MSc Mechanical Engineering
Master Thesis

Development and Evaluation of a Maintenance Maturity Matrix for Small and Medium Enterprises

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June 26, 2024

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Acknowledgements

First of all, I want to thank Sebastian Pohlman for his guidance during this project and the opportunity to work with a case study company. I also thank Willem Haanstra for his insights and enthusiastic guidance during the thesis. His support was amazing and this thesis would not have been the same without him. I am grateful for the employees that participated in the case study. They gave good feedback which helped me massively. Lastly, I want to thank my family and friends. This thesis marks the end of my student life and I will be forever grateful for the continued support, especially from my parents.

Graduation marks
A life of new beginnings
Bittersweet endings

Summary

Situated in Almelo, a manufacturing Small- Medium Enterprise (SME) feels the need to evaluate and improve their maintenance organization. Currently the organization has no clear way of doing this and has no insight in the maintenance organization. This organization is not alone in this, since other SMEs face a similar problem. SMEs are crucial in the manufacturing chain and due to increased importance of maintenance in industry, these companies need to be able to evaluate and improve their organization. One way of doing this is by utilizing a maturity model, in this case specifically a maintenance maturity model. This thesis identifies 15 other maintenance maturity models developed in literature which are often applied and tested within large enterprises. Due to a recent surge of attention for the importance of maintenance, more maintenance maturity models are developed in recent years. However, these studies often focus on large enterprises with a large maintenance organization with plenty of resources. In comparison, SMEs often have limited resources and limited technological knowledge and skills. It is for this reason that existing models are often not applicable for SMEs. This research focuses on the development of a maturity assessment tool specifically for SMEs, the implementation of such a maturity assessment tool and the consequences for determining a long-term improvement strategy.

Design Science Research is used as base for the development of a new maturity matrix. The study shows that combining several development methods in a roadmap provides a lot of important decision points. Rigor of the development method is achieved by following design guidelines of Becker et al.[4]. The problem identification is a crucial step in development of maturity model. SMEs have certain characteristics and following success criteria which influence the design of a maturity assessment tool as well as the assessment method. The main goal of the research is to provide more insight in the maintenance organization of SMEs and their possibilities for improvement. It has been found that consulting a case study company and experts provide good feedback to implement an iterative design process. The research revealed that especially for SMEs, a maturity matrix is preferred over a maturity model. The complexity of the matrix should be kept to a minimum to minimize the amount of necessary resources. It was chosen to include simple terminology as much as possible such that SMEs, with limited knowledge, could understand and implement the model using a self-assessment.

The main result of the research is a maturity matrix which is used as assessment tool in a case study company. The self-assessment is carried out in a group-workshop. This assessment was evaluated using a short questionnaire consisting of several statements related to the success criteria. The participants of the group-workshop indicated that this method of assessment gave them more insight in the maintenance organization. Next to this, the evaluation also demonstrated that the developed maturity matrix was easy to understand and easy to use. Due to inclusion of a desired maturity level next to a current maturity level, the company is enabled to think about sensible commitment of their valuable resources.

It is observed that often it is not as useful for SMEs to achieve world-class maturity as compared to a lower maturity level in terms of resource efficiency. By selecting clear goals for each dimension in the maturity matrix, an SME is able to have a better understanding of a long-term improvement strategy. The development of the maturity matrix revealed that ease of understanding and stimulation of continuous behavior were crucial factors for SME focused maintenance maturity models. The maturity matrix addresses this by incorporation of carefully selected dimensions and by adding the possibility of selecting a desired maturity level during a self-assessment. The application of the newly developed maturity matrix shows that is is possible for SMEs to self-assess their maintenance maturity and that this method creates insight into different choices and routes that SMEs can take to grow towards world-class maintenance maturity.

List of Abbreviations and Acronyms

AMMM Asset Maintenance Maturity Model.

CBM Condition Based Maintenance.

CMM Capability Maturity Model.

CMMS Computerized Maintenance Management System.

DSR Design Science Research.

DSRM Design Science Research Methodology.

KBM Knowledge-Based Maintenance.

KPI Key Performance Indicator.

MMIS Maintenance Management Information System.

MPM Maintenance Performance Measurement.

RCM Reliability Centered Maintenance.

SMEs Small and Medium-sized Enterprises.

Contents

Chapter 1

Introduction

As stated by the European Union, Small and Medium-sized Enterprises (SMEs) form the backbone of Europe's economy, since they represent 99% of businesses in the EU[1]. These companies contribute significantly to employment and economic growth, also in The Netherlands. These businesses have fewer resources than large enterprises whilst challenged to continuously enhance their competitiveness. SMEs are often faced with the same challenges as large enterprises but have less resources to work with. One of the main challenges for enterprises nowadays comes from maintenance management. Larger enterprises often have specific maintenance departments that deal with setting up maintenance strategies, determining possible faults in operation and performing the maintenance. SMEs do not have this luxury and maintenance is often a side task of an operations department. However, the importance of maintenance and maintenance management within manufacturing organizations has grown. Maintenance management is often considered as a complex management process that plays an important role in supporting organizations to reach their goals of productivity, profitability, sustainability, competitiveness, and in ensuring that their equipment operates effectively and efficiently[3].

Especially in this rapidly developing world with the next industrial revolution, Industry 4.0, enterprises are challenged to catch on and develop. Part of this change is the role of maintenance in manufacturing industries. Where maintenance used to be seen as "Necessary evil", nowadays maintenance is more often seen as "value-increasing practice". Maintenance is defined by the European Standard EN 13306[15] as 'combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function'. Maintenance is therefore crucial to manufacturing organizations to keep the production systems efficient and keep products at the required quality. This importance for manufacturing organizations has lead to rapid developments of new maintenance practices and strategies. Incorporating these strategies (e.g. Total Productive Maintenance) and techniques (e.g. Condition Monitoring) already poses a challenge for larger enterprises which have to spend quite some resources. The challenge for SMEs that want to incorporate these state-of-the-art techniques is even bigger due to their limited resources.
More companies realize the enormous potential for improvements regarding maintenance management and want to act on this. Implementation guidelines and case studies are available for larger enterprises, but not for SMEs. SMEs also have the desire to improve their maintenance management and find a fitting strategy for their business. In order to understand the progress and define where enterprises currently stand, maturity models can be used. Maturity models have been in use quite some time already and recently found more applications in regards to maintenance management. This will be further discussed within the literature review.

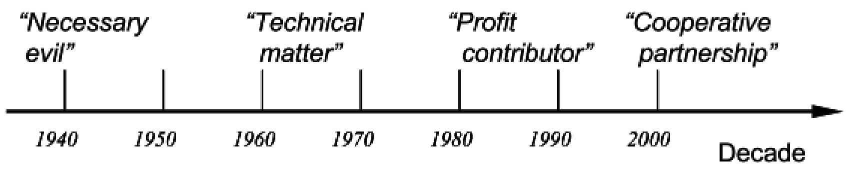


Figure 1.1: Maintenance function in a time perspective (Taken from [50])

1.1 Introduction to case organization

The research will be conducted in cooperation with a manufacturing company in the Netherlands. The company is further referred to as the case study company. The company is an independent worldwide supplier of linear- and torque motors. Headquarters are based in Almelo where also a main part of manufacturing is conducted. Next to this, the company has a manufacturing plant in China and global sales presence. This research will focus on the manufacturing plant in Almelo which produces several types of motors. The operations in Almelo mostly produces build-to-print for the semi-conductor market. Despite its global presence, the company can still be qualified as a SME. In the last couple of years, the production has grown exponentially from 25 to 115 operators. The supporting organization consists of roughly 20 persons. This has also lead to an enormous growth in assets and therefore an increased demand for maintenance. Due to increased market demand, the company expects this growth to continue for the upcoming years. Therefore it is necessary to ensure that every aspect of the organization can handle this growth. Currently the company feels that the maintenance management is not on the same level as the rest of the organization. The company wants to increase their maintenance management maturity without investing a lot of resources.

The company is already used to working with a sort of maturity model. This was implemented regarding lean manufacturing and the subsequent cycle of continuous improvement. Next to this, the company has tried multiple times to implement changes regarding maintenance management. These attempts have failed due to numerous reasons, but the main reason for failed implementation was that nobody was responsible. In an attempt to change this the company has the desire to hire a 'Maintenance Engineer' that will oversee the maintenance management. The company understands that just hiring an engineer is not the sole solution. Therefore the company requested this research to be conducted. Next to short-term plans to align the maintenance management with the rest of the organization, the company also looks for a long-term roadmap to assist in determining correct maintenance strategies when the company has grown even further. The results of this research should aid the new 'Maintenance Engineer' in the quest to continuously improve the maintenance management.

1.2 Motivation

The case study company is not the only company that experiences growing pains regarding maintenance management. The transition towards Industry 4.0 continues to challenge SMEs with limited resources. Maintenance is often considered as a high-potential for improvements. SMEs often do not have the resources to improve the maintenance organization in the same way that large enterprises are able to. Studies also often tend to focus on larger enterprises and most research conducted regarding maintenance is performed for companies that have a large maintenance organization in place. Of course, asset management is of great importance in these large enterprises. This is also the case for SMEs, but they are often not part of the scope. Currently, maturity models are often used as a method of evaluation and starting point for improvements. Maturity models tend to focus on specific aspects of the maintenance organization such as the development of preventive maintenance. These models tend to be very useful in large enterprises since they provide a roadmap towards a higher maturity. Often these models are not developed specifically for SMEs and the case study also shows that these maturity models are not efficient for SMEs. The case study does not know about any existing maintenance maturity models. SMEs face different challenges and come with specific requirements which are not taken into account during development of most current maturity models.

The aim of this paper is to focus on the development of a maturity assessment tool for SMEs specifically. The needs and requirements of SMEs are taken into account from the start to create an useful maturity assessment. This assessment should lead to critical thinking and insight in the current maintenance organization as well as possible improvements of the organization. The constraints that SMEs have, such as lack of knowledge and lack of resources, are taken into account whilst developing this assessment tool. The development of such a tool is described in literature, but also not made specifically for SMEs. As outlined in the previous section, SMEs form the backbone of the manufacturing industry. Enabling these enterprises to evaluate themselves and search for good improvements is essential. Another goal of this research is therefore to enable SMEs to think about a long-term improvement strategy. SMEs have limited resources to spend on improvement projects and are forced into making important decisions regarding the deployment of resources. One reason why maturity models developed for large enterprises are often not useful, is that it is near impossible for SMEs to reach the highest level of maturity, since high level maturity is very resource intensive. This research aims to change the way that maturity is considered to ensure that with limited resources, SMEs can still grow towards a high state of maturity.

1.3 Research Question

Based on the challenges outlined, the main research question that will be answered in this thesis is:

'How can a Small and Medium Enterprise effectively measure and elevate their maintenance maturity with limited resources?'

To support the main research question, the following sub-questions will be answered in the thesis:

1. *How can you develop a maturity assessment tool for SMEs?*
2. *What should a maturity assessment tool for SMEs look like?*
3. *How can a SME implement the maturity assessment tool?*
4. *How can a SME use a maturity evaluation for a long-term improvement strategy?*

1.4 Outline

Answers to the research questions are found throughout the report and given in conclusion at the end of this report. Chapter 2 gives an overview of available literature on maintenance maturity models and shows a few methods which can be used in the development of a maturity assessment tool. Chapter 3 elaborates on the method of development in this research. Multiple development methods are combined in creating a development roadmap to ensure a maturity assessment tool with sufficient rigor. This chapter also specifies how the quality of the research is determined. The development of the maturity matrix is explained in detail in Chapter 4. Every step of the development roadmap is explained in detail and important design choices are highlighted. The chapter starts by outlining the problem definition and setting up success criteria and ends with a description of the final application of the maturity assessment. The success criteria are then evaluated in chapter 5. Not only the criteria, but also the rigor of the development is evaluated in this chapter. The discussion and implications of the results of this research are shown in chapter 6. Finally, answers to the research questions are summarized in chapter 7 which also answers the main research question of this thesis.

Chapter 2

Literature review

This literature review investigates critical areas for the research area. Firstly, SMEs will be further investigated for their specific characteristics. Secondly, an overview will be given of the history and development of maturity models and specific maturity models for maintenance management will be discussed. The most important models will be presented in a tabular overview. This is necessary to develop a method in which SMEs are able to determine their maturity model and eventually improve it. Lastly a short overview is given regarding several model development methods.

2.1 SME Characteristics

Small and Medium Enterprises are of great importance in the European Union. In 2017 they made up 99.8% of European enterprises[17]. They are the predominant form of enterprises. In recent years, SMEs have attracted attention from researchers in several fields. Research conducted especially for SMEs has been done regarding cyber security, financial security and many more. Most of this research is irrelevant for the research questions presented in this paper. The importance however is that SMEs differ greatly from large enterprises and therefore have different characteristics. Several studies actually suggest that SMEs may be differentiated from larger companies by a number of key characteristics[9][53][29]. Despite the recognized heterogeneity of SMEs, there appears to be a consensus from researchers in this field that many SMEs share a number of general characteristics[28]. Organizational characteristics are difficult to define and different approaches are taken in literature. Mijnhardt et al. use an indicator approach to distinguish between a wide variety of organisations for example[40]. Cocca and Alberti [9] performed an extensive literature review on SME characteristics. Their findings were grouped into two main categories: external and internal. The factors that are related to the external environment are typically outside the control of the organisation[10]. Therefore the internal category is the most important regarding SME characteristics and requirements. These characteristics have already been used in research in context of the design of an information security maturity model by Ozkan and Spruit[47]. Ozkan and Spruit used the characteristics found by Cocca and Alberti to investigate the effect on general design principles. This was used to determine requirements that are necessary to design an information security maturity model. The following SME characteristics were discovered by Cocca and Alberti[9]:

- Flexible and adaptable to changes, innovative
- Loose and flat structure, lack of bureaucracy
- Skills shortages
- Lack of management expertise
- Risk of personal assets
- Limited resources: time, human, financial
- Lack of organizational capabilities
- Specialist and tacit knowledge
- Poor strategic planning
- Reliance on financially based performance measures
- Control and decision-making rest primarly with one or a few people
- Reactive, fire-fighting strategy
- Intuition-based decision making
- Learning-by-doing processes
- Short term vision and orientation
- Incremental improvements and adjustments
- Poor human resource management
- Focus on technical aspects and production
- Misconception of performance measurement

It must be noted that not all of these characteristics apply to every SME. The case study which is used in this research might not fit all of these characteristics. This extensive list of characteristics is also developed into several requirements for a performance measurement system by Cocca and Alberti[9]. The aim of that paper was to develop a framework that SMEs can use to assess their performance measurement system in order to identify weaknesses and take corrective measures. The requirements that are useful in this research will be identified in Chapter 4.

2.2 Maintenance maturity models

Maintenance maturity models, drawing inspiration from broader organizational maturity models, provide a means to evaluate the maturity of the maintenance management within an organization. These models often offer a holistic perspective to the maintenance management which emphasizes the need for strategic alignment, continuous improvement and proactive management of assets. As organizations strive for world-class maintenance, the adoption and development of these models has gained prominence. Most models are also meant to be used as a roadmap such that organizations can take the steps necessary to reach world-class maintenance. The first well-known maturity model developed is the Capability Maturity Model (CMM). CMM was originally developed as tool to objectively assess the ability of government software contractors. This model has since developed into the Capability Maturity Model Integration (CMMMI). This model was developed in 2006 by the the Software Engineering Institute at Carnegie Mellon University. Even though the CMMI model originates from the field of software development, it is now also used as model to assist in business processes. CMMI is widely applicable and widely used. These models are however not the oldest models. CMM originates from the quality management maturity grid (QMMG) which was proposed by Crosby in 1979[11]. This original grid defined five maturity levels contrasted against several dimensions. Maturity is implied here as "the evolutionary progress in demonstrating the specific ability or accomplishment of a target from an initial stage to a final desired stage"[39]. Dimensions refer to important process areas within the organisation where the emphasis is placed. These dimensions differ between models. The original grid proposed by Crosby is visible in Figure 2.1. Crosby might be the first to propose a maturity grid. However, the first maturity grid found in literature regarding maintenance is by Antil in 1991[2]. This maturity grid was an adaptation of the grid proposed by Crosby and aimed towards maintenance management.

	Management Concepts	Definition	System	Performance standard	Measurement
Certainty	"No reason for not doing things right"	Conform the require-ments	Prevention	Zero defects	The price of non-conformance
Enlighten-ment	"Get serious about quality"	Satisfy customer	What do we really need to know?	Six Sigma	Complete transaction rating
Awakening	"We need to get better"	Continuous improve-ment	ISO 9000: Mil-Q-9858	Continuous improvement	Customer complaints
Regression	"Let's apply for the award"	Delight the customer	Buy some guru tapes and show them	Acceptable Quality Levels	Bench-marking
Uncertainty	"Let's get certified"	Goodness	Award criteria	What traffic will bear	Opinion

Figure 2.1: Original Quality Management Process Maturity Grid by Crosby[11]

Typically speaking, maturity models consist of the following[20]:

1. Maturity levels
2. Dimensions / Process areas (e.g. performance standard)
3. Description of elements in each dimension (e.g., the 'performance standard' may be defined by elements such as the number of defects)

The development of maturity models, not necessarily aimed towards maintenance, is extensively discussed in literature. Reviews conducted on several maturity grids by Maier et al.[37] and Wendler[57] conclude that a significant proportion of existing research largely deals with model development in several fields. These reviews highlight important aspects regarding model development and architecture such as dimensions, maturity levels and assessment items. More recently, maintenance maturity models have evolved and more models have been proposed in literature. Each model uses a specific approach to maintenance management and maturity evaluation which might be very broad or very focused on one aspect. Several models have been identified in literature and the interesting model for this study are shown in Table 2.1. In the next sections specific maturity models will be discussed in more detail.

