you standardize a way of working, cooperating, and delivering quality in the partial deliveries. And as a part of this quality in partial deliveries, it is accounted for risk. All the requirements related to mitigating risk, which is not acceptable is integrated into the standards, and there is also built into the standards the quality required to avoid large accidents. So, this is the only way to build quality into the standards. Because if you do not have standards accounting for risk and quality, mitigating actions, you will see that in the wheel, there is the activity called "assess risk, search AT". The next activity is then "approve and prepare". So, you need to actually sit down and make this assessment, to ensure that you will do something according to the standardized plan before you get the approval actually to fix something. So, this is the opportunity that the company actually has, to standardize a work pattern, to mitigate the risk to avoid larger and smaller accidents.

[H.T.]: Yes, so we talked a bit about ICT up until today. But what we have not done is to talk about ICT's role in The Maintenance Wheel specifically. Do you see it as an absolute requirement to have an ICT system to make The Maintenance Wheel work in practice?

[MWC]: Yes. Digitalization is a must. It is more or less impossible to do this without having an ICT tool to support up under the value chain. At least on the sophisticated level that we are talking about here. For tiny companies, you could possibly be able to implement it [without ICT], but it would be tough.

[H.T.]: Yeah. When I read Iden's book, I do not know if you have read the newest version?

[MWC]: No, I have not seen it yet.

[H.T.]: Okay. The reason why I am asking is that he has included a new chapter which discusses digitalization. And he says in this chapter that the first-time digitalization was used as an expression was around 2010, in academia, and the industry followed a bit later. So, has ICT been a part of The Maintenance Wheel since its first version, back in 2006?

[MWC]: Yes. Typically, then, however, was that the ICT tools were set up regardless of the way we worked. So, we did not have any particular flow in the ICT program when we conducted a task. So, to take one example, if you needed to report a particular issue, you used an ICT program to report this. But the further processing of this report was not built, so for example, there was no check of whether it was a duplicate, if it required further processing, if it had to be stopped, and so on. So, the wear rate of a given component could possibly be completely normal, meaning that it did not require anything else, meaning that it could be completed based on its history. Because this is something, you can do with the wheel. You do not need to complete a lap around the wheel. You can decide to say that, after the three first activities that there is no need for maintenance. So, you remove maintenance notifications that are not actually required, meaning that you can categorize the work. And this was not part of the beginning. But today, it is made in such a way that you can actually measure based on where you are in the wheel. The status codes are known. And these codes are where you extract, and sort reports from. **[60:00]:** And these reports are where you extract the KPIs from, and the PIs, which you highlight on the strategic level. They enable root-cause analyses of why you are not performing as you want to. So, we started quite rudimentary, but we continuously improved the ICT tools from there. And we have also implemented some digital sensors, which captures digital data that you need while working, to deliver according to the defined objectives of time and quality. So, there are a lot of different ICT tools which are used, but they are mainly used to increase flow, more or less.
Regarding customer-supplier agreements, about standards, they are also digitized with attributes connected to where in the wheel you are. For example, if you are to make a decision, there is a standard connected to that decision, and you find it immediately if you need it. And there are approximately 70 standards connected to The Maintenance Wheel, and these may be identified quickly when you need them. So, digitalization is an absolute requirement, but the first priority is to standardize the value-chain. Digitalization is then used to meet the needs of these standards, not the other way around.

[H.T.]: Yeah. As far as I know, in Equinor, you use an ERP system. Such systems are known for being quite rigid, and many of the users of this type of computer program usually find them to be quite challenging to change. So, making change happen quickly, which is often desired within the ICT division, for example, is difficult. How have you worked with continuous improvements related to this? Is it a problem with a lack of flexibility, or do you have good experiences with it?

[MWC]: What we have seen is that those who have not really invested any effort into understanding this way of managing maintenance, they will commonly use an argument that computer programs would be able to solve all of the problems currently faced if they were only able to change them. But when you have standardized the value-chain, and the measurements are up and running, and you have a culture which pursues continuous improvements through blackboard meetings and root-cause analyses to identify why the desired results are not achieved, other approaches become more important. And this is often related to the contents of the standards and behavioural patterns, such as the contents of standards, behaviour, how you find standards when you need them, what was the last version of the standard, what type of training is given, and so on. So, soft measures become much more critical.