RCM Maturity Level Roadmap

One of the first models identified was developed for specific needs. Hauge and Mercier identified that numerous maintenance organisations were implementing various forms of Reliability Centered Maintenance (RCM). Organisations needed guidance to implement RCM consistently across the company and improve their ability to manage key RCM processes. The model developed, RCM Maturity Level Roadmap, provides structure for an organization to assess RCM maturity whilst also establishing priorities for improvement. This model is based on CMM. The five levels of RCM maturity are graphically shown in Figure 2.2. Each level is a layer in the foundation for continuous improvement and cannot be skipped. Whereas the model itself is slightly outdated, the contents remain relevant to this day in case of RCM implementation. As one of the first models developed for maintenance management it also sets a standard. The distinction in five maturity levels has since been the standard for most newly developed maturity models.

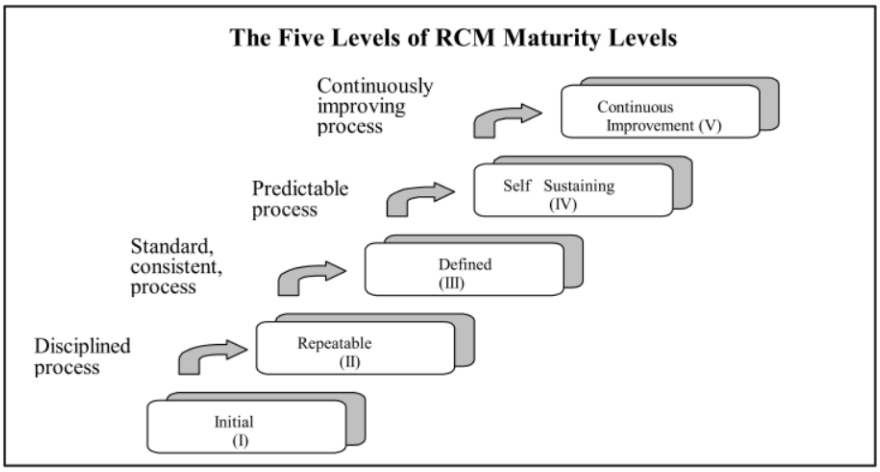


Figure 2.2: The five levels of RCM maturity, proposed by Hauge and Mercier[22]

House of Maintenance

The house of maintenance was developed at the RWTH Aachen University in 2010 by Schuh et al [52]. The house of maintenance is used as framework to describe nine fields of action that describe the elements of a typical maintenance organization on a generic level. These nine fields of action are shown in Figure 2.3.

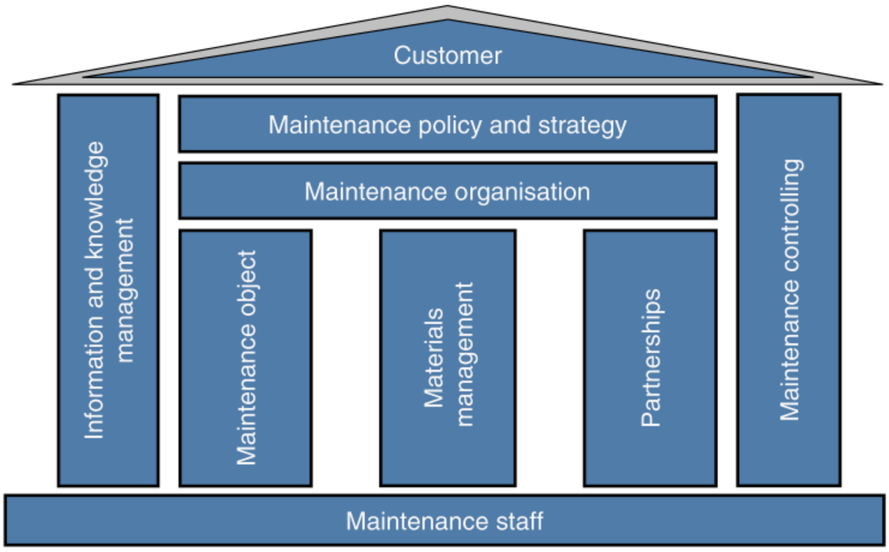


Figure 2.3: House of maintenance, by [52]

This framework is supported by the "IH-check" which was developed to recognize strengths and weaknesses in the maintenance departments of SMEs. The paper states that this can also be used to recognize potential for improvement. The paper also presents the results of a survey amongst 56 SMEs as to which are the main problems that prevent the application of maintenance concepts in SMEs. This survey was conducted in 2004 [54] and the following points were recognized as the main problems:

- Systematic support in identifying potentials for improvement
- A systematic and integrated view of maintenance
- Internal analysis (Estimation of potentials in maintenance)
- Insufficient consideration of resources (human resources as well as financial resources) of SMEs

Even though the results of this survey are 20 years old at this time, the main problems that are identified are still relevant. The maturity assessment that follows from the "IH-check" define the level of maturity per dimension shown in the House of Maintenance framework. The levels of maturity are developed according to the CMM. The assessment is followed by an individual maturity profile regarding maintenance management that determines the company's potential for improvement. The paper suggests to make a combination with prioritisation to identify the crucial fields of action, this can be done using pair-wise comparison for example. The prioritisation can be used to develop specific measures to exploit the company's full potential in maintenance. The assessment itself is carried out using 81 evaluation criteria (nine per dimension) using a questionnaire based approach including collective discussions in a workshop setting. The results are plotted in a radar chart. This radar chart also allows enterprises to determine a 'TO-BE'-scenario, the level of maturity that the enterprise wants to achieve regarding the several dimensions. In a depicted case-study the fields of actions are weighted using pair-wise comparison. This is used to develop a prioritisation matrix which is shown in Figure 2.4. These fields of action are suggested to provide the biggest opportunities for improvement and growing the maintenance maturity. This assessment clearly is a powerful tool which was dedicated for SMEs. However, it is not widely available and the company still does not have a clear idea what improvement actions are the most effective. Another benefit of the method is that the employees are more directly involved in the measures derived for the company.

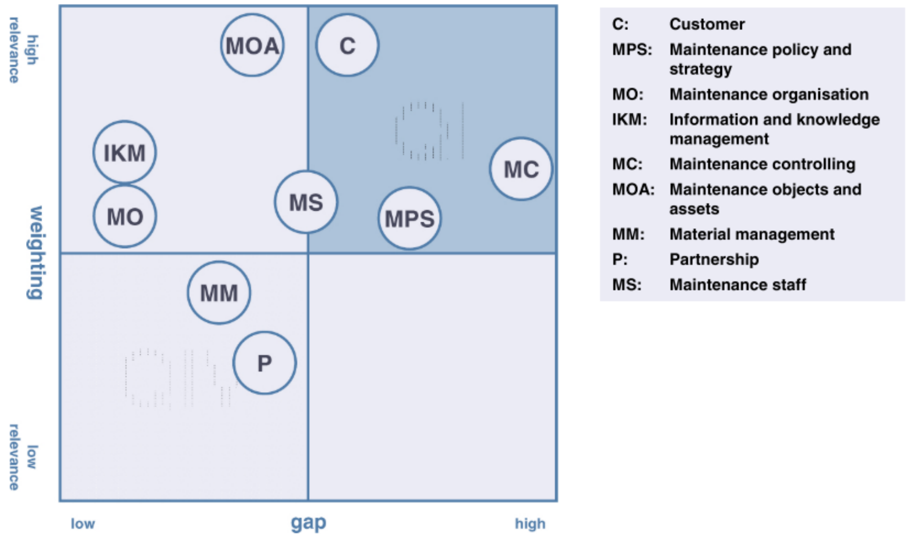


Figure 2.4: Example of prioritisation matrix, taken from [52]

Asset Maintenance Maturity Model

The authors of this paper acknowledged that existing models lacked decision making aspects and therefore proposed a generic Asset Maintenance Maturity Model (AMMM). This model uses the method of Maintenance Performance Measurement (MPM) which was originally proposed by Van Horenbeek and Pintelon [26]. The AMMM can also be seen as an extension of the MPM framework. The MPM framework uses maintenance performance indicators (MPIs). A generic MPM framework is customized for business specific by translating maintenance objectives into MPIs. These are used to measure the maintenance performance and define continuous improvement actions.

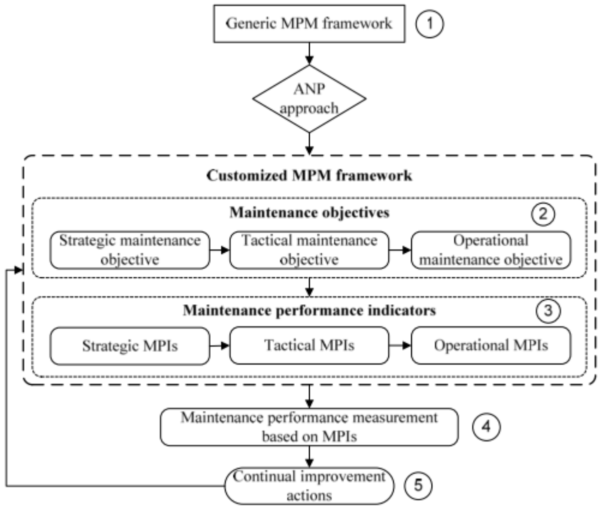


Figure 2.5: MPM framework as proposed by Van Horenbeek and Pintelon [26]

The paper by Van Horenbeek and Pintelon focuses on the first three steps where maintenance objectives and MPIs are derived. The paper by Chemweno et al. [7] extends this framework and focuses on steps 4 and 5. The several steps can be seen in Figure 2.5. The AMMM proposes to include the weighted performance assessment score (wPAS) as the basis for performance measurement and benchmarking studies. The wPAS is a mathematical formulation proposed by Hsieh[27] which was modified to suit the context of the AMM study. Some MPIs can be computed objectively (such as reliablity) but the models also allows a subjective approach where domain experts can assign the performance assessment score. The result of the mathematical formulation for the wPAS is considered the maturity of the company which is evaluated. The higher the score, the more mature the company is. The advantage of using an algorithm to assess the effectiveness of implemented maintenance policies is that it presents an important opportunity to extend the approach for e-maintenance. Essentially, it would be possible for organizations with well-established databases to link the wPAS algorithm with the databases. The disadvantages of this method are also clear, especially in the context of SMEs. The AMMM is based on the assumption that organizations have a reliable MPM framework. Setting up such a framework and further implementing an algorithm takes up massive amounts of resources. This makes this method suitable for some larger enterprises but mostly not suitable for SMEs.

M^3AIN4SME

The Maintenance Maturity Model for Assessing Information Management Practices for Small and Medium Enterprises, or M^3AIN4SME in short, is a model developed in 2022 specifically for SMEs[55]. The model has been reviewed and improved by the authors by adding sustainability assessment in 2023[19]. The authors recognize the need for a specific maturity model focuses on maintenance information management, especially in SMEs. Even though existing models allow for the assessment of the maturity level, most papers do not assist in identifying actions to reach the highest level. This model was developed to counter the problem that most SMEs take a rather unsuccessful approach to information management. It is recognized that this is mostly due to a lack of resources. In order to make better decisions, a huge amount of maintenance data needs to be analyzed quickly and efficiently[23]. Therefore, a Maintenance Management Information System (MMIS) is crucial to improve the overall maintenance process. The M^3AIN4SME model was developed to tackle one of the main issues with the development of an MMIS, which is to understand the maturity stage of the maintenance function. Recognizing the current maturity state of the maintenance process is a crucial step to determine the specific need in an industrial context[55]. The development of the model is focused on eventual adaptation of an MMIS.

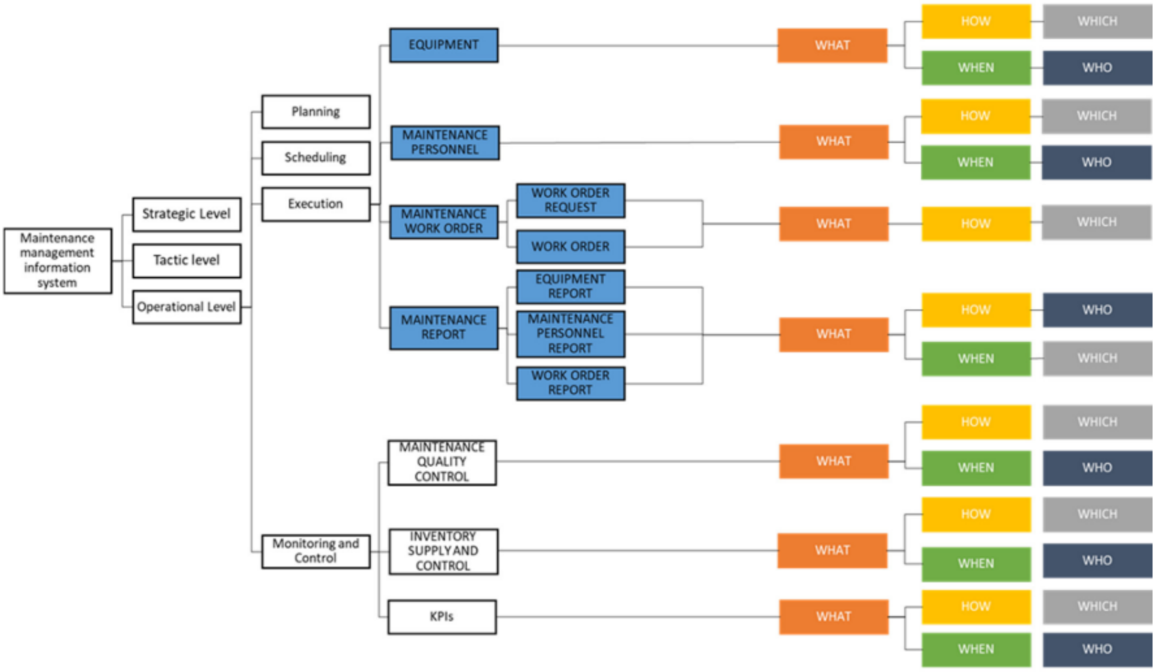


Figure 2.6: M^{3}AIN4SME architecture, taken from [55]

Figure 2.6 shows the architecture of this model. It is visible that the model focuses mostly on operational level. The maturity is determined by the authors based on a questionnaire which is filled in by the maintenance responsible within an enterprise. An algorithm in Excel returned the specific maturity levels for each dimension. By splitting up the model in HOW, WHEN, WHICH and WHO the authors claim that it is easier to see the gaps and potential for improvement. This roadmap towards maturity growth is not shown in the presented paper.

2.2.1 Overview

Table 2.1 shows an extensive overview of the models that were found during the literature review. Next to the models that are discussed in more detail in the section above, many more models were found regarding maintenance maturity.

Table 2.1: Overview of maturity models found in literature

Authors (year)	**Title**	**Short description / Objective**	**Method of assessment**	**Dimensions considered in the model**	**Maturity levels**
Fernandez, Labib, Walmsley and Petty (2003)[18]	A decision support maintenance management system	Slight adaptation of the model proposed by Antil [2]. Evolution from reactive state to preventive and eventually into a predictive state.	Not specified	1. Management Understanding & Attitude 2. Problem Handling 3. Company maintenance posture 4. CMMS	5
Hauge and Mercier (2003)[22]	Reliability-Centered maintenance maturity level roadmap	Roadmap for the assessment of Reliability Centered Maintenance maturity level. Paper also proposes improvements for the management of RCM processes.	Not specified	1. Analysis 2. Analysis documentation 3. Metrics 4. Mentoring and facilitation 5. Training 6. Living Process	5
Schuh, Lorenz, Winter and Gudergan (2010)[52]	The house of maintenance: Identifying the potential for improvement in internal maintenance organisations by means of a capability maturity model	Paper makes use of assessment tool to identify gaps in maintenance performance and potential for improvements, the so-called IH-check.	Survey + Workshop	1. Information & knowledge management 2. Maintenance object 3. Materials management 4. Partnerships 5. Maintenance control 6. Maintenance organisation 7. Maintenance policy & strategy 8. Customer 9. Maintenance staff	5

Table 2.1 continued from previous page

Authors (year)	Title	Short description	Method of assessment	Dimensions considered in the model	Maturity levels
Kans, Ehsani-fard and Moniri (2012)[31]	Criteria and model for assessing and improving information technology maturity within maintenance	Paper focuses on Information Technology within maintenance. Assessment of this maturity is done and divided in 2 levels, high and low maturity.	Not specified	1. Maintenance management Information Technology (MMIT) utilization level 2. Decision-making using MMIT 3. MMIT Integration 4. KPI monitoring/controlling by MMIT 5. Data quality in MMIT	2
Oliveira, Lopes and Figueiredo (2012)[46]	Maintenance management based on the organization level of maturity	Paper proposes a maturity grid that allows understanding of the appropriate strategy, tools, techniques and indicators. Maturity is divided in 3 levels (low, medium, high).	Interview	1. Maintenance strategy 2. KPIs 3. Maintenance data systems 4. Technical competences 5. Management models	3
Macchi and Fumagalli (2013)[35]	A maintenance maturity assessment method for the manufacturing industry	Maturity assessment provided to measure state of maintenance practices. Paper states that company classifies criticalities and makes a benchmark with the best companies in order to better drive investment. The maturity assessment can be used to identify the practices to be improved.	Questionnaire	1. Organisational 2. Managerial 3. Technological 4. Several key process areas in each of the above mentioned dimensions	5

Table 2.1 continued from previous page

Authors (year)	Title	Short description	Method of assessment	Dimensions considered in the model	Maturity levels
Chemweno, Pintelon and Van Horenbeek (2015)[7]	Asset maintenance maturity model: Structured guide to maintenance process maturity	A generic AMMM is introduced in this paper since existing models lack decision making aspects. AMMM uses maintenance performance measures (MPM) as indicators of effectiveness. AMMM is more applicable to larger organizations.	Analytic Network Process (ANP) + Indicators	1. People and Environment 2. Functional and technical aspects 3. Plant design life 4. Support 5. Maintenance budget	5
Mehairjan, van Hattem, Djairam and Smit (2016)[38]	Development and implementation of a maturity model for professionalising maintenance management	M^4 model developed mostly aimed towards gas/electricity companies. Five organizational dimensions are recognized and measured on 3 levels by carrying out a survey and multiple interviews with the personnel.	Survey + Interview	1. Organisation and processes 2. Policy and criteria 3. Information and systems 4. Data quality 5. Performance and portfolio	3
Nemeth, Ansari and Sihn (2019)[43]	A maturity assessment procedure model for realizing knowledge-based maintenance strategies in smart manufacturing enterprises	Paper focuses on maturity levels for Knowledge-Based Maintenance (KBM). The maturity is determined using six to twenty quality indicators per factor. These are defined, calculated and assigned to a Balanced Scorecard. This does require data to be present.	Indicators on Balanced Scorecard	1. Data 2. Information 3. Knowledge	Not fixed, scale of 1-100%
Van de Kerkhof, Akkermans and Noorderhaven (2019)[33]	CBM Maturity Model (CBM3) for asset owners in the process industry	Paper sees that there is no specific maturity model regarding Condition Based Maintenance (CBM) and fills this gap with a maturity model that can be used for self-assessment. This model was developed together with Tata Steel and BP.	Self-Assessment in focus groups	1. Value 2. Technology 3. Organization 4. People	5

Table 2.1 continued from previous page

Authors (year)	Title	Short description	Method of assessment	Dimensions considered in the model	Maturity levels
Oliveira and Lopes (2019)[45]	Evaluation and improvement of maintenance management performance using a maturity model	The maturity model focuses on behavior instead of results. Behavior that leads to good results have been identified by means of a literature review and the 5 levels are established by the authors' experience. The model identifies the current state of maintenance and the actions to increase its efficiency and effectiveness.	Maintenance manager self-assessment tool, based on reading content of a table.	1. Organisational culture 2. Maintenance policy 3. Performance management 4. Failure analysis 5. Planning and scheduling of preventive maintenance activities 6. CMMS 7. Spare parts inventory management 8. Standardization and document control 9. Human resource management 10. Results management (costs and quality maintenance)	5
Duque and El-Thalji (2020)[14]	Intelligent maintenance maturity of offshore oil and gas platform: A customized assessment model complies with the Industry 4.0 Vision	The maturity model is used to assess smart maintenance within the industry 4.0 vision for the offshore oil & gas platform.	Questionnaire	1. Physical space 2. Cyberspace 3. Business layer	4

Table 2.1 continued from previous page

Authors (year)	Title	Short description	Method of assessment	Dimensions considered in the model	Maturity levels
Tortora, Di Pasquale and Iannone (2022)[55]	A Maintenance Maturity Model for Assessing Information Management Practices for Small and Medium Enterprises (M^3AIN4SME)	The model is specifically designed for SMEs. A questionnaire is used to assess the maturity of the four databases with the help of several questions, e.g. What, How, Which, When and Who. The maturity is assessed using 4 levels and should provide a starting point for improvement	Questionnaire	1. Equipment 2. Maintenance personnel 3. Maintenance work order 4. Maintenance report	4
Errandonea, Alvarado, Beltrán and Arriz-abalaga (2022)[16]	A maturity model proposal for industrial maintenance and its application to the railway sector	The Maintenance Maturity Model (M3) presented in this paper identifies three areas of action, four levels of maturity and most importantly the activities to be carried out in each of them to make progress in the maturity level. The paper describes the model as a hybrid model which is seen as a roadmap for acquiring maturity. This model sees preventive maintenance as lowest maturity and prescriptive maintenance as highest.	Not specified	1. Asset 2. Status 3. Maintenance	4
Franciosi, Tortora and Miranda (2023)[19]	A maintenance maturity and sustainability assessment model for manufacturing systems	The paper adapts the model by Macchi and Fumagalli (2013) by not only considering Maintenance maturity level (MML), but also the sustainability maturity level (SML).	Questionnaire + Interviews	1. Organisational 2. Managerial 3. Technological 4. Several key process areas in each of the above mentioned dimensions	4 for MML, 7 for SML

2.3 Model development

This section provides a short overview of available and usable literature regarding maturity model development. This is input for chapter 3 where the specific methodology will be discussed. Knowing about available methods and usefulness is therefore worth an investigation. Even though maturity models are common and broad in application, only few guidelines and methods are presented on how to develop a maturity model that is theoretically sound, rigorously tested and widely accepted. This section will discuss some of these maturity models in some more detail.

2.3.1 Design Science Research

Design Science Research (DSR) (DSR) is firstly presented by Hevner et al. in 2004.[24] DSR is a problem-solving paradigm that seeks to enhance human knowledge via the creation of innovative artifacts. This means that DSR seeks to enhance technology by creation of artifacts that solve problems and improve the environment in which they are instantiated[5]. DSR is very often used in the Information Science field. Figure 2.7 shows the conceptual framework to further understand design science research. As seen, DSR consists of three important pillars: Environment, Design and Knowledge Base. The environment defines the problem space. It is composed of organizations, people and existing technologies. Needs are assessed in context to the organization and existing work processes. Needs are positioned relative to existing technologies, frameworks or applications. Together they define the research problem. By correctly identifying real stakeholder needs, relevance is assured. The other side of DSR is the knowledge base. This contains prior research, results from reference disciplines, frameworks, models, methods and foundational theories. By correctly applying existing foundations and methodologies, rigor is achieved.

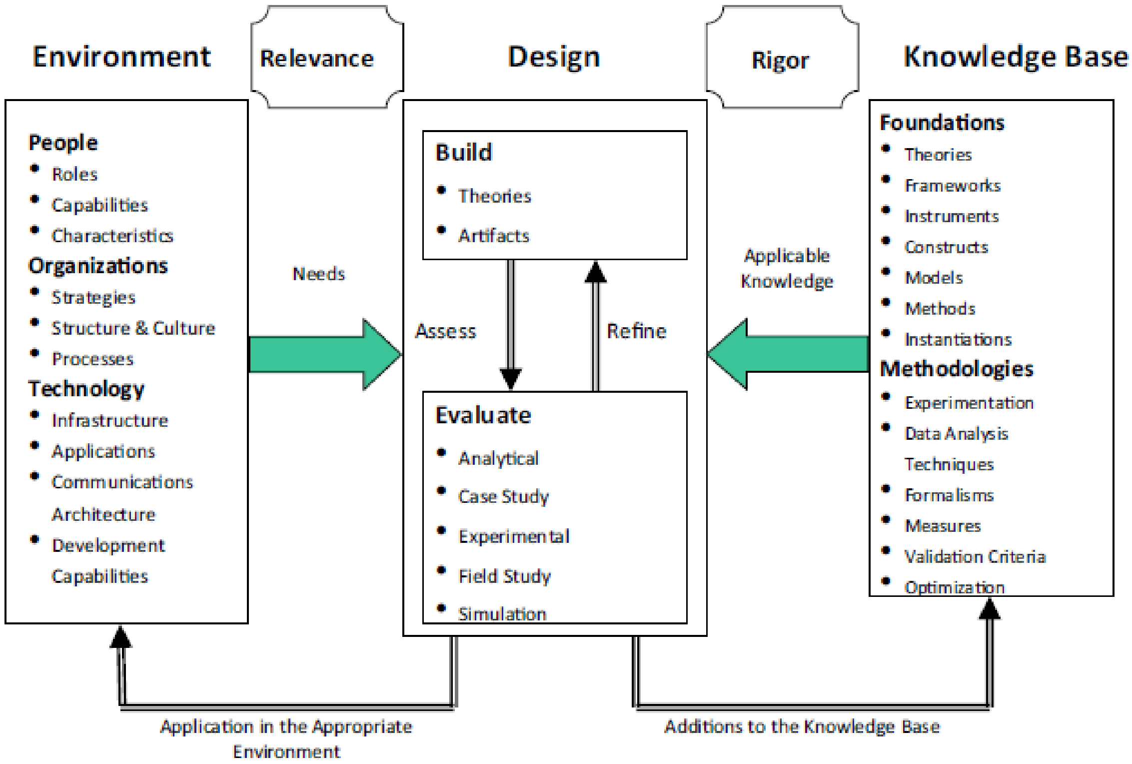


Figure 2.7: Design Science Research Framework (Adapted from [24])

In short, DSR studies relevant problems in a real-world environment. The analysis starts by derivation of specific needs from a business environment. Next, a knowledge base is investigated to study in which extent design knowledge is available to solve the problem of interest. In case this knowledge is not available, or incomplete, DSR sets out to create an innovative solution to the problem. In most cases building on existing parts of solution and combining existing knowledge. Hevner et al. [24] developed 7 guidelines for DSR which are shown below.

1. **Design as an artifact**: Design science research must produce a viable artifact in the form of a construct, a model. a method or an instantiation.

2. **Problem relevance**: The objective of design-science research is to develop technology-based solutions to important and relevant business problems.

3. **Design Evaluation**: The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.

4. **Research Contributions**: Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.

5. **Research Rigor**: Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.

6. **Design as a search process**: The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.

7. **Communication of research**: Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

These guidelines were proposed for the use of DSR in Information Science research. A study by Venable[56] in 2010 showed that there are doubts about the use of these guidelines. Not all guidelines seem as important. Guideline 3, Design Evaluation, is considered the most important guideline. This was also mentioned by Hevner et al [24]. Even though some concerns are raised, DSR still continues to be a viable approach to address and solve problems. Venable also recognized that there was a general consensus that a clear design artifact is part of DSR[56].

Performance of DSR has been based on several process models. These include Nunamaker, Chen and Purdin[44] and Hevner[25]. The most widespread process model however is proposed by Peffers et al.[32]. This paper proposed the Design Science Research Methodology (DSRM). This process model includes 6 steps which are shown below.

1. Problem identification and motivation

2. Define the objectives for a solution

3. Design and development

4. Demonstration

5. Evaluation

6. Communication

Following these steps forms a very good basis of conducting DSR research. Vom Brocke [5] et al. state that even though it is not mentioned in the process model by Peffers, it should be seen as an iterative process to comply more with the guidelines of DSR set by Hevner.

2.3.2 De Bruin framework

One of the first papers to really discuss the main phases in developing a maturity assessment model is by de Bruin et al.[6]. She proposes an framework consisting of six phases. The framework can be seen in Figure 2.8.Even though the phases are generic, the order is important. Decisions made early in development influence the latter phases greatly. In the first phase, *Scope*, the decisions influence all remaining phases. Determining the scope will set outer boundaries for the use of the model. Major decisions include the model focus and the stakeholders involved in development. The *Design* phase of the framework is important to design an architecture for the model that forms a basis for further development. It has some big decisions such as the audience, method of application, and respondents. These decisions influence the contents of the model, since each choice comes with specific requirements. Once the scope and design are agreed, the model should be populated. This means that it is necessary to identify what needs to be measured and how this can be measured. The *Populate* phase its goal is to enable a deeper understanding of maturity and attain domain components and sub-components that are mutually exclusive and collectively exhaustive[6]. Once the model is populated the *Test* phase starts. The model should be tested for relevance and rigor. The assessment method should be tested alongside the contents of the model. After testing, the model should be made available for use in the

Deploy phase. The aim of this phase is to further go towards standardization and global acceptance of the developed model. One thing that benefits this is to identify organizations that might benefit from future application of the maturity model. The last phase that is proposed is the *Maintain* phase. To successfully be able to generalize the model, requires maintaining of the model. Over time, the model might become outdated. The only way to ensure relevance of a model is by maintaining it.

Figure 2.8: Model Development Phases, as proposed by de Bruin [6]

2.3.3 Maier roadmap

Another paper presenting both a reference point and guidance for the development of maturity grids is the paper by Maier et al.[37]. This paper recognizes several important factors for the design of a maturity model. The paper states that in case of voluntary evaluation, companies tend to look for assessments that do not take long and do not cost much. This makes maturity grid assessments attractive. This paper also specifies the *difference* between maturity models and maturity grids. Whereas a model mostly identifies best practices for specific processes, maturity grids often do not specify what a particular process should look like. Besides the evaluation of common practices in development of maturity grids, the paper also identifies similarities between maturity grids. This will aid the development of a maturity model later in this paper. Maier et al. identify 4 phases in the development of a maturity grid. These phases, including decision points, can be seen in Figure 2.9. It can be seen that these phases have a lot of overlap with the phases identified by De Bruin[6]. Maier et al. specify that one of the most important stages in the *Planning* phase is to define success criteria; how to determine whether development and application was successful?

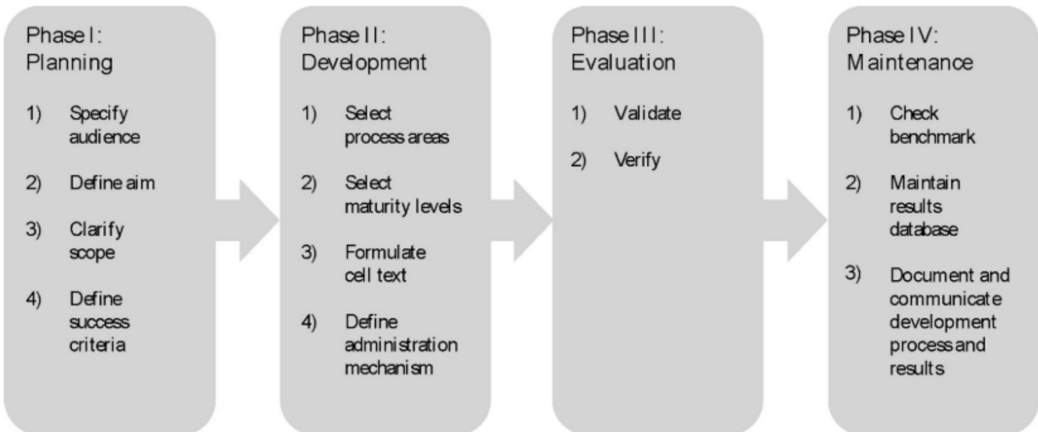


Figure 2.9: Roadmap containing phases and decision points to develop new maturity grids (Adapted from [37]

2.3.4 Becker guidelines

A paper by Becker et al.[4] presented an adaption of the guidelines from Hevner[24] to suit the design of maturity models. The paper states that maturity models may be understood as artifacts which serve to solve the problems of determining a company's status quo of its capabilities and deriving measures for improvement therefrom[4]. The adapted guidelines were motivated by the criticism of Zelewski on some guidelines[59]. The adapted guidelines are listed below (taken from [4].

1. **Comparison with existing maturity models**: The need for the development of a new maturity model must be substantiated by a comparison with existing models. The new model may also just be an improvement of an already existing one[59].

2. **Iterative procedure**: Maturity models must be developed iteratively, i.e., step by step.

3. **Evaluation**: All principles and premises for the development of a maturity model, as well as usefulness, quality and effectiveness of the artifact must be evaluated iteratively.

4. **Multi-methodological Procedure**: The development of maturity models employs a variety of research methods, the use of which needs to be well-founded and finely attuned.

5. **Identification of problem relevance**: The relevance of the solution proposed by the projected maturity model for researchers and/or practitioners must be demonstrated.

6. **Problem Definition**: The prospective application domain of the maturity model, as well as the conditions for its application and the intended benefits, must be determined prior to design.

7. **Targeted Presentation of Results**: The presentation of the maturity model must be targeted with regard to the conditions of its application and the needs of its users.

8. **Scientific Documentation**: The design process of the maturity model needs to be documented in detail, considering each step of the process, the parties involved, the applied methods, and the results.

Becker et al. also use their paper to propose a procedure model that distinguishes eight phases in the development of a maturity model. This procedure model is visible in Figure 2.10.