[H.T.]: Ok, that was all the questions I had about ICT. The next questions are about the so-called "20/20/20" which we discussed in our first conversation [not an interview]. Could you elaborate a bit on this, what is the thought behind it?

[MWC]: This is connected to having an elementary business process understanding. Every process has an input, and every process has an output. And every process has a set of primary tasks. And every process has a set of subtasks per main task. So, you could say that it is a standard way of thinking for everyone who thinks "process". And it is like, the input, what is that? If you, for example, have the value-chain of the supplier of a service, there could be a goal to increase the amount of input, which could be contracted. Or, you could think the opposite way, to think that you want less input than what you currently have, because it is a value-chain which generate expenditures, such as maintenance. So, you have to think that you either want to increase or decrease the input, which is what the first 20% is about. And here you can decide on what number suits you, such as 10%, 20% or 40%. But here you have the first number.
The second number, is related to when you have decided on something, or a project has been granted, you want to deliver that project in a satisfactory way for the customer so that the end product is delivered according to the set objectives to time and quality. And here we can talk about flow, about OEE, different measures related to flow efficiency, and so on. But, if you break this down, you will see that flow, or improving flow, is about removing waste. And then we say that the [next] 20% is about removing 20% of the waste categories, of which there are eight categories.

And the last 20% is related to if you are able to do something with the first 20%, and the second 20% related to flow, you will realize a benefit. You agree, right?

[H.T.]: Yes, correct.

[MWC]: So, this benefit, you can capitalize on in different ways. If you want to take it out through lower bottom line expenditures, you need to get rid of some of the resources which you have, or you could stop purchasing expensive services or products which you do not need, or you could produce more for the same resources. So you could say that the last 20% is about when you have actually increased the value-chains efficiency and have excess resources, you could, instead of letting your own employees go, you could order less external services. This will result in a lower bottom line cost. But you could also say that you would have 20% fewer incidents as an end-product, or something else.

[H.T.]: So, it is a way of communicating how you want to realize a benefit, the last 20%?

[MWC]: Yes. And this will be standard for all forms of processes.

[H.T.]: Yes, ok. Something I am also wondering about is between the innermost "dimension" of The Maintenance Wheel, so between "notification" and "work order", or "M2" as it says in one of the PowerPoints if I am not mistaken. So, where you decide which notifications will become work orders. Here there is a selection process, where you decide which notifications to move forward with, and which that is unnecessary or is actually needed at a later moment. What I am curious about is how this selection process happens? How do you actually reduce the 20% of input? Are there some criteria used here or is it up to each individual manager to decide what they deem the best?

[MWC]: No, here is where the value-chain with standards and measurements comes in handy. If you have a need, such as to have something you identified fixed, whether it is due to vibration, corrosion, a lack of paint, or the degradation of a pump's capacity, or whatever need be, you decide it based on your own competency. And you may be very good at describing an issue, but it does not actually need to be a fact. Because the vibration you are feeling [, for example,] could stem from a normal degradation and it does not meet the requirements to the lowest status for degradation. This is the type of information professionals may have. And I think I used an example for you the last time, about your car, where you are out driving, and you notice a noise [coming from your car]. So, you sit down and describe the noise you are hearing in a fantastic way, and conclude that it is likely the gearbox which is the problem because you hear the noise underneath your seat and you feel the vibrations. So, when you now deliver this car to your auto repair, it is not like the car mechanic will read your description and simply assume it to be true. He will read it as information and investigate himself. And it is this investigation that will give you the status which you are interested in. The outcome can either be pleasant, where you get a telephone saying that "you have made a good observation, but it is not the gearbox that is the problem, it is the wheel bearings". So instead of getting a bill of 100000 NOK, it costs 3000 NOK. Or he could find that it is merely a normal noise caused by that cars age and the regular wear rate for this age. And this is the whole point. You standardize the entire way with which decisions are made. You cannot decide on how to treat notifications without having the necessary information to make these decisions. So, if you make decisions solely based on notifiers' notifications, you have breached a barrier towards the standard. So, the **standards** act as barriers against making the wrong decisions, which result in resources being spent on things which do not generate value. A better product is not achieved. The safety is not increased. The deliveries are not improved. You only increase the resources being spent. So, the sorting is based on factual information. Then you can decide to reject the notification because the description is wrong. You could solve the notification based on historical accounts, as the degradation is normal. You could say that you could complete the notification as "simplified" maintenance, as it does not need to go further in the process, you simply fix it once you are examining the issue. So, the decisions of letting the notification become a work order are only possible when the error condition satisfies the requirements set in the standard to do so. Often, 20% are connected to more than 20% less input. The 20% less input is connected to this being achieved without it happening at the expense of the plant's uptime, regularity, or integrity. So, what I mentioned previously about it being performance management previously.

[H.T.]: Yes.

[MWC]: That was a long and complicated explanation. But did you understand it?

[H.T.]: Yes, I think so, but I need to write it down first. But I think this is critical to my thesis to understand why and how you remove waste because it is essential to how to adapt the framework.

[MWC]: Yes, because you could say that you could set up a Maintenance Wheel which looks very good, and you measure that the speed is excellent, and the use of resources is excellent, but the end-product is very bad, and the customer does not want to purchase it or pay for it. And then you need to ask yourself if it is something wrong with the value-chain or with the deliveries into the value-chain. And most of the time, it is the lack of standards with regards to what is to be delivered. And this is where the aspects related to human resources becomes relevant. Because, if you want a good argument for what in fact quality is, you can look at the standard. If me and you are to do the same task and receive the same training, and we are going to be measured on how the task is delivered, there will undoubtedly be quite a degree of variation to our deliveries, regardless of us in principle being seen as similar. So, you will not be able to avoid the identification of the most critical deliveries and to standardize them to be able to measure them because you cannot reduce the inputs by 20% if you do not have some criteria to make decisions on. And this must be the case, always.

[H.T.]: Yes, okay, that was very clear, but I think it will be even easier when I have transcribed it and translated it.

[MWC]: Yes. And I think it will be quite easy to conclude, or discuss, that here we have humans, standards, compliance with standards, measurements of standards, breakpoints in the value-chain if the requirements set in the standards are not met, to avoid that end up with a more expensive product or the wrong product. So, the entire concept is built around understanding the concepts of business process management, regardless of the employee's place in the organizational hierarchy. You have to understand performance management. You have to understand end-to-end value chains. You have to understand continuous improvements. And to have the correct competency for the various tasks. So, there are some points that are needed in order to be able to conclude with something. And the wheel is a picture of a complex value-chain, simplified to start a discussion of these topics. Because how do you start the process of anchoring and motivating the staff for this form of management. Everybody needs to understand that they are building a cathedral. You do not live in an isolated department within a complex organization, where you may hand in one task, whereafter you are finished with the end-product when you are done with that task. So, you need to make everyone understand that this is an end-product which everybody shares the responsibility of ensuring that something with adequate customer value is produced.

[H.T.]: Yeah.

[MWC]: And this is sort of, the understanding of why you need all of these standards, measurements, all of these customer-supplier agreements, and so on to make this work in practice.

[H.T.]: Okay, good. Do you have enough time for some concluding questions?

[MWC]: Yes, I have around 10 minutes.

[H.T.]: Great. So, the first question is related to what form of maintenance that passes through The Maintenance Wheel? Because you have corrective and preventive maintenance. I saw that another of Karabin's clients wants to implement preventive

maintenance in the wheel. Is this something you have experience with? Because, we have predominantly discussed something related to there being notification of a particular error, and then that is fixed.

[MWC]: Yes, and this is related to us focusing on from 12:00 to 14:00 in the wheel, not from 14:00 to midnight. And preventive maintenance enters at 14:00. And where you decide on whether or not to maintenance, corrective maintenance, you do it in a supporting process which hits the main flow [the primary process] at 14:00 if that makes sense.

[H.T.]: Oh, okay. Yes, that makes sense and sounds a bit like in the case of Karabin's other client.

[MWC]: Yes, it is similar.

[H.T.]: Yes. So, what about the smaller maintenance tasks, such as the change of a filter. Is this integrated into The Maintenance Wheel, or is this seen as such a small task that it is fixed by the technicians when they are inspecting the asset?