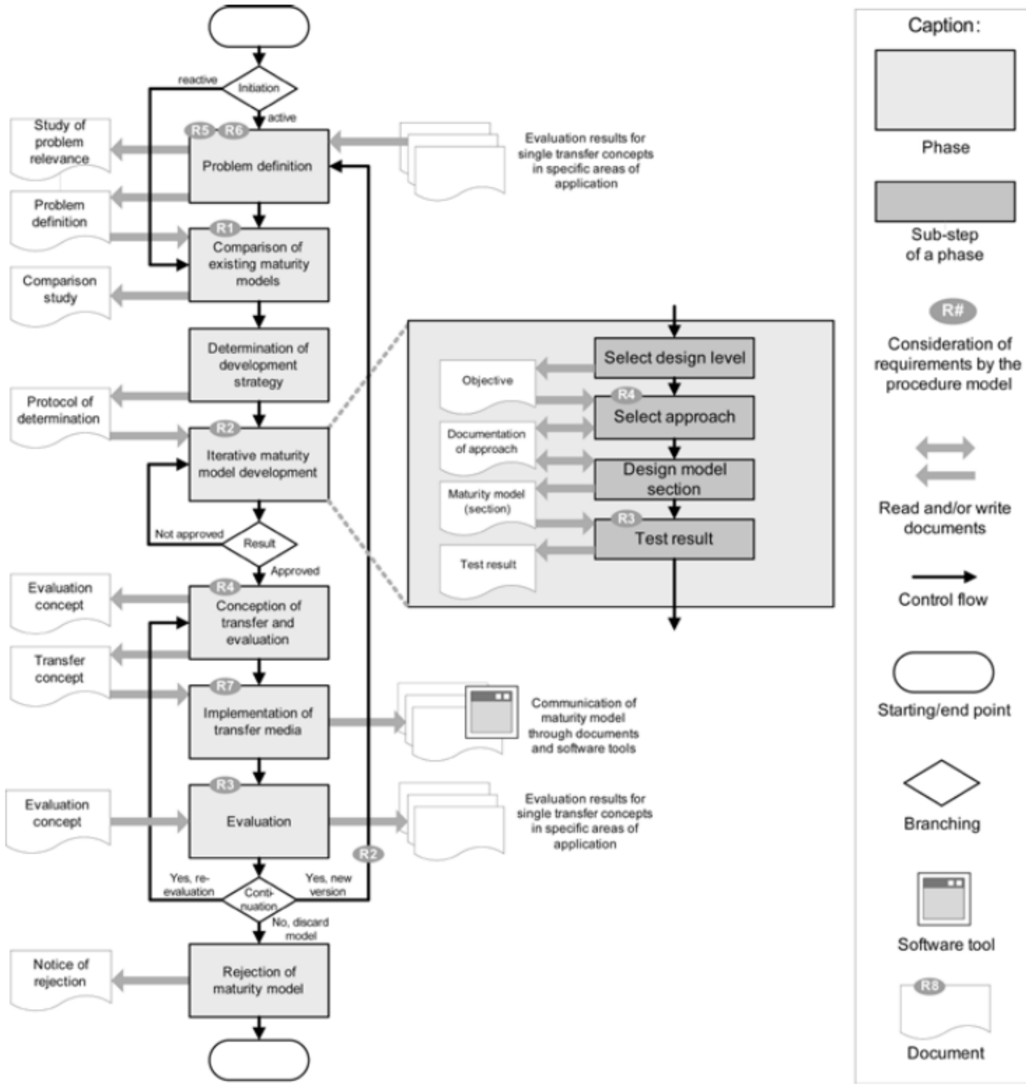


Figure 2.10: Procedure model for developing maturity models (Adapted from [4])

Chapter 3

Methodology

The previous chapter inventoried existing (maintenance) maturity models and some model development methods. This chapter dives into the specific methodology for development of a maturity assessment tool for SMEs. The development is a crucial step towards achieving the research goals. Therefore it is crucial to have a good methodology to ensure proper results. The aim of the paper is to deliver a method to SMEs that can be used to measure and elevate the maintenance maturity of the organization. This chapter is used is to give clear insight in how an assessment tool will be developed. Firstly, the methodology for development of an assessment tool will be discussed. The literature review on model development techniques is used for this purpose. Next to this, the chapter will discuss how the maturity model will be evaluated compared to the research objectives.

3.1 Design Method

As can be seen in section 2.3, there are several ways described in literature regarding model development. These guidelines are mostly developed for larger enterprises and might not be as useful on its own for the purposes of this thesis. This section explains rationale behind choosing some guidelines and describes the way in which the maturity assessment tool is developed in chapter 4. The aim is to achieve rigor by following a widely accepted design method.

3.1.1 Design Science Research

The overall methodology which is followed is DSR. The literature review shows that DSR is an excellent method to answer the proposed research questions of this thesis. The case study where the thesis is performed provides a relevant problem in the real world. This problem is believed to be existent in other SMEs which is determined in the literature review. There also is an existent knowledge base available with multiple frameworks and models. Even though there are models that are specifically designed for SMEs, or viewed as so by the authors at least, these models do not seem to align with the characteristics and requirements of SMEs. This will be further demonstrated in Chapter 4. The aim of the paper is to enhance the models that currently exist and come up with a new artifact which solves the real-world problem that exists within the case study.

DSR has its limitations, especially the developed DSRM. This is a very suitable approach for the general development of artifacts but is not specifically for the development of a maturity assessment tool. Therefore within the main approach of DSR, there is a need for more specific guidelines.

3.1.2 Used method

The other development tools and guidelines that are shown in section 2.3 also mostly follow the DSR framework. Each separate method could be suitable for the development of an assessment tool, but each of the methods is also not specifically used within the SME context. Most of the methods contain common development phases. Where these models propose a generic method of developing maturity models, key elements related to SMEs are not considered. General activities that most development road maps specify can be seen below:

1. Problem identification

2. Design strategy and architecture

3. Building an instrument to measure the maturity

4. Validation

5. Deployment and Maintenance

Since the evaluation of maturity in SMEs will be mostly driven by intrinsic motivation and voluntary action, the paper by Maier et al.[37] specifies that an assessment should not take long and cost too much. This aligns with the characteristics of SMEs which can be seen in Section 2.1. The method which is used as basis in this thesis to develop a maturity assessment tool is the general roadmap in Figure 2.9. Next to a clear pathway of phases it also highlights some important decisions. The paper by Maier et al.[37] also evaluates the suggested roadmap against the guidelines by Hevner[24] which were reformulated by Becker et al.[4] Therefore it fits in perfectly with the methodology of DSR and provides a structured way of development. The suggestion is thus to use a combination of methods for this thesis. The guidelines are mostly used as evaluation tool.

An important note is that the terms *Maturity Matrix/Grid* and *Maturity Model* are often used in literature to denote roughly the same assessment tool. There are some differences however. As mentioned earlier in this section, maturity models often identify best practices for several processes. This means that the assessment is whether a company is behaving according to the best practice or not. Most maturity grids do not specify what a particular process should look like and apply to companies in any industry. The goal of this research is to provide a common assessment method which can be used for SMEs in industries that have a maintenance organization which supports the manufacturing business. Therefore the most applicable assessment method is the maturity grid. Maturity grids also tend to be less complex as diagnostic and improvement tools[37]. This is another reason why the development roadmap by Maier et al. is very applicable. This roadmap focuses on the creation of a maturity matrix mostly instead of a maturity model.

3.1.3 Development Roadmap

The previous section highlights the applicability of the development suggested by Maier et al. in combination with the guidelines by Becker et al. However, this method also has some limitations. Inclusion of decision points suggested by De Bruin could be helpful towards the development of a good assessment tool suitable for SMEs. Therefore, a roadmap is suggested which is followed in the development of a maturity assessment tool in this thesis. This roadmap can be seen in Figure 3.1.

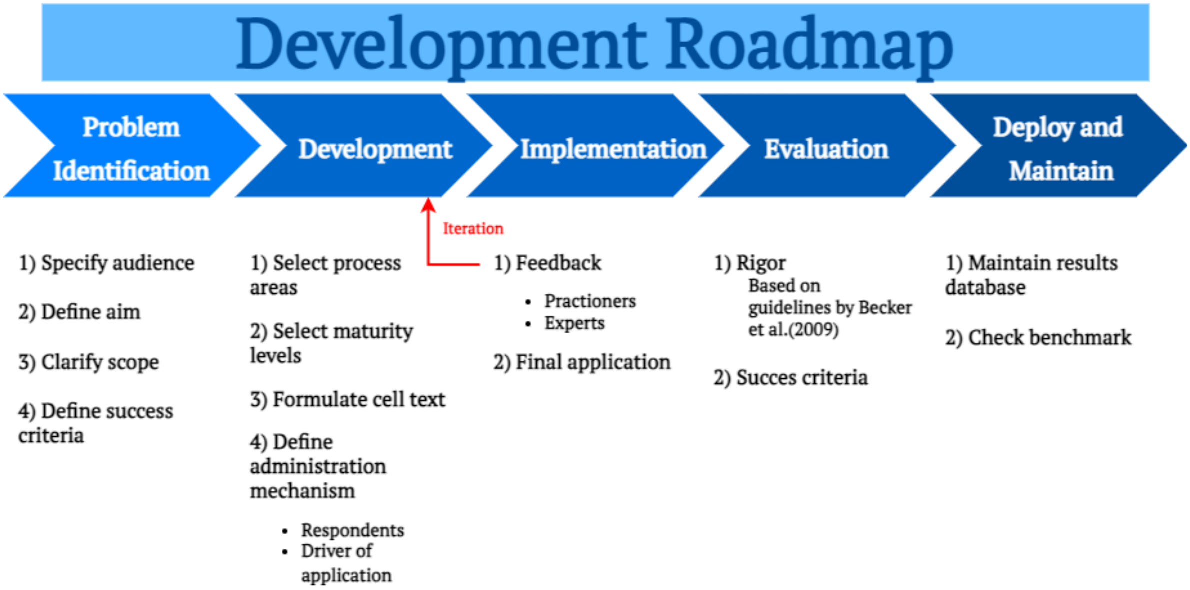


Figure 3.1: Development Roadmap

The roadmap specifies 5 different phases of development. The last phase, Deploy and maintain, is not within the scope of this thesis since it requires a larger sample of enterprises and maintaining takes a great amount of time. The other phases are discussed in Chapter 4. In this chapter, it is also outlined in more detailed which decisions are important in each of the phases. There are multiple iterations possible within this roadmap, where one of them is shown. The initial feedback from individual implementation is used to assist in the development. Also the evaluation stage can be used to tweak the maturity matrix before deployment.

3.2 Research Quality

This paragraph describes the essence of the analysis and areas in which conclusions are sought and described to ensure the quality of the research. This means that after a model has been developed, it should be evaluated to check whether the research objectives are met. This research has several objectives that are shown below which should be used to check the quality of the research;

- Create insight within a SME regarding the status of their maintenance management.
- Provide SMEs with a method which they can use to self-evaluate their maintenance maturity.
- Stimulate long-term strategy thinking on the subject of maintenance management.

To ensure that the research has been successful, these objectives should be fulfilled. Therefore an evaluation must be done on the maturity model to check whether the research objectives have been met, and that with the fulfillment of these objectives the research questions have been answered.

3.2.1 Validity

This research has multiple outputs. In addition to the generation of a new maintenance maturity assessment tool for SMEs, the research also has interest in the implementation of this model. The implementation is crucial in proving that the maturity model is successful in achieving the research objectives. By meeting these objectives, the model is also validated as a successful tool for SMEs. The model is developed in collaboration with a case study company. This company has been introduced in Chapter 1. The developed model will be implemented in this company and this implementation phase can be used to evaluate the model. Firstly, the maturity assessment tool needs to be validated. Even though the case study itself might not provide sufficient rigor, it provides sufficient information whether the maturity assessment tool benefits the organizations that are targeted in this study[34]. Sufficient rigor is achieved by following DSR and reviewing the developed assessment tool against the guidelines which are set by Becker et al[4]. By following DSR guidelines, the developed assessment tool can be validated. The implementation of the assessment tool and achieving the objectives of this thesis are checked separately. In Section 4.1.3 several requirements are laid out that determine the success of the developed assessment tool. By checking these requirements, the success of the developed tool can be proven. This is done by implementing a survey among participants in the assessment with statements related to the requirements. This survey is combined with a thorough observation of the final assessment. Together, these findings should provide enough information on whether the objectives of the thesis are managed.

Chapter 4

Design of maturity model

This chapter describes the design of a maturity matrix as specified in Chapter 3. The design of the matrix is split up in several phases that are each discussed separately. These building blocks will result in a maturity model which is presented at the end of this chapter. The maturity matrix can then be tested within the case study company. Firstly, the problem identification is performed. The development phase is also discussed and feedback from initial implementation is already incorporated in the results shown in this chapter. Finally, the chapter discusses the final application which is used for the evaluation stage that is discussed in chapter 5.

4.1 Problem identification

The first phase in the development of a maturity assessment tool, in this research a maturity grid, is to identify the problem. This is a crucial step of the research since it outlines the need for developing a maturity grid whilst identifying success criteria to evaluate the developed tool. The problem is already shortly outlined in the introduction of this paper, but this section will provide a more detailed problem description. This starts by identifying the intended audience, after which the aim and scope are determined. Lastly, the success criteria are mentioned as requirements to help evaluate the maturity grid after development.

4.1.1 Audience

The audience refers to the expected users. It means that al stakeholders who will participate in aspects of the assessments are outlined. The intended audience for the maturity matrix has been mentioned before in this paper. The intended audience are SMEs. However, not all SMEs are the same. Since the case study is an SME in the manufacturing industry this will also be the intended company for the maturity grid. The manufacturing industry often makes use of several machines and assets which are important for the quality or the amount produced. Having these assets also means that there is a need for maintenance. The focus will be on SMEs that are undergoing a growth process. This growth comes with extra challenges and the need to do things in a more structured manner. SMEs targeting growth are also part of the audience. These companies often have the need for a long-term strategy, which is one of the goals of the research. Next to this, the goal of the research, and therefore the maturity grid, is to provide more insight in the maturity of the maintenance operation. From this it should be clear that users of the maturity matrix can include the operations manager, maintenance

manager or the Chief Operational Officer. Within the context of SMEs, these exact positions might not exist within the company. This can be due to a smaller size. Therefore the intended user can be explained as 'The responsible employee regarding the operations department or the employee in charge of the maintenance department'. This employee might be the same person in some SMEs. Since the goal of the assessment is to assess the maintenance operation, the user should be connected to this in a leading capacity.
The improvement entity is to enhance the maintenance organization within the whole company. The results are aimed at the people who also provide the assessment. These people are working on the maintenance organization and therefore they benefit from the results.

4.1.2 Aim and Scope

Generally speaking, two 'improvement' paradigms have been distinguished: an analytic and a benchmarking one[30]. Even though this was identified for software improvement initiatives, the literature review in this paper identifies the same trend for maintenance maturity models. The analytic paradigm goal is to gather evidence to determine what improvements are needed and whether an improvement initiative is successful. The benchmarking paradigm aims to identify best practices. It specifies best practices that either have been demonstrated as value-adding in a particular context or practices that have been stated in models and standards. Analytic and benchmarking strategies can be complementary[48].

In this research, by using a maturity grid, it is implied that the analytic strategy is chosen as improvement paradigm. In order for a maturity grid to be used for benchmarking, it must be applied to a high number of companies with similar parameters to attain sufficient data for valid comparison [37]. Since this research is based on a sole case study, this is not possible. Next to the impossibility of benchmarking, the main aim of the study is to raise awareness within SMEs regarding the maintenance operation. This is also the aim of the analytic paradigm. The goal is to improve by raising awareness.

The scope of the maturity grid should also be determined. The maturity grid is supposed to be mostly generic within the domain of maintenance. The context is supposed to be an SME that is actively producing goods in the manufacturing industry. However, it should be available to use for all SMEs that have a maintenance operations which covers a wide range of assets.

4.1.3 Success Criteria

Success criteria are crucial to understand whether this research was successful. Success criteria are manifested in the form of high-level and specific requirements. High-level requirements in managerially focused action research [42] are, for example, usability and usefulness. Usefulness can be seen as to whether a company, from its perspective, finds the assessment helpful in stimulating learn effects. The company might also see if the assessment lead to effective plans for improvement which can be seen as useful. Usability addresses the degree as to which users understand the language and concepts used[58]. Specific requirements should be drafted from individual context and influenced by the developer's and the user's objectives.

It should be clear that SMEs have other requirements in comparison to large enterprises, especially for a maturity matrix. These requirements come from the special nature and characteristics of SMEs. The characteristics shown in Section 2.1 are used as a basis for the development of the requirements. Based on talks and short, informal, interviews with employees working in the case study company these characteristics were checked for applicability in the case study company. It was found that most characteristics that were found in the literature study are applicable but not all. The development of good requirements are essential in the development of an effective maturity assessment tool. These requirements are used as starting point for the development and will be referred back to when necessary in explaining design choices. The requirements are also used as validation. The goal of this research is not only to develop a maturity assessment tool, but to develop this tool specifically useful for SMEs. The requirements that are drafted for this research are shown below with some extra information about why they are important in this research.

SC1 The tool should be time-efficient to use. This means that the tool should only need to be used once in a longer period of time, especially if it is slightly time-consuming. SMEs often do not have the required personnel to fill in and think about a maturity assessment tool every day or week.

SC2 It should be possible to use the tool with only a couple of people. It is clear that SMEs have a lack of highly-educated maintenance personnel. The 'experts' that a company provides should be enough to use the tool. This means it should also be understandable without extensive knowledge about maintenance.

SC3 The contents of the tool should be easy to understand. This means that with simple language the message can be understood by SME managers.

SC4 The tool should make clear what is necessary to reach higher maturity levels. This will ensure that there is no extra step necessary for SMEs to understand how to reach a higher maturity. Such an extra step would be time consuming.

SC5 The tool should include an option where the SME can determine the desired maturity level. In contrast to larger organizations, the goal of an SME is often not to grow to the highest level of maturity for every dimension. Due to the limited resources, this can be considered highly unlikely. Therefore an SME should be able to make conscious choice as to where higher maturity is desired and where a lower maturity level is acceptable.

SC6 The tool can stimulate continuous behavior. The maturity should not be viewed as a static object which is evaluated every now and then but should be viewed as a tool to think about continuous improvement to ensure that the company keeps developing.

SC7 The results should be easy to collect and these should provide fast and accurate feedback. The results can then be used to stimulate thought for improvements which help to enhance the maturity. Practically, outside help for using the tool should not be necessary.

SC8 The tool should create more insight in the maintenance operation for the people involved. The aim is of the tool is to engage a discussion which leads to more insight as to 'why' things are done in a certain way and 'what' consists of a successful maintenance operation.

SC9 The tool should cover a large part of the maintenance operation. The tool is aimed towards gathering insight in the maintenance operation and that is not possible by only focusing on one part of maintenance (e.g. preventive maintenance). Therefore a more all-including view to maintenance should be the approach for design.

In order to follow DSR and the corresponding guidelines a quick comparison is made. It is important for this thesis to show the value of the research by comparing the requirements with models found in the literature review. If one of the models already fulfills all the requirements stated above, there is no further need for the development of an assessment tool. It is difficult to gather all this knowledge from reading the papers but an attempt was made. Considering the guidelines of DSR again, correct

Table 4.1: Comparing a few maturity models against requirements

Requirements/Model	RCM[22]	House of Maintenance[52]	AMMM[7]	M3AIN 4SME[55]	Oliveira and Lopes [45]	CBM3[33]
Developed for SMEs	X	✓	X	✓	X	X
SC1	?	X (4-6 hours)	?	✓(33 question survey)	?	?
SC2	?	✓	?	✓	?	?
SC3	✓	✓	X	✓	✓	?
SC4	✓	X	X	X	✓	?
SC5	X	✓	X	X	X	X
SC6	✓	✓	✓	✓	✓	✓
SC7	✓	X	X	X	✓	X
SC8	?	✓	?	?	✓	✓
SC9	X	✓	✓	✓	✓	X

scientific documentation is of great importance. Therefore a good maturity assessment tool should be well documented and has steps could be retraced. The requirements shown above are evaluated for a couple of maturity models that are introduced in the literature review. All the models with some short information can be seen in Table 2.1. These models have been evaluated whether or not the requirements are met. This was done by reading the papers in detail.

Table 4.1 shows the overview of requirements that are met for each maturity model. If the requirement is met a check mark (✓) is shown. If the requirement is clearly not met by the model, an X is shown. Some requirements were especially difficult to check, such as 'Easy to understand'. This comparison aims to be as complete as possible but sometimes the information was unable to be found in the corresponding paper. In this case a question mark (?) is shown in the Table. The requirement regarding time efficiency was also very difficult to determine. The time it takes to do the maturity assessment was not always mentioned in the paper. Time efficient is taken as do-able within 2 hours for the sake of determination. The requirement 'Easy to collect results' was compared using the information whether or not outside help was needed for the assessment. If outside help was required the requirement was considered as not met.

4.2 Development

Whereas the previous section dealt with the initial steps of problem identification, this section moves on to the actual design of a maturity matrix. This is the second phase in the development of an assessment tool and consists of multiple steps, in this case four steps. The four steps are as follows:

1. Select process areas
2. Select maturity levels
3. Formulate cell text
4. Define administration mechanism

The development process was an iterative procedure. After each iteration of either selecting process areas, maturity levels or cell text feedback was requested from the expert supervisor and the supervisor in the case study company. An iterative procedure provides a good basis due to the constant feedback loops. This section will outline the process and show (if possible) final results. Considerations that were done will be discussed and changes due to iteration are mentioned.

4.2.1 Select process areas

Selecting process areas is a very important step in the development. Process areas are also called dimensions and that is predominantly the name used in literature. Selecting dimensions is a challenging process since the assessment must be complete enough but not too lengthy. The literature provided on maintenance maturity models gives a good overview of what other researches deemed important as dimension. Not all dimensions provided in these models are important for SMEs or are deemed important by the researcher of this thesis. The important thing is to keep the balance between a well-rounded and time-efficient assessment. Since there is a good number of existing models and maturity grids this provides a good basis of dimension options. It is suggested in literature that for reasons of feasibility and logistics, an appropriate number of dimensions is around 20[41]. This is however not considered in the context of the time-constraint SMEs. The aim therefore is to have a maximum of 20 dimensions but less are preferred if possible.

Below, a list of chosen dimensions is provided with the reasoning behind the dimension. These dimensions are also used in the final maturity matrix. One important focus in terms of dimensions is the focus on the operation side. Most dimensions chosen focus on the actual operation side of maintenance. There are also some dimensions that cover the tactical and strategic aspect slightly more such that the dimensions cover a wide enough base regarding the maintenance operation.

Classification of equipment Classification of equipment is a dimension which is rarely seen in other maturity models regarding maintenance. However, it can be seen as quite important. Most large enterprises have a strategy in place where critical assets are identified in the organization as well as other types of assets. This differentiation in classification is often not found within SMEs due to a lack of organizational capacity. Classifying assets in a good way is crucial to maintenance management. In order to spend the available resources in the right manner, it is good to know which assets require the most attention. Classification of equipment therefore makes a lot of sense as a dimension. If all assets are considered of same importance whilst they are not it can mean two things; either money is spent on maintenance where it is not necessary or maintenance is not carried out as good as it should for some assets. This reason is why it is included in this maturity matrix.

Maintenance strategy Whilst talking about maintenance, there are several strategies that can be adopted. A few examples are corrective maintenance, preventive maintenance or predictive maintenance. This dimension is also very often considered in literature and a crucial part of the maintenance organization. Widening the choice of available maintenance strategies and being able to perform these strategies correctly are a big part of this dimension.

Autonomous maintenance Autonomous maintenance is maintenance carried out by operators. This dimension is not always found in literature but was mentioned a few times. Due to SMEs having a lack of trained personnel in the maintenance department, options should be taken to involve operators as much as possible. When maintenance becomes more complex and the enterprise grows, the skilled maintenance technicians are busy with these issues. To aid the lack of time, autonomous maintenance could be used. Therefore this is chosen as dimension since it is considered an important strategy to overcome issues faced by SMEs.

Failure analysis The method of failure analysis and when it is performed is often found in literature. Understanding the failures that drive the need for maintenance is crucial for having a good maintenance organization, since understanding of failures also helps with preventing them. This dimensions therefore focuses on creating understanding and insight which is one of the goals of this maturity matrix.

Intervals of scheduled maintenance In the case study it is seen that scheduled maintenance is performed with some regularity. This is also the case in other SMEs that have assets used in manufacturing. This dimension is not specified in this way in most other models found in literature. Understanding when to perform scheduled maintenance and ensuring that it is not too early nor too late is an important aspect. This can help by lowering costs but also by lowering breakdowns. This means that technicians are less busy with performing corrective maintenance and thus freeing up time. Improving the maturity in this dimension and having better insight in this scheduling process is therefore considered important in the maintenance maturity of SMEs.

Documentation Correct documentation regarding assets is a rarity within the case study. This means that when technicians need documentation of machines, it is a lengthy search process to find the documents. Ensuring correct and up-to-date documentation is a dimension which is also used in many other maturity models regarding maintenance maturity. Since having correct documentation which is easily accessible can save a lot of time, it is very useful for a SME to grow in maturity regarding documentation.

Spare parts The inclusion of spare parts is sometimes found in other maturity models. This dimension mostly means the handling of the spare parts and the consideration whilst stocking. Since SMEs mostly perform corrective maintenance, spare parts are often needed. This also connects to the characteristic that SMEs often deploy a reactive, fire-fighting strategy. This means that knowing which spare parts to keep to ensure that breakdowns do not cause massive production delays is important for the general SME. This dimension focuses on gaining insight in the stocking of spare parts to ensure that breakdowns do not lead to long downtime.

Key Performance Indicators Identifying the strong and weak points of the maintenance organization and finding points for improvement is often easier by deploying KPIs. This is another dimension which is only sometimes seen in other maturity models. Having KPIs and keeping these up-to-date can help the organization with identifying points for improvement. This therefore helps with creating insight in the performance of the maintenance organization which connects to the goals of this maturity matrix. Having KPIs can also save resources for the organization since an evaluation of the maintenance organization takes less time.

Computerized Maintenance Management System CMMS is often considered in other maturity models. With the increasing amount of technology in enterprises this dimension is important to consider. Deploying a CMMS system can help the enterprise with a lot of other dimensions as well. Especially to save resources a CMMS can be very useful. This way several things can be automated and therefore free up time of employees in the maintenance organization.

Company Policy A more strategic dimension is considered with the company policy. This is often found in other maturity models as well. Ensuring that employees and management are on the same level of commitment to maintenance is important in realizing goals. The growth of maturity is often only possible when maintenance is considered more important. This dimension is also added to help create insight in the maintenance organization on a company-wide level. Ensuring that everyone from operators to management in operations understand the importance of maintenance helps with the implementation of other improvements.

4.2.2 Select maturity levels

One of the most important questions that this section aims to answer is: 'How to define maturity?'. The notion of maturity is widespread but the definition as to what is (im)mature is varying between grids and models. It is common to represent maturity as a number of cumulative stages, this is also seen in multiple models during the literature review. The rating scales that are used, however, are mostly different. Also the naming of the maturity levels is different. Selecting the maturity levels to be used require a certain rationale and consistent implementation. As Maier et al.[37] phrase it: 'Levels need to be distinct, well defined, and need to show a logical progression as clear definition eases interpretation of results'. Translating this to the context of SMEs, this means that the naming and progression of the maturity levels should be logical for SME managers. This follows the requirements of 'Easy to understand' and 'Clear what is necessary to reach higher levels'. Deciding the rationale behind the rating scale also means deciding on a leverage point for organizational change. The review by Maier et al. discerns different underlying notions which are shown below[37]:

1. Existence and adherence to a structured process
2. Alteration of organizational structure
3. Emphasis on people
4. Emphasis on learning

Sometimes a mixture is used as well. In this thesis the focus is mostly on *existence and adherence to a structured process*. To evaluate the maintenance organization, this is a good maturity rationale. However, the goal of this thesis is also to create insight within the company regarding the maintenance organization. Therefore the *emphasis on learning* rationale can also be applicable. The concept would be to raise awareness in order to progress on the maturity scale. A combination of these rationales seems in order for the development of this maturity grid.

The definition of maturity goes back to the early development of the CMM model. Maturity is defined as "the extent to which a specific process is explicitly defined, managed, measured, controlled and effective"[49]. Thus, maturity is defined as the degree to which a process is institutionalized and effective[13]. This is a good theoretical term for maturity, but what does it mean in practice? In practice this means that most maturity models aim towards gaining the best practice for every aspect. This means that with maintenance strategy, the aim is to reach the most mature strategy for all assets. Most models that are identified in literature describe for this example the following lowest and highest level[1]:

Lowest level Only corrective maintenance is performed when breakdowns occur.

Highest level Assets are maintained using a predictive maintenance strategy.

This maturity definition is understandable, but might not be as applicable in the situation with SMEs. Considering the lack of resources, the highest level in this example will likely never be reached. Therefore the maturity should be approached from a different angle. The idea that it only speaks of high maturity when high-level maintenance approaches and techniques are used is a bit short-sighted. Understanding and having knowledge of assets and insightfully corresponding a right method to the right asset can also be considered highly mature. This concept will be worked out further when formulating

[1]This is an interpretation by the author based on some models in literature. The description in these models might be different but this is the main deducted message from the descriptions given in the maturity models.

the cell text in the next Section.

The maturity levels used for this matrix can be seen in Table 4.2. This also includes a short description of what this maturity level means in short. The maturity levels aim to provide a clear path towards world-class maturity where understanding and insight is created with each step. The steps have a clear interpretation and provide a clear description that is understandable by SME managers. Each maturity level requires extra effort and resources to achieve and also requires extra resources to maintain. However, higher maturity levels also often reap higher rewards. This means that there is always a trade-off to make between effort and value, which is an important part of setting a long-term strategy.

Table 4.2: Maturity levels used in the matrix

Levels		Description
1	Low maturity	The organization has no insight in the maintenance operations and decisions are made ad-hoc
2	Initial maturity	The organization starts to gain some insight and decisions are mostly based on experience.
3	Balanced maturity	The organization has insight in why decisions are made and understand the reasoning behind implementation of new tools and methods.
4	Advanced maturity	The organization has deployed improvement strategies and starts to benefit from the improved organization which comes from advanced insight.
5	World-class maturity	The organization is able to keep an up-to-date maintenance organization and has advanced insight in reasoning behind maintenance decisions. These decisions are made keeping company objectives in mind.

4.2.3 Formulate cell text

The cell text is the description which is placed at the intersection of the dimension with the maturity levels. Identifying and formulation of the cell text is the way to finalize the maturity matrix. In order to discriminate between maturity levels, the description should be precise, clear and concise. A few decisions need to be made here. Firstly, a decision on whether the cell text will be 'prescriptive' or 'descriptive'. Secondly, a justification on the information source; how are the descriptions made? Lastly a decision needs to be made concerning the mechanism of formulating the text descriptions.

The cell text will have a 'prescriptive' purpose. It does not focus on best-practices necessarily but organizations should be able to determine what is needed to reach a higher maturity level. Therefore this should be included in the cell text. The information source for the cell text is mostly influenced by earlier maturity models. The models identified in literature have been studied to find commonalities in description and evaluation of maturity. Since maintenance maturity models and matrices are found in literature this was a good source of information. Next to this, the cell text are discussed within the case study company and with a maintenance expert. This feedback forms in itself an iterative process again where the cell-text is fine-tuned to be as understandable and complete as possible. Where this models differs greatly from other models however is the inclusion of equipment classification. Due to the resource constraints that SMEs face it has been found impossible to implement world-class activities that were described in other models. Therefore the cell text has a gradual increase in maturity which also follows the amount of differentiation an enterprise is able to do. High-understanding of specific needs per asset is considered very valuable. The cell text is formulated by first identifying the extreme ends of the maturity scale. By identifying what is considered 'low maturity' and 'world-class maturity' per dimension it was easier to determine the levels inbetween.

As said earlier, the development was an iterative process. The figures that are shown below, show the final result of this iterative process. Feedback that is acquired during the development of the is taken into account and processed. Each dimension is split in a separate figure for ease of reading and understanding. Some extra information will be given for each of the figures explaining the underlying motives of formulating the cell text.

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Classification of equipment	Assets are not classified in any way.	Critical assets are identified within the organization. These critical assets are clear to everyone involved in operation.	All assets are given a classification using an uniform system. This is done to not only identify critical assets but also differentiate within other assets. Non-critical assets are also given separate classification and at least 3 classes are identified.	All assets are classified using an uniform system. This classification is updated sometimes, but not on a regular basis. It is possible to have 3 or more classes.	Assets are classified according to an uniform system. This is done when assets are acquired and the classification is updated on a regular basis (e.g. every 6 months).

Figure 4.1: Classification of equipment

Figure 4.1 shows one of the most important dimensions considered in this matrix. Classification of equipment is a dimension which was not encountered in other maturity models. This has made it a bit more difficult to fill in the cells. It is clear that 'low maturity' means that there is no classification. Identification of critical assets is the most important step in order to progress the maturity. By having more classifications the company can differentiate easier between assets and find fitting maintenance strategies. This is helpful for reducing unnecessary costs and making sure resources are spend were they are needed the most. By moving to 'advanced' and 'world-class' the company is able to update the classification on a regular basis and keep track of this asset classification in a good manner. Figure 4.2 follows this classification. As mentioned earlier, due to resource constraints SMEs need to choose more carefully where to spend their efforts. By differentiation in maintenance strategy this is possible. Ensuring that high-impact failures are prevented as much as possible is an important goal, found out from employees within the case-study company. In this case 'low maturity' is defined as no differentiation in maintenance strategy. Either all assets are correctively maintained or combined with some preventive maintenance, but the strategy is the same for all assets. By identifying the critical assets and assigning a fitting strategy for these critical assets, there is some differentiation already. This might mean that some assets still do not have the correct strategy, but a step is made in a good direction which is why this is considered 'balanced maturity'. Moving to 'world-class maturity' means that an SME is able to identify the needs of individual assets and being able to assign a fitting maintenance strategy. High-impact failures might be prevented using condition monitoring, but low-impact assets can still be maintained using breakdown maintenance. The important thing is that enterprises know **what** they are doing and especially **why** that option is the best option.

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Maintenance strategy	No differentiation in maintenance strategy. Assets are mostly correctively maintained.	Differentiation between assets in maintenance strategy based on experience or other factors. Mostly a combination of corrective and preventive maintenance is used.	Maintenance strategy is differentiated using asset classification. Each type of asset is assigned a maintenance strategy. E.G. All critical assets are preventively maintained, all non-critical assets correctively.	Maintenance strategy is differentiated using asset classification. Critical assets are assigned a fitting maintenance strategy individually. This could include using a form of predictive maintenance.	Every asset is assigned the correct maintenance strategy based on historical data with downtime and frequency of failures.

Figure 4.2: Maintenance strategy

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Failure analysis	Failure analysis is not performed and has no defined method.	In case of high-impact failures, a failure analysis is performed without a defined method.	Failure analysis has a defined method. It is performed on all critical assets and on other assets in case of high-impact failures.	Failure analysis is periodically performed on critical assets and critical failures are detected. Failure analysis also performed on assets with a high frequency of failures. Measures are implemented to lower the recurrence of these failures.	Information on critical failures is frequently updated and based on a methodic failure analysis. All assets that benefit are examined using a failure analysis. Measures are implemented which leads to absence of critical fault recurrence.