[MWC]: No, all forms of maintenance should be tested, be assessed, of whether there is actually a need, except for shift-based maintenance. Shift-based maintenance is maintenance which is part of the daily routines of the shifts. This is not processed here. So, what actually enters [the wheel], should be decided on, meaning either a rejection, completed, completed based on history and so on. But, for example, if I take a plant as an example, around 70% of the notifications move on, and move past 14:00 in the wheel. So, the change of a filter change is done without completing a lap around the wheel. You can do it as simplified maintenance, which is one possibility in approving and prioritizing maintenance.

[H.T.]: Okay. Then there is something about the shape of the wheel, why the wheel shape? Is it based on any literature, or does it have another purpose?

[MWC]: Well, it has a purpose. Visually, it is simpler to have a wheel. And it is one-piece flow, where one error condition hits the top of the wheel, whereafter it takes a lap around the wheel [to be fixed]. So, it is set up for one-piece flow. If you have several error conditions, either in parallel or in sequence, you will have a lot of loops in the wheel. And you also have a lot of information on a tiny surface. Because, if you wanted to put all of the information in boxes after one another, you would not get one flow, you would need multiple PowerPoint slides. So, you would have to visualize it in a less precise way. And here you can have four different dimensions, to highlight the computer program, the status codes in The Maintenance Wheel, the activities of the wheel, and the persons responsible for these activities.

[H.T.]: Great. So, you said to yourself that we had talked a lot about 12:00 to 14:00 in the wheel. But from 14:00 to midnight, we have not discussed as much. I am wondering about how you close a work order?

[MWC]: Well, you follow all of the sequences [in the wheel], and you have delivered in accordance with the standards. The quality is in accordance with the customer value. And then the last activity is to enter the history, control that all activities have been done before the work order is closed. A form of quality control before it is closed. It is not quality control of whether or not you have produced a good product, but control of whether you have done what the standards and the value-chain have specified. It is the person responsible for the product which does this.

[H.T.]: The person responsible for the asset which is serviced?

[MWC]: Yes. Each asset has a "person responsible", and this person is responsible for completing a work order. So, it is one-piece flow, so if you have an error in the automation, there is a person responsible for automation, and if there is a person responsible for mechanical errors. And there are a lot of activities related to one error condition. In this wheel, you can have everything from automation, electronical, and so on, to be involved in fixing the error condition. But it is only the person who is responsible for the main issue which may end [complete] the work order. So, you can see that the last box is "Coordinator MWC" and "Complete WO". And when this happens, it is finished.

[H.T.]: Okay, good. So, the last question is whether you think there is a question I should have asked you, but which I have not?

[MWC]: No, I think we have touched upon all of the most important aspects. Naturally, we have not gone into high levels of detail, but we have looked at the most important aspects. If you had seen this in practice, you would have seen the standards, and you would have seen the customer-supplier agreements, you would have seen how the computer programs work in real life, you would have seen how you extract reports, how you analyse to identify why indicators are not indicating the expected and set objectives, and so on. So, we have discussed more the overarching concept, about the concept behind all of these specifics. But you have done this in a good way. So, I do not have anything to add, really.

[H.T.]: I am glad to hear that. Thank you for your time.

[4 minutes at the end of the interview has been omitted due to a lack of relevance.]

APPENDIX E

ATTRIBUTES OF REVIEWED MAINTENANCE PERFORMANCE MEASUREMENT APPROACHES

	Approach	Balanced Indicators	Multi-Criteria	Hierarchical	Indicator Selection Methodology	Example of Indicators	Process Performance	Proof of concept	Adaptability
1	Tsang (1998)	+ Tsang argues for the importance of treating maintenance as both a short-term and long-term activity.	-+ The perspectives used in the BSC does account for multiple stakeholders. However, as argued by Alsyouf (2006), the BSC fails to acknowledge all relevant stakeholders.	- Does not discuss hierarchy.	+ Provides methodology.	-+ Only provides four indicators, one for each BSC perspective.	- One of the perspectives in the BSC is “internal processes”. However, no discussion is provided.	- Does not implement the framework.	- No discussion of how to account for different contexts.
2	Alsyouf (2006)	+ Uses both long-term and short-term indicators.	+ Accounts for a wide variety of stakeholders.	-+ Discusses performance measures which can be related to different hierarchical levels but does not discuss it explicitly.	- No methodology.	+ Multiple indicators.	- Sees maintenance as a part of a value chain. However, no discussion of maintenance as a process.	+ Validates the framework by using historical data from a real company.	- Fixed framework, no other indicators used.
3	Muchiri et al. (2011)	+	- Focuses mainly on the maintenance process. Maintenance is seen as an isolated silo, having to satisfy the performance requirements imposed by manufacturing.	-	+ Provides methodology.	+	-+ Discusses performance measurements of a four-step maintenance process.	-	+ As there is no fixed set of indicators, all companies should be able to use the framework.