Figure 4.3: Failure Analysis

It has been found in the case study that in most cases there will be a form of preventive maintenance. Defining the intervals of preventive maintenance is challenging since it is unwanted to do maintenance too late but also unwanted to do it too early. This is a challenge for SMEs and in the case study it has been found that there is a general interval for preventive maintenance which is used commonly across all assets but not really considered in much detail. Figure 4.4 shows the progress towards world-class maturity regarding scheduling of preventive maintenance. 'Initial maturity' is reached quickly. By performing preventive maintenance and having a general ('randomly') interval for all assets. Following the intervals by the manufacturer is already more mature. This also means that sometimes for one asset, maintenance intervals differ. For example a motorcycle; The oil should be changed every year, but the coolant only every two years. Identifying these needs and being able to follow them is important. Moving towards 'advanced maturity' and 'world-class' the enterprise is able to revise an interval based on actual data and observations. This can mean that either the interval shortens or lengthens. Considering the production is also important here to interfere as little as possible with the amount produced.

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Intervals of scheduled maintenance	Preventive maintenance activities are not defined and therefore no intervals are defined.	Preventive maintenance activities are defined based on a 'randomly' chosen interval. This could be a standard interval for every asset.	In case the manufacturer recommends preventive maintenance, these intervals are followed in the maintenance scheduling. For assets where this is not recommended, a standard interval is chosen. This interval can be changed based on experience.	If necessary, critical assets receive a revised maintenance planning based on the failure rate. Maintenance is scheduled in accordance with production.	Assets that are preventively maintained are monitored whether the maintenance interval should be adapted due to a high failure rate. Planning based on failure rate or equipment monitoring, whichever is more suitable for the asset class.

Figure 4.4: Intervals of Scheduled Maintenance

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Documentation	Documentation is mostly unavailable or outdated.	Documentation is unorganized, some maintenance processes are standardized.	Documentation is organized. Documentation on critical assets is readily available and maintenance activities are standardized for these assets. There is a procedure in place to take care of correct management of equipment maintenance files. This could be assiginging a specific employee	Documentation is organized and standardized. Documentation is quickly and easily accesible for all assets. Maintenance activities are standardized.	Documentation is organized and standardized with quick and easy access regarding all assets. This documentation is systematically updated. Maintenantenance activities are standardized and systematically revised.

Figure 4.5: Documentation

Figure 4.5 shows the progress in maturity on the front of documentation. Here it is mostly about the documentation of the assets within the enterprise. Having all the documentation in the right place which is easy to find can save a lot of time during the day. Being able to quickly assess drawings or suggestions by the manufacturer can benefit the maintenance of the asset. The maturity goes from unavailable and outdated documentation to organized, standardized and updated documentation. It can take time to organize this, especially if documents are currently widely spread but will save time in the long run.

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Spare parts	Spare parts are not kept based on forecast of future demand.	Spare parts are kept for assets that are maintained using breakdown maintenance. Future demand is not forecasted.	Spare parts are kept for assets that are maintained using breakdown maintenance. Future demand is forecasted based on historical consumption.	Spare parts are kept for critical assets and their critical failures. Spare parts are also kept for assets that are maintained using breakdown maintenance. Future demand is forecasted empirically based on historical consumption	Spare parts are kept for all assets that have high-impact parts with a long lead time. Inventory levels of all spare parts are regularly reviewed based on forecast demand.

Figure 4.6: Spare Parts

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Key Performance Indicators	No KPIs are defined.	At least one KPI is defined and monitored which can be used to measure the maintenance performance for critical assets.	Performance of critical assets is effectively monitored using relevant KPIs. The maintenance organisation has a KPI in place to measure the overall performance.	Performance of critical assets is effectively monitored using relevant KPIs. The maintenance organisation has 2-3 KPIs in place to measure the overall performance. KPIs are continously monitored and a relevant goal is defined.	Performance of all assets is effectively monitored using relevant KPIs. The maintenance organisation has all KPIs in place to effectively measure the overall performance. KPIs are continously monitored and a relevant goal is defined. The goal is aligned with company objectives.

Figure 4.7: Key Performance Indicators

Spare parts is in literature not very often considered separately. Considering the case study, it is identified that there often is a lot of breakdown maintenance. This means that parts have to be ordered every now and then. This can take up a lot of time. Understanding which spare parts are good to keep in stock to prevent long downtime is key to gaining maturity. Maturity is then further developed using a prediction of future demand. This requires data collection of failures and amount of downtime per failure. This is necessary to assess the need of spare parts and how many spare parts should be kept in stock. Figure 4.7 show the development regarding the dimension about Key Performance Indicators. Of course, KPIs can be used in other parts of the manufacturing organization but in this case it is about KPIs regarding the maintenance organization. There are a lot of possible KPIs that an organization can define and monitor. Gaining insight in which KPIs to monitor is crucial in gaining maturity. 'World-class' for this dimension is being able to monitor the performance of assets and the whole maintenance organization. Not just monitoring them is important but aligning these with company objectives. Lowering the cost of maintenance could be such an objective, but also the decrease of production downtime.

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Computerized Maintenance Management System (CMMS)	No use of CMMS and no electronic records.	Use of computer applications for maintenance management. Not integrated with other systems.	Computerized system for planning and control of maintenance. Not all functions are used and not integrated with other computer systems.	CMMS where not all functions are widely and properly used. Not integrated with other systems of the company. Some automation is present.	CMMS to support all functions of maintenance management with high degree of automation. Functions are available and effectively used. Integrated with other systems of the company.

Figure 4.8: Computerized Maintenance Management System

Figure 4.8 shows a maturity development considering CMMS. Even though this might not be necessary for all SMEs, it can benefit the maintenance organization greatly. 'Initial maturity' is quickly gained by using a computer application such as Excel. Having a CMMS does not mean that an enterprise has reached 'world-class maturity' immediately. Only world-class is reached when the CMMS is used to support the maintenance management and it has a degree of automation. This means for example that the system can help with computing relevant KPIs automatically. Also some integration with other systems of the company should be looked at.

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Company policy	Maintenance is considered a necessary evil, being focused on the resolution of faults in the shortest time.	Maintenance is considered a necessary evil, but the need to act preventively is recognized.	Maintenance is considered important in achieving organization's objectives. Preventive maintenance is done to increase productivity and reduce costs.	Maintenance is considered important in achieving organization's objectives. Acting proactively (including improving equipment) in order to increase productivity, reduce costs and improve quality.	Maintenance is considered a strategic function. Acting proactively (including improving equipment) and efficiently in order to increase productivity, reduce costs, improve quality and reduce accidents and environmental impact.

Figure 4.9: Company Policy

Lastly the matrix defines the maturity regarding the company policy, shown in Figure 4.9. This is less on the operation side of maintenance and more on the strategic side. Ideally, the company policy is the same within the whole enterprise. Often this is not the case. Whereas management might see maintenance as important, operators might not feel the same way. This is therefore a difficult point to assess in the whole organization and requires some discussion at the assessment. It should be noted specifically that there is a change of viewing maintenance as costs mostly and identifying the value-potential of maintenance. Viewing maintenance as value-adding is considered a higher maturity since this mindset can put more focus on the maintenance organisation and help improve it. Instead of only lowering the costs for maintenance it can be seen that sometimes the enterprise benefits from investing in a good maintenance organization. This can be visible in other factors such as the Overall Equipment Effectiveness or high, constant production.

4.2.4 Define administration mechanism

This step is integral in the success of the maturity grid. It is especially important in this step to consider the aim of the assessment and the resources available. This therefore links to the requirements that are set, but also to the characteristics of SMEs. The focus of this research, as stated in the requirements, is to raise awareness and improving performance. Literature shows that models that take this approach often select paper-based distribution mechanisms that might include interviews and/or group workshops[42]. In order to decrease the single-respondent bias that might happen when only the operations manager fills in the matrix, it was chosen to do it a group workshop involving more employees that deal with the maintenance organization. It is good to include management but also technicians in this workshop. Completion of the grid in a group workshop has a number of advantages, as shown in literature[36][21][42]. Response rate is high. Also, if respondents are unclear about the meaning of a term they are able to ask their coworkers for clarification. This ensures that participants have a common reference point, which facilitates interpretation of resulting scores. Next to this, working in a group can lead to a discussion about the current maturity of the maintenance organization which might lead to more insight. This is also one of the goals regarding this matrix. Furthermore, since each dimension is addressed as a group, the workshop can also function a a short team-building exercise[8] and a common look towards maintenance.

Of course, the result of this group self-assessment is important to understand the current maturity of the maintenance organization. Another goal of the assessment tool set in the requirements is aiding the process towards a long-term strategy. This means that next to the current maturity level, the group workshop should also determine a desired maturity level. The description in the cells then work in guiding the development of a long-term strategy by identifying the needs. This means that there is another possibility for a good, insight-creating discussion with the group. By setting the goals together in a session where management and technicians are present means that there is a common perspective on the future. This helps in understanding for both parties in what is needed in order to progress the maintenance organization. Setting a desired maturity levels also aids the needs of SMEs again. It is already mentioned that often it is impossible for SMEs to reach 'world-class maturity' in every dimension due to resource constraints. The case study also shows that there is no desire to reach world-class maturity in every dimension. For some dimensions, such as CMMS, the enterprise benefits more from a balanced maturity state. This is due to the fact that higher levels of maturity require a high amount of resources (effort, time, money) to reach, but also require a high amount of resources to stay at that level. SMEs do not have this capability and need to make a decision on where resources are well spend by having a high maturity level and where a lower maturity level is acceptable.

4.3 Final maturity matrix and application

The final maturity matrix is the combination of the separate figures shown previously. Since this matrix becomes quite large, it is shown in Appendix C. This matrix is used for a final application within the case study company.

In order to enable a final evaluation of the maturity matrix, a test in practice is necessary. For this, the case study company is used. An introduction to this company is given in Section 1. For a good evaluation of the model, the application must come as close to use in practice as possible. Therefore the manager engineering operations who leads the maintenance maturity project was given the lead in application. The researcher of the thesis was merely an observer of the process in order to do a valuable evaluation. The composition of the group for the group assessment was also mostly based on the ideas of the manager in the company. To limit the bias of employees participating in the maturity assessment, the researcher gave no further information before the start of the assessment. This was purely done by the company manager. All the participants of the maturity assessment can be seen in Table 4.3. It should be noted that although the manager engineering operations is in charge of the maintenance maturity project, he is supervised by the Operations Manager who was also attending the assessment. The industrial improvement engineer works on improving processes to enhance production. The assessment started with a short introduction regarding the idea of the assessment. The first half

Table 4.3: Participants for the maturity assessment

Name (acronym)	**Role**	**Experience within organization**
Participant A	Manager Engineering Operations	3 years
Participant B	Operations Manager	6 years
Participant C	Industrial Improvement Engineer	2 years
Participant D	Maintenance Engineer	2-3 months
Participant E	Factory Technician	4 years
Participant F	Manager projects Advanced Motors	20 years

of the meeting is spend on determining the current level of maturity within the company. The second half of the meeting is spend on determining the desired level. This second half of the meeting was also already intended to discuss future plans regarding the maintenance operation. It was explained that the goal of the assessment was to use this determination to be able to better develop a long-term strategy. The whole assessment was observed by the researcher of this thesis. The observations and use of these observations regarding success criteria can be found in Section 5.

The results of the assessment are shown using a radar diagram which can be seen in Figure 4.10. It is clear that the company does not desire world-class maturity for every dimension. It is also clear from this graph that there is overall quite a big gap between the current and desired situation.

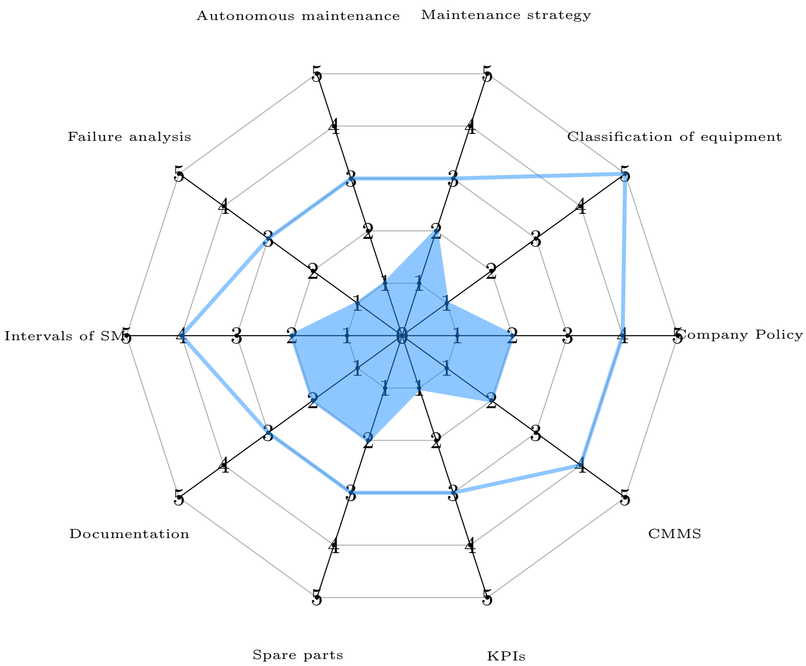


Figure 4.10: Spiderweb Diagram showing results of case study. Solid line is desired level, filled plot shows the current level

Chapter 5

Evaluation of maturity model

This chapter focuses on validating the developed maturity matrix. As mentioned in the Methodology this is done by verifying the rigor of the development method. The rigor is verified using the guidelines set by Becker et al.[4]. Secondly, this chapter aims to answer the question whether the success criteria mentioned in section 4.1.3 are achieved. This is done by a thorough observation of the final application of the maturity matrix and a short questionnaire based on the success criteria. By following these two steps the model can be validated to have enough rigor and being applicable in practice. This will help in answering the research questions of the thesis and achieving the goals.

5.1 Rigor

As said, rigor can be achieved by following the DSR method and verifying the guidelines. It is chosen to use the guidelines by Becker et al.[4] since these are specifically on the topic of maturity models. Even though the paper mostly focuses on maturity models in the IT sector it is still considered useful. This type of validation of rigor is also performed by Maier et al.[37] to verify the maturity grid. Each of the guidelines which are mentioned by Becker et al. are shown and an explanation is given whether the guidelines are met and in which part of the development it was considered.

R1: Comparison with existing maturity models A lot of existing maturity models in maintenance are found in the literature study. A specific comparison is done in section 4.1.3 using some of the models identified in literature. By this comparison the need for the development of this maturity matrix is shown in the context of SMEs.

R2: Iterative procedure The maturity matrix was developed in an iterative procedure with continuous feedback from a maintenance expert and the case study company. This iterative procedure was followed in the development of the maturity levels, the dimensions and the cell text. This was also based on field experience of the author.

R3: Evaluation Iterative development of the maturity matrix was used to evaluate the artifact inbetween design phases. Refinement was done based on individual application of the method and a short interview afterwards with employees of the case study company. Next to this, the evaluation of the artifact is done through final application in industry followed by a small survey which is presented in section 5.2.

R4: Multi-methodological procedure A variety of research methods was used in the development of the maturity matrix. Firstly a literature research was conducted separately. Next to this, short interviews were held at the case study company to identify the problem. Observation and a survey are used in the validation of the matrix which was applied in a group-workshop setting. All of the methods used are often used in literature and relevance is explained.

R5: Identification of problem relevance The problem relevance is demonstrated by the literature review, the interviews at the case study company and the comparison with current maturity models. Since a lot of maturity models are developed, also for SMEs, there is a need for maturity models in general. This need comes from industry where it is important to constantly evaluate and improve yourself to stay ahead of the competition. Maturity models are very commonly used as evaluation method. The need for a maturity matrix specifically for maintenance is proven by the fact that such a maturity assessment tool was not available and suitable for SMEs yet.

R6: Problem definition The conditions and application regarding the need of users is clearly demonstrated in section 4.1. The conditions for success are also shown. Defining the problem was done prior to design and the prospective application domain was made clear in that section.

R7: Targeted publication of results The results are presented to the case study using a presentation. Next to this, the thesis is publicly available for academia and practitioners.

R8: Scientific documentation The process of developing this maturity matrix is explained in detail in Chapter 4. This chapter has focused on specifying every step in the development and ensuring that important choices were highlighted. The methods and results are also clearly found in this chapter.

5.2 Success Criteria

This section will discuss whether the success criteria stated in section 4.1.3 are met and therefore the identified problem is solved with the designed artifact. This is done by observing the group-workshop which was used in the final application and furthermore by conducting a small survey with a few statements. An expert evaluation form regarding maturity models is suggested by Salah et al.[51]. This paper provides a form where statements are answered on a 5-point Likert scale ranging from *Strongly disagree* to *Strongly agree*. This paper has some validation criteria which are shown below with a description[51];

Sufficiency The maturity levels are sufficient to represent all maturation stages of the domain.

Accuracy There is no overlap between descriptions of maturity levels and processes and practices are assigned to the respective maturity level.

Relevance The processes and practices are relevant to the domain.

Comprehensiveness Processes and practices cover all aspects impacting/involving the domain.

Mutual Exclusion The dimensions are distinct.

Understandability The maturity levels, dimensions and contents are understandable.

Ease of Use The maturity model is easy to use.

Usefulness The maturity model is useful for conducting a maturity assessment and available for use in practice.

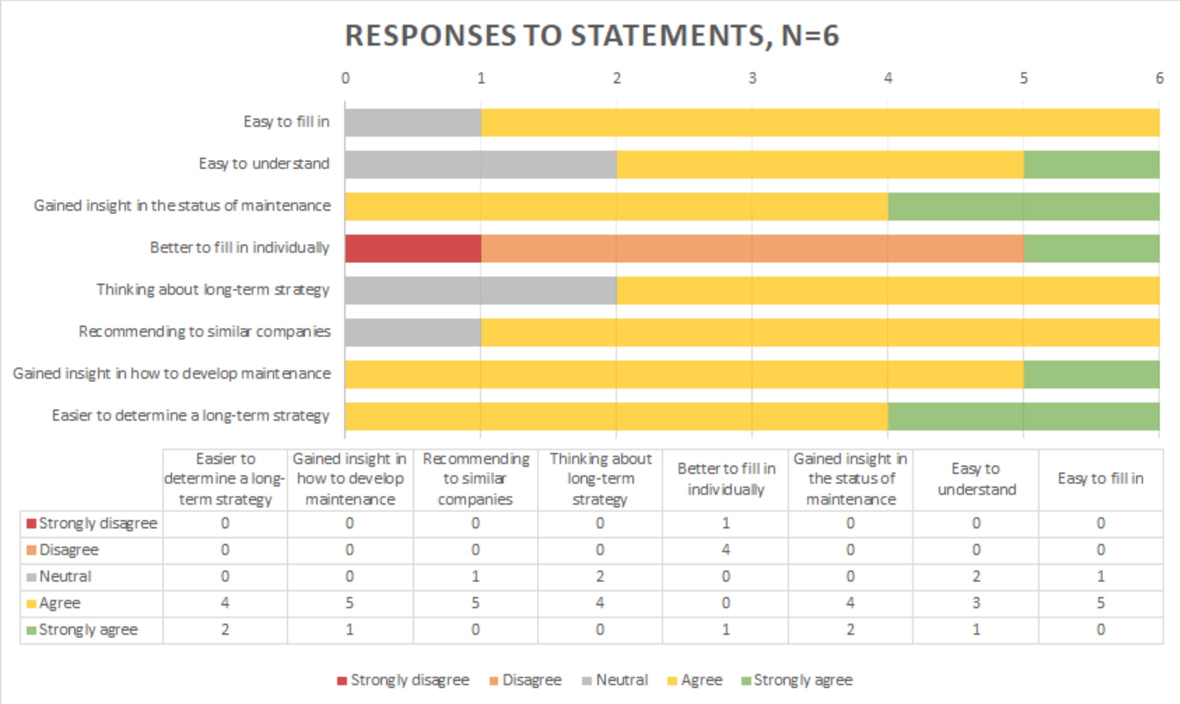
The study suggests to evaluate these criteria using an evaluation form. In this thesis, some criteria are answered based on the observation during the group-workshop and some criteria are answered using statements that are answered on 5-point Likert scale by all participants. The statements are developed based on the success criteria. The evaluation form by Salah et al.[51] is therefore not fully used as intended.

The following statements were answered by the participants of the final application on a 5-point Likert scale as suggested by Salah et al.[1]

1. It was easy to fill in the matrix.
2. The matrix was easy to understand.
3. The matrix provided me with more insight in the current situation regarding maintenance within the company.
4. I would have preferred filling in the matrix by myself instead of the group-workshop.
5. Due to the matrix I started thinking about a long-term strategy.
6. I would recommend the matrix for use within similar companies.
7. The model gave me more insight in how maintenance is able to develop within this company.
8. Through the use of the model it has become easier to determine a long-term strategy for the maintenance organization.

The answers that were given can be seen visually in Figure 5.1. The table below shows the amount of answers that were given per question. The statements are shortened slightly. The amount of respondents was six, equal to the amount of participants at the final application. The composition of this group is shown in Table 4.3.

[1] Questionnaire was conducted in Dutch for ease of understanding but has been converted to English for the purpose of this thesis. The original questions can be found in Appendix B.



	Easier to determine a long-term strategy	Gained insight in how to develop maintenance	Recommending to similar companies	Thinking about long-term strategy	Better to fill in individually	Gained insight in the status of maintenance	Easy to understand	Easy to fill in
Strongly disagree	0	0	0	0	1	0	0	0
Disagree	0	0	0	0	4	0	0	0
Neutral	0	0	1	2	0	0	2	1
Agree	4	5	5	4	0	4	3	5
Strongly agree	2	1	0	0	1	2	1	0

Figure 5.1: A visual showing the responses to the statements

5.2.1 Overview of meeting success criteria

This short section gives a short overview as to why the success criteria are met. The success criteria stated in section 4.1.3 are the most important for this maturity matrix. This is due to the fact that these criteria are based on the needs of SMEs specifically instead of general criteria that are valid for most maturity models. There is some overlap with the validation criteria mentioned earlier, so when necessary these criteria will also be discussed. The comparison can be made with Table 4.1 where these success criteria are evaluated in regards to other maintenance maturity models. The goal of this research is to meet all success criteria and therefore have a maturity assessment tool which is specifically for SMEs and helps SMEs meet their needs. The first point addressed in Figure 4.1 is whether the model is specifically developed for SMEs. In this thesis, the answer is yes. The other requirements are shown below with explanation.

SC1 The implementation of the tool only took 1 hour within the case study. This included determination of the current and desired maturity level and discussing potential improvements. The results are valid for some period of time and it is not time-consuming to use the matrix. The evaluation statements also show that almost every participant agrees that the matrix is easy to fill in.

SC2 The case study shows that it is possible to use the matrix with 6 people with varying experience within the company. Even without extensive knowledge of the maintenance operation, through discussion it was possible to fill in the matrix. Experience provided by the maintenance technician was valuable but also the management side was highlighted by the participants. Every SME should be able to gather a group of people with some experience regarding maintenance and be able to fill in the matrix. This also connects to the 'Ease of Use' criteria of Salah et al.[51].

SC3 As can be seen with the evaluation statements, most participants agree that the matrix is easy to understand. Due to the varying level of English it may have been more difficult for some participants to understand the matrix. Even though this language barrier exists, the matrix still was perceived as easy to understand. This shows that the English language used is also available for non-native speakers which widens the applicability. The criteria of 'Understandability' by Salah et al.[51] is also met by the matrix.

SC4 The assessment tool makes clear as to what is necessary to reach a higher level of maturity. Again this is shown by the evaluation, since all participants agreed that the matrix ensured that they gained insight in how to develop maintenance within the company. That it was clear to the participants how to reach higher level of maturity was also observed during the implementation. The participants were discussing what tools could be implemented to reach higher maturity levels and were discussing the meaning of the contents. One such example was the evaluation of **Classification of Equipment**. The participants were doubting between low or initial maturity. Even though the case study has identified some critical assets, it is not well-documented and probably not clear to everyone working with these critical assets. The participants recognized that ensuring that operators are aware of the critical assets is important in reaching initial maturity and therefore evaluated themselves at low maturity. It was recognized and understood clearly what was necessary to reach the higher maturity level.

SC5 The tool provides an option to determine a desired maturity level. The case study implementation also shows that this option was found very valuable since in most dimensions, the company does not desire world-class maturity and therefore is able to spend resources another way. Since most participants also agree that they would recommend the matrix for similar companies; it shows that the way the implementation was done was appreciated. This includes determination of a desired level. The observation also showed that the determination of this desired level was paired with determination of a long-term strategy. The participants were using this part of the assessment to discuss tools and strategies that could be implemented. This discussion helped to create insight in strategies that lead to higher maturity. The option to indicate a desired maturity level was therefore appreciated by the participants and the requirement was met.

SC6 The evaluation showed that most participants agree that they started thinking about a long-term strategy. The assessment provides the company with a guideline on how to develop towards the desired maturity levels. The observation showed that whilst determining the desired maturity levels, the participants were also already discussing the order in which improvements could occur and therefore incorporating continuous improvement. This is further developed by the maintenance engineer who is able to use the assessment to create a roadmap on how the company can grow their maturity within several dimensions in the coming years.

SC7 The participants were gathered in a group-workshop and when the maturity level was determined this was noted by the workshop leader. This was then used to create a radar plot which is also visible for the case study in Figure 4.10. The results were easy to collect and thoughts were provoked regarding potential improvements. This also connects to the 'Usefulness' criteria by Salah et al.[51] since it shows that the assessment can be used in practice and is useful in conducting a maturity assessment.

SC8 The assessment clearly created more insight among the participants in the group-workshop. This is also shown in the evaluation. The participants mostly agree that they gained insight in the current status of maintenance and also agree on the creation of insight in the development of maintenance. The observation of the assessment also showed these results. During the discussion on **Classification of Equipment** the participants had a discussion on the meaning of 'critical'.

Several participants had their own ideas on what critical assets were within the company and the discussion provided an in-depth view on how the company should tackle this problem. This discussion continued for the other dimensions were participants were sometimes surprised when something was not done as it was laid out during implementation. There is a clear way that participants agree that the documentation should be handled, however this is not done in practice. The participants seemed to like this group discussion since most, except for one outlier, disagree that it would be better to fill in individually. This shows that the group discussion is favoured and the observation also showed that participants were enjoying the discussion.

SC9 The assessment matrix includes 10 dimensions. There is a fine trade-off between the time it takes to do the assessment and the amount of dimensions to include. Section 4.2.1 explains why these dimensions where chosen to be included. It is of course possible to take a wider approach however the final application shows that the included dimensions are sufficient for an evaluation of the maintenance organization.

Not all criteria by Salah et al.[51] were used during validation of the matrix. It is more important for the development of the matrix whether the success criteria related to SME specifics are met.

5.3 Conclusion

Concluding the validation, it can be seen the success criteria are adequately met. Next to this, rigor is achieved whilst designing the maturity assessment tool. This chapter aids the answering of the research questions and is also used as base for the discussion, done in Chapter 6. The validation is done according the available guidelines as much as possible. Observation showed that the tool can be implemented in practice using the case study and that this creates insight among the participants.

Chapter 6

Discussion

The discussion aims to interpret the results and relate them to the research questions. Next to this, the discussion points out limitations. This interpretation is used to help future implementers of the maturity matrix with lessons learned in this development and implementation process. Furthermore, implications are discussed in this chapter for practitioners and academia. The implications on SMEs and other enterprises is also discussed. Lastly, the chapter gives suggestions for further research.

6.1 Interpretation of findings

This study shows that it is possible to develop a maturity assessment tool specifically for SMEs. It has been found that an appropriate way of doing this is by using a maturity matrix which is used in a self-assessment. The following sections interpret the findings in relation to the research questions posed in this thesis.

Important decision points in a development roadmap

The development roadmap which is followed in this research provides us with an adequate amount of decision points to develop a maturity matrix with sufficient rigor. The explanation of all choices is elaborated upon greatly in this thesis. The thesis shows that the roadmap presented in Figure 3.1 can be used to develop a maturity matrix that can be used by SMEs. It might be possible to include more or less decision points in the development roadmap. By considering other aspects or perhaps neglecting others the resulting matrix might change. All the steps that are currently in the development roadmap are useful since thinking about development step-by-step is important in gaining a trustworthy maturity matrix. This development method has also been proven to be effective in this research. It has been shown that the problem definition is worth special attention. The combination with the design guidelines by Becker et al.[4] provide a good starting point since comparison with other models is of great importance whilst defining the problem. This study shows that the currently available models are not compliant with SME requirements. Thinking separately about dimensions, maturity levels and cell text was also found very useful. By performing these steps in order it becomes easier to perform an iterative process by constantly checking with experts and practitioners. The constant feedback provides good directions. Determining the dimensions could have been elaborated upon. In this thesis the dimensions are determined by combining existing models and the ideas of the author. Performing a survey and gathering input from the case study about what dimensions they deem important could have been efficient. Input from the case study was considered using some informal, non-transcripted, interviews. Another way of gathering this input could be by using some guided focus group sessions where several dimensions are considered. This could have provided perhaps a bit more feedback since this is also done in several other model development processes.

Most importantly, it has been discovered that iteratively testing and evaluation within an actual SME is beneficial to development. The experience that the case study provide from practice is very useful. By getting feedback from the case study it was possible to narrow down the dimensions to the most useful ones. A dimension regarding work order management was considered at some point. Even though it is useful to have the right content in a work order, it is not of great importance to the whole maintenance organization. Due to feedback gathered from the case study, this dimension could be removed from the final matrix.

Success criteria for SMEs

The success criteria were also determined using input from the case study SME. These criteria are connected with the characteristics of a SME. It might be that by gathering input from several organizations the success criteria differ slightly. However, the general SME characteristics that are listed in section 2.1 prove to be mostly true for the case study SME. Therefore, the success criteria also are likely to be true for most SMEs, especially SMEs that are active in the manufacturing industry. It is relevant to base success criteria on general characteristics of organizations, but verifying these with a case study. By using good success criteria as starting point, it is more likely that the developed maturity model is usable by more organizations in practice.

Use of maturity matrix to assess maturity

The maturity matrix which is developed in this thesis consists of 10 dimensions and evaluating these over 5 maturity levels. Simple language and terminology was chosen over more complex language because of success criterion 3: 'The contents of the tool should be easy to understand'. Combining this with the characteristic that SMEs often lack specialist knowledge it becomes clear that simple terminology is preferred. By only evaluating maturity over 10 dimensions, the speed of assessment could be reduced compared to more complex models. The expense of this is that information might be lost or SMEs might not develop other aspects of the maintenance organization since these aspects are not included in the maturity matrix. In a maturity assessment of SMEs, trading-off speed for detail is worthwhile because an characteristic of SMEs is that they often lack time and resources. Having a complex model makes an assessment more time-costly, but also takes more time to evaluate for possible improvements. If more dimensions or maturity levels are included it becomes more difficult to find the right improvement strategy and this also would take more valuable time. In the case study organization, the assessment took only 1 hour allowing for quick intermediate assessments when necessary.

Creating insight through self-assessment

This maturity assessment tool uses a form of self-assessment. It was decided to perform the assessment using a group-workshop. This was done in order to combine the expertise within the company. It could be argued that the results are more accurate if an expert is used for the assessment and evaluation. Especially due to the characteristic of SMEs regarding the lack of specific technical knowledge. Other study's have shown that often there is a gap between an expert assessment and a self-assessment. However, in this case it does not matter that much. The main goal of this assessment is that SMEs gain insight in the maintenance operation and that they are able to elevate their maturity. The precise maturity level is less relevant. As the evaluation shows, the group-workshop is appreciated. This could be researched in more depth by employing several other case studies and evaluating those results.

The assessment shows that the case study is able to sufficiently determine their maturity level. The most important thing is that the maturity matrix is easy to understand. The evaluation shows that this is the case, even with non-native English speakers. The use of a matrix instead of an elaborate model (e.g. with a survey) makes it easier to perform a self-assessment. The evaluation also shows that the self-assessment creates insight in the maintenance organization and needs to grow maturity among the participants. This awareness and insight is traded-off against a perfect assessment. The creation of insight into the necessity of maintenance in the organization is seen as more valuable.

Aiding the development of a long-term strategy

The maturity matrix puts forward the importance of choices and enables the organization to develop a long-term strategy. The participants of the case study also agreed that the matrix did provide insight in developing a long-term strategy. The creation of a long-term roadmap is not worked out further in this thesis. It is clear that the matrix can be used as an input for creating an improvement strategy, since the matrix stimulates the organization to think about important choices. The SME is still responsible for developing the long-term improvement strategy and is not guided in this process. Determination of desired maturity levels does aid this process. Guiding the process of selecting improvement strategies can help in saving resources. Even though it is not considered in this thesis, it would be a good elaboration upon this research work.

Relative cost of maturity

As with all things, maturity comes at a 'cost'. This cost mostly consists of time, money or other resources that need to be spend. A lower maturity level is likely to require less resources to implement and less resources to maintain. Often, these small maturity increases already offer a great improvement opportunity. These increases are therefore very resource efficient. The highest maturity levels are likely to be resource intensive to implement and to maintain. It could be that this is not in line with the organizational gain and that the higher maturity levels offer diminishing returns. Next to this, often the limit of resources is reached much quicker within SMEs; the step to the next maturity level is already to big. The organization needs to think deeply about this, if resources are spend on dimension A less resources are available for improvement within other dimensions. These factors ensure that the organization needs to make a balanced and conscious choice whilst considering improvement plans. The maturity matrix aids this process with the opportunity to determine a desired maturity level. The organization is invited to think about the need for high maturity regarding each dimension. By recognizing that world-class maturity is not necessary for each dimension, resources can be saved trying to reach world-class maturity. Instead resources can be allocated according to the need and spend wisely. The assessment method assists in consciously choosing specific improvements. Previous literature has not shown this cost-based approach since this necessity is not recognized for large enterprises.

6.2 Implication

Practical implications

The practical implications of this thesis consists of a couple of things. First, the research provides a usable maturity matrix which can be used by SMEs to assess their maintenance maturity. This assessment can be used to help in determining a long-term strategy and identify points for improvement. The case study demonstrates promising results for use in practice. The evaluation of the maturity matrix shows this, since the participants gave high scores to all evaluation criteria. Especially the high scores regarding the ease of use and usefulness are interesting since this results in a high behavioural intention to use the assessment tool, according to the Technology Acceptance Model[12]. This intention to use the matrix and the corresponding results was also visible during the implementation in the case study.