	Approach	Balanced Indicators	Multi-Criteria	Hierarchical	Indicator Selection Methodology	Example of Indicators	Process Performance	Case Study	Adaptability
4	Kutucuoglu et al. (2001)	+	-+ The authors define cross-functional performance measurements as essential. However, in the methodology, mostly maintenance-related staff is involved in indicator identification.	+ Sees alignment of indicators according to hierarchy as an essential part in maintenance performance measurement.	+ Detailed methodology.	+	- Sees maintenance as a process. However, likely to remain adaptable, no specific maintenance process is defined.	+ Validates the framework using real people.	+ Focuses on the methodology. Could be used by any company.
5	Parida & Chattopadhyay (2007), Parida (2006a)	+	+	+	- Parida (2006a) discusses indicator selection briefly, but no methodology is provided.	+	-	- Parida (2006a) provides two case studies. These focus on how to select indicators, not on assessing the framework's effect.	- Since it is difficult to understand the methodology, the adaptability suffers.
6	Van Horenbeek & Pintelon (2014)	+	+	+ Discusses hierarchy.	+ Detailed methodology.	+ Multiple indicators.	-	- Compares how different companies prioritize different requirements.	+ Adapts the framework to 5 different companies.
7	Al-Najjar & Alsyouf (2004)	+	- Focuses on equipment related indicators.	-	+	+	-	+	+
8	Parida (2006b)	- Focuses on equipment performance.	-	-	-	+ Discusses it briefly.	-	-	+ Usable for all companies with an ICT system and equipment suited for sensor-based performance measurements.
9	Stenström et al. (2013)	+ Uses leading, coincident, and lagging indicators.	-	-	- Fixed set of indicators.	+	-+ Uses an IPO-model to explain where different indicators measure.	-	- Fixed set of indicators.

APPENDIX F

EVALUATION INTERVIEW PROTOCOL

Estimated length: 45 minutes

Interview type: Semi-structured interviews

Sample: 3 senior managers from the oil and gas industry

Phase 1: [2 min]

- Present myself/ purpose of thesis/ theme of the thesis
- Go over the rules: anonymity, recorded interview, published results. Is this OK?
- The interview subject may interrupt if anything is unclear.
- Mention that the thesis is not evaluated on their ability to understand the framework, so be critical.

Start recording

Phase 2: - About the interview subject: [2 min]

- Position in the company?
- How long has he/she worked with this?
- Experience with maintenance?
- Experience with BPM?
- Experience in performance improvement?

Phase 3: [20 min]

- Present the framework

Phase 4: Evaluation [20 min]

- Transferability:
    - Did you understand the framework?

  (Explain in his own words):
    - Do you understand how BPM is applied in the framework?
    - Do you understand how the maintenance process is standardised?
    - Do you understand how performance management is applied in the framework?
    - Do you understand how the framework may be used to identify waste?

- Do you understand how the framework can be used to continuously improve the maintenance process?
- Complexity:
  - Was there anything you found difficult to understand?
  - Did you clearly understand the relationship between the different elements in the framework?
- Compatibility:
  - Does the framework come across as practically relevant?
  - Do you believe the framework could be of value in your company?
- Misc
  - Is there anything you would improve in the framework?
  - Do you have any questions about any parts of the framework?

Phase 5: End interview [1 min]

Thank you for the interview.

- Do you have any other questions?

APPENDIX G

INTERVIEW SUMMARIES: EVALUATION

Subject 1

Background:

He is a technical superintendent of an oil platform. He is responsible for all the maintenance on this platform, and that it satisfies the various requirements related to integrity and maintenance performance. He is the focal point of all technical project activities on the platform and has the daily supervision of the technicians on the platform. He has had this job for one year. He has experience with maintenance and business process management.