Whilst the case study displays promise for use in similar enterprises, the question remains whether the matrix is usable in other practices. Currently the matrix is quite specific and focuses on organizations that use a maintenance organization to support their manufacturing business. It can also be used by larger enterprises, but some dimensions might be added to have a more complete overview of the maintenance organization. An example is people management; whilst this is important for all enterprises it becomes more apparent when the maintenance department grows larger. Therefore, this can be a dimension which is important to add. Next to this, the assessment method and goal of the matrix changes. The matrix in its current form is therefore not as suitable for larger enterprises, but there are several maturity models found in literature that are suitable.

All in all, SMEs have gained the option to self-assess their maintenance maturity and use this for a long-term improvement strategy. The addition of discussing a desired maturity level aids this thought process. The opportunities for improvement can be found in the matrix but still offer a lot of room for own ideas.

Theoretical implications

This scientific research contributes by introducing a maturity assessment tool specifically for SMEs which can be elaborated upon by other researchers. The maturity matrix which is presented in this research is unique since it combines several maturity models into a new assessment method. The maturity matrix focuses on SMEs and makes use of a self-assessment which is unique. By comparing existing maturity models with the needs of SMEs a new maturity matrix is created which fits the needs of SMEs as shown by the case study. The developed maturity matrix incorporates a self-assessment which is shown to be very efficient for SMEs. A self-assessment is incorporated by several other studies[33][52]. Creating insight in the maintenance organization and changing the way organizations think about maintenance is considered the main starting point for improvements. The use of a self-assessment method is considered crucial in creating this insight. This is different compared to other models which often use external experts or surveys[55][35][14] Whilst these methods can help with benchmarking performance with other organizations, it does not contribute directly to creating insight.

Other models also tend to be very high-level in what is considered highly mature. This means that a model considering the dimension 'Preventive maintenance' states that performing predictive maintenance using condition monitoring is the highest maturity level[16]. This kind of maintenance strategy is very resource-costly and often not applicable or suitable for SMEs. The developed maturity matrix changes the way in which maturity is considered. This is aided by the implementation of equipment classification. By classifying equipment in a correct manner, diversification of maintenance strategies is possible whilst using solid reasoning. The way in which maturity is defined using classification is unique and not found in other maintenance maturity models. Is it uncommon to incorporate equipment classification as a part of the maintenance organization, which is done by this maturity matrix. This is not found in any model in literature. A case can be made that it is not part of the maintenance organization. In theory, this is true. This also shows in other maturity models where this dimension, or a similar one, is often not found. However, incorporation of classification in the maturity matrix provokes a though process within organizations. It is important for SMEs to gain understanding in suitable maintenance strategies for various assets. By diversification of strategies according to importance, resources can be saved. Recognizing that it is not necessary to monitor the condition of all assets, but that this strategy is only relevant for a couple of assets for example. Therefore the dimension of classification is a crucial step in the maturity matrix towards creating the right insight, as to why the organization is performing certain actions.

The development of the maturity matrix was done following a development roadmap. This roadmap is heavily influenced by a couple of existing development methods. There is currently no specific development method which involves SME needs from the start. The development roadmap combination which is shown in this research provides a complete overview and ensures that the most important thought processes are worked out.

6.3 Limitations

The assessment tool was implemented at one company. The focus and characteristics are developed in the specific context of this case study. Similar characteristics are found in literature. However, despite generalization there may be a slight tunnel vision or biases mixed in the conclusions that arise from implementation at only one company. It might be the case that by comparing multiple case study's and evaluating multiple applications the conclusions change slightly.

Only 10 dimensions were considered in the maturity matrix. It might be that valuable information is left behind. Even though the choice of dimensions is explained in detail, other companies might benefit from the addition of several other dimensions to evaluate. By observing and interviewing more SMEs in a similar industry other dimensions could have been included. It remains that there is a trade-off to make between the time it takes to do an assessment and the broadness of the assessment. This conclusion characterizes a common problem for SMEs, due to lack of resources these trade-offs need to be made all the time.

The addition of dimensions that are deemed necessary is also part of the continuous maintenance phase in the development of a maturity assessment tool. Demands might change within the industry and to keep the model up-to-date this should be implemented. Maintaining the matrix is not possible in the scope of this thesis since this takes perhaps years of feedback. Unfortunately, this phase in development can not be carried out in the time frame of this thesis.

The development of a maturity assessment tool is also heavily influenced by the view of the developer. Bias was prevented as much as possible by iteration using a maintenance expert and employees of the case study. However, the contents were not cross-checked with other experts and therefore might be influenced by the views of the author. This is difficult to prevent. The explanation of choices has been done in such a way that practitioners can decide whether the assessment matrix is useful in their situation.

6.4 Further Research

There are several points that could be part of future research. These are shown below.

- Deploy and maintain the maturity matrix. The maturity matrix was deployed and tested in the environment of a single case study. Expanding the amount of enterprises participating in a case study, relevant feedback can be acquired and the matrix could undergo another design iteration. A test on a larger scale can also show further strengths and weaknesses of the assessment method. The evaluation of a single case study shows that there is promise for a useful assessment method, but the group of respondents should be expanded. This also enhances the reliability of the maturity matrix. This step would be the first towards wide-scale deployment of the maturity matrix.

- Further dive in to how SMEs can be assisted in selecting good improvement methods. The focus of this thesis was on the development of a maturity matrix and the evaluation of maturity. It is found that SMEs also have difficulty to set a focus for improvement and decide which improvements are worth spending resources on. Further developing a tool which helps SMEs do this can be very valuable since it provides a guideline to realize a long-term improvement strategy. The results of the maturity matrix can be used as a starting point and decisions can be taken according to importance and value of improvements.

- Continue to maintain the maturity model by adding/removing dimensions that prove to be necessary or redundant in the future. The field of maintenance is under constant development and the matrix should be adapted when necessary. Addition of the IoT can be valuable in the future for example. Larger enterprises aim to move towards Maintenance 4.0 and even Maintenance 5.0 and the development of SMEs should be aimed towards keeping track with developments as much as possible.

- Further enhance the way SMEs can evaluate their own working. This paper focuses on the maintenance organization but also maturity models could be developed for other sectors where growth is relevant for SMEs. SMEs do not only lack knowledge regarding maintenance, but sometimes also in other sectors. Focusing on continuous improvement is not only important regarding the maintenance operation but also for example within the quality department. Widening the amount of available maturity models can enhance the self evaluation of SMEs and can stimulate growth in multiple sectors.

- Identify a development roadmap to develop maturity models specifically for SMEs. This research shows that a general way of working does lead to a maturity matrix for SMEs. If SMEs want to develop a maturity model themselves, this is not sufficient. Development using the roadmap in this research still takes a lot of time which is unavailable for SMEs. If a development guideline is available for SMEs to develop their own maturity model, this can help with identification of specific needs for an individual company. Each company has their own needs and might not benefit from using a general model. If these companies are provided with clear instructions on how to adapt or develop a maturity matrix this can be beneficial.

Chapter 7

Conclusion

This thesis has focused on several important research questions.

1. How can a maturity model for SMEs be developed?

2. What should such a maturity model look like?

3. How can a SME implement such a maturity model and use it for a long-term improvement strategy?

This thesis used DSR to develop, test and evaluate a novel method to assess the maintenance maturity of SMEs. The assessment method chosen is a maturity matrix which was used for assessment within a case study. This chapter aims to answer the aforementioned questions and finally answer the main research question of this thesis.

This thesis has found that within the development of a maturity model there are several crucial steps. Problem identification has been identified as a crucial factor in the development of maturity models. SMEs specifically show different characteristics and needs compared to large enterprises. Being aware of characteristics and needs of the type of organization, is pivotal in development of a maturity model. Gathering success criteria and choosing an assessment method according to research goals is also found of great importance. The assessment method can assist in achieving goals. Employing an iterative process also is key to development, preferably gathering feedback from a SME case study in practice as well as experts. The main challenges in developing maturity models specifically for SMEs are: 1) Resource constraints, 2) Trade-off between exhaustive assessment versus ease of assessment and 3) Stimulating continuous behavior. An important objective is to ensure that the maturity model is easy to understand and that the maturity model provides a clear development path towards high maturity. This makes it more likely to create insight within a SME compared to maturity models for larger organizations which often focus on benchmarking performance.

An example of how such a maturity model could look like is discovered in this research. This research has developed a maturity matrix suitable for self-assessment as shown by the SME case study. The matrix developed in this thesis employs 10 dimensions evaluated over 5 maturity levels. The maturity matrix provides a clear roadmap towards higher maturity and is understandable by SME employees. Implementation in the case study has shown promise for wider implementation of this maturity matrix. The self-assessment in a group-workshop has been found to assist in the creation of insight. Participants indicated that they have gained insight in the current status of the maintenance organization as well as necessary improvements to reach a higher maturity level.

The maturity assessment used in this research also provides an indication of a desired maturity level, next to a current maturity level. This aids the SME towards thinking about a long-term improvement strategy. Not striving towards world-class maturity all of the time is considered beneficial due to the high relative cost of gaining and maintaining the world-class maturity level. Lower maturity levels can be more resource efficient and especially interesting for the resource-constrained SMEs. Addition of an option to indicate a desired maturity level ensures that organizations think about which level is necessary and achievable for the organization and therefore setting realistic improvement goals. Evaluation of the gap between current and desired maturity level gives room to immediately discuss possible improvements. During evaluation, participants of the assessment also indicated that the developed maturity matrix made it easier to determine a long-term strategy.

How can a Small and Medium Enterprise effectively measure and elevate their maintenance maturity with limited resources?

A type of maturity model is shown to be an effective method. However, most maturity models are not as suitable and applicable to SMEs which creates the need for a maturity model development process. The developed maturity matrix in this thesis shows a method that SMEs can use to effectively measure their maintenance maturity. The implementation in the case study shows that this assessment of maturity can be used to aid the determination of a long-term improvement strategy. Even with limited resources it is possible to understand the maturity matrix and gain insight in the maintenance organization. Improvements can also be considered based on available resources due to the option to include a desired maturity level. This study demonstrates that by following the development roadmap and implementing a self-assessment maturity matrix, a SME is able to measure and elevate their maintenance maturity.

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Appendix A

Usage of AI tools

With the increasing potential of AI tools, a declaration of the use of AI has been added to this appendix, as recommended by the University of Twente.

During this work Mendeley is used as a reference manager. Connectedpapers.com is used as method to find papers related to interesting literature. This was merely used to find connections between papers to discover as much existing literature as possible. After the use of these tools, I thoroughly reviewed and edited content as needed, taking full responsibility for the final outcome.

Appendix B

Questionnaire in Dutch

The following questions were asked:

1. Het model was gemakkelijk in te vullen.
2. Het model was gemakkelijk te begrijpen.
3. Het model heeft mij meer inzicht gebracht in de status van onderhoud binnen het bedrijf.
4. Ik zou het beter vinden om het model individueel in te vullen in plaats van groepsvorm.
5. Door het model ben ik gaan nadenken over de lange-termijn strategie.
6. Ik zou het model aanraden voor gebruik binnen vergelijkbare bedrijven.
7. Het model heeft mij meer inzicht gebracht in hoe onderhoud zich verder kan ontwikkelen binnen het bedrijf.
8. Door gebruik te maken van het model is het bepalen van een lange-termijn strategie makkelijker geworden.

Questions were answered using a Likert-scale with the following descriptions:

1. Sterk oneens
2. Oneens
3. Niet eens of oneens
4. Eens
5. Sterk eens

Appendix C

Full maturity matrix

The full maturity matrix which is developed in this thesis can be found in this Appendix. It is visible in the landscape orientation for the purposes of fitting on one A4.

	Low maturity	Initial Maturity	Balanced Maturity	Advanced maturity	World-class maturity
Classification of equipment	Assets are not classified in any way.	Critical assets are identified within the organization. These critical assets are clear to everyone involved in operation.	All assets are given a classification using an uniform system. This is done to not only identify critical assets but also differentiate within other assets. Non-critical assets are also given separate classification and at least 3 classes are identified.	All assets are classified using an uniform system. This classification is updated sometimes, but not on a regular basis. It is possible to have 3 or more classes.	Assets are classified according to an uniform system. This is done when assets are acquired and the classification is updated on a regular basis (e.g. every 6 months).
Maintenance strategy	No differentiation in maintenance strategy. Assets are mostly correctively maintained.	Differentiation between assets in maintenance strategy based on experience or other factors. Mostly a combination of corrective and preventive maintenance is used.	Maintenance strategy is differentiated using asset classification. Each type of asset is assigned a maintenance strategy. E.G. All critical assets are preventively maintained, all non-critical assets correctively.	Maintenance strategy is differentiated using asset classification. Critical assets are assigned a fitting maintenance strategy individually. This could include using a form of predictive maintenance.	Every asset is assigned the correct maintenance strategy based on historical data with downtime and frequency of failures.
Autonomous maintenance	Autonomous maintenance is almost not utilized.	Production employees are sporadically involved in autonomous maintenance, mostly on critical assets.	Production employees are aware of the added benefit of autonomous maintenance. Critical assets are autonomously maintained where possible.	Production employees that should perform autonomous maintenance are trained if necessary. They are also involved in maintenance activities. Autonomous maintenance is extended to non-critical assets as well if there is added benefit.	Autonomous maintenance is performed on all assets that benefit from this. It is consistently performed and the responsible production employees are pro-actively used.
Failure analysis	Failure analysis is not performed and has no defined method.	In case of high-impact failures, a failure analysis is performed without a defined method.	Failure analysis has a defined method. It is performed on all critical assets and on other assets in case of high-impact failures.	Failure analysis is periodically performed on critical assets and critical failures are detected. Failure analysis also performed on assets with a high frequency of failures. Measures are implemented to lower the recurrence of these failures.	Information on critical failures is frequently updated and based on a methodic failure analysis. All assets that benefit are examined using a failure analysis. Measures are implemented which leads to absence of critical fault recurrence.
Intervals of scheduled maintenance	Preventive maintenance activities are not defined and therefore no intervals are defined.	Preventive maintenance activities are defined based on a 'randomly' chosen interval. This could be a standard interval for every asset.	In case the manufacturer recommends preventive maintenance, these intervals are followed in the maintenance scheduling. For assets where this is not recommended, a standard interval is chosen. This interval can be changed based on experience.	If necessary, critical assets receive a revised maintenance planning based on the failure rate. Maintenance is scheduled in accordance with production.	Assets that are preventively maintained are monitored whether the maintenance interval should be adapted due to a high failure rate. Planning based on failure rate or equipment monitoring, whichever is more suitable for the asset class.
Documentation	Documentation is mostly unavailable or outdated.	Documentation is unorganized, some maintenance processes are standardized.	Documentation is organized. Documentation on critical assets is readily available and maintenance activities are standardized for these assets. There is a procedure in place to take care of correct management of equipment maintenance files. This could be assigining a specific employee	Documentation is organized and standardized. Documentation is quickly and easily accesible for all assets. Maintenance activities are standardized.	Documentation is organized and standardized with quick and easy access regarding all assets. This documentation is systematically updated. Maintenanentenance activities are standardized and systematically revised.
Spare parts	Spare parts are not kept based on forecast of future demand.	Spare parts are kept for assets that are maintained using breakdown maintenance. Future demand is not forecasted.	Spare parts are kept for assets that are maintained using breakdown maintenance. Future demand is forecasted based on historical consumption.	Spare parts are kept for critical assets and their critical failures. Spare parts are also kept for assets that are maintained using breakdown maintenance. Future demand is forecasted empirically based on historical consumption	Spare parts are kept for all assets that have high-impact parts with a long lead time. Inventory levels of all spare parts are regularly reviewed based on forecast demand.
Key Performance Indicators	No KPIs are defined.	At least one KPI is defined and monitored which can be used to measure the maintenance performance for critical assets.	Performance of critical assets is effectively monitored using relevant KPIs. The maintenance organisation has a KPI in place to measure the overall performance.	Performance of critical assets is effectively monitored using relevant KPIs. The maintenance organisation has 2-3 KPIs in place to measure the overall performance. KPIs are continously monitored and a relevant goal is defined.	Performance of all assets is effectively monitored using relevant KPIs. The maintenance organisation has all KPIs in place to effectively measure the overall performance. KPIs are continously monitored and a relevant goal is defined. The goal is aligned with company objectives.
Computerized Maintenance Management System (CMMS)	No use of CMMS and no electronic records.	Use of computer applications for maintenance management. Not integrated with other systems.	Computerized system for planning and control of maintenance. Not all functions are used and not integrated with other computer systems.	CMMS where not all functions are widely and properly used. Not integrated with other systems of the company. Some automation is present.	CMMS to support all functions of maintenance management with high degree of automation. Functions are available and effectively used. Integrated with other systems of the company.
Company policy	Maintenance is considered a necessary evil, being focused on the resolution of faults in the shortest time.	Maintenance is considered a necessary evil, but the need to act preventively is recognized.	Maintenance is considered important in achieving organization's objectives. Preventive maintenance is done to increase productivity and reduce costs.	Maintenance is considered important in achieving organization's objectives. Acting proactively (including improving equipment) in order to increase productivity, reduce costs and improve quality.	Maintenance is considered a strategic function. Acting proactively (including improving equipment) and efficiently in order to increase productivity, reduce costs, improve quality and reduce accidents and environmental impact.