Was the framework understood?

Overall, the framework was well understood. He stated that the connection between the different elements was easy to follow, and the framework made sense to him. By asking him to explain parts of the framework in his own words, this was confirmed.

The only question regarding how something worked was in connection with how corrective work orders are strategically reduced. He wondered how this was done in practice, i.e., how do they actually identify the 20% of waste. He argued that for minor work orders, there is still some need for maintenance, although it might be minor.

Additionally, he had a comment where he asked for more examples of how it worked in practice. For example, how is waste eliminated, and what are the contents of standards.

Was the framework difficult to understand?

He explained that he did not have a personal preference for simply looking at process diagrams, as he preferred to see the process in practice himself. Otherwise, he had no remarks on complexity.

Compatibility:

He said the framework communicated a smarter system for how to manage maintenance than what they currently have, and that he was very interested in it: "It is a smarter system, and we have to try to have as smart systems as possible". He did question how operative staff would experience working with this form of continuous monitoring and evaluation of their work against the best practice. However, he did question his own company's ability to change to facilitate this form of maintenance, as his experience is that changes in his company take very long. He also questioned whether it was possibly better suited for an even larger company, as in his company, some of the tasks in the process would be executed by the same person.

Subject 2

Background:

He has previously been technical superintendent of one of the largest Oil and Gas company's fleet of oil platforms and is currently the technical superintendent of the same company's fleet of oil platforms on the Norwegian Continental shelf. Here he is responsible for all technical operations such as maintenance, e.g., for mechanical and electrical assets. He has previous experience from several improvement projects related to maintenance.

Transferability:

He understood most of the framework. While discussing with him, he had a good understanding of the most important elements of the framework, and it was possible to have an in-depth discussion on how The Maintenance Wheel works. He also said that the flowchart was easy to follow, and the most important maintenance management activities were covered. When he was asked about different parts of the framework, he explained in his own words sufficiently how best-practice standards are used to control and continuously improve.

However, he did suggest providing more examples to understand how it works in practice specifically. In the interview, he had remarks about aspects having to do with how the specific tasks and standards would be defined in practice, i.e., with the implementation of the framework.

Complexity:

He said the explanation was very easy to follow. In fact, he asked for more in-depth information, as he was very curious about how it would work in practice.

Compatibility:

He said the framework made sense to him, but he would want more examples of how it works in practice. He said he was very interested in the framework and relevant to what he has to in his job, namely, to optimize the entire maintenance process. So, he said it seemed as if this framework provided an easy way of doing so. However, he wanted more examples of how it works in practice, as he wanted to get a better understanding of how it works in practice.

Subject 3

Background:

Subject 3 has almost 20 years' worth of maintenance and maintenance management experience from the oil and gas industry. He is currently working as a technical superintendent for a smaller oil and gas company but has previously held the same position for larger firms. He has some experience with BPM.

Transferability:

Subject 3 said he understood it. When he was asked to explain different parts of the framework in his own words, he was able to explain how the MMF uses performance management to identify waste, and how the maintenance process is continuously improved by updating the best practice standards. This confirmed that he had understood the framework.

While presenting the framework to Subject 3, he asked one question related to how the framework worked. Specifically, he asked whether the maintenance process is the same for corrective and preventive work orders. When discussing this with him, it turned out that he had not fully understood how the process was standardized, but once the contents of the best-practice standards were clarified, he was able to resonate to how corrective and preventive work orders follow the same process himself.

As with the other subjects, he did have some questions related to how the framework would work in practice and did suggest providing more examples to understand how it works in practice. In the interview, he had remarks about aspects having to do deal with planning etc. with the framework; however, this is out of this thesis scope.

Complexity:

He said the explanation was easy to follow, and that he did not miss anything in the framework.

Compatibility:

He believed that it was a valuable approach to maintenance management. However, he had some concerns related to how the framework would work in practice. First, he questioned how the operational staff would feel about having their performance measured in detail. Second, he questioned how valuable the framework would be in smaller companies, where one person is often responsible for many parts of the framework.

I am impressed you made it this far.

TU Delft

korobin