UNIVERSITY OF TWENTE.

Master's Thesis

A Maturity Model for Improved Enterprise Asset Management

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A thesis submitted in fulfilment of the requirements for the degree of Master of Science

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Specialising in
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Faculty of
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Preface

This thesis marks the end of an exciting yet challenging journey and indicates the end of my student life at the University of Twente. This final academic journey was filled with exploring the topics of maturity modelling and enterprise asset management (EAM). This was done, not only, by reading literature on the topic but also by extensively discussing these topics with experts in the field of EAM. During this period I was able to experience and learn a lot of new things and meet numerous interesting people. Along the way, I have received help from a multitude of people who helped make this thesis possible. Considering their significant impact and helpful guidance / cooperation during this period, I would like to mention a few here explicitly.

I would like to thank Dr. Daneva for numerous meetings and her extensive feedback. From the very start, Dr. Daneva has been very enthusiastic and this never decreased during the course of the thesis. At first, it seemed difficult to make this collaboration happen since Dr. Daneva is part of the EEMCS faculty and not the BMS faculty. Luckily, we were able to get the authorization needed for her to supervise and grade this thesis after submitting a request to the exam committee. I am very glad I chose this, perhaps a bit unusual route, as Dr. Daneva her extensive feedback, enthusiasm and expertise have been of great help.

Furthermore, I would like to thank Prof. Dr. Schiele for taking on the role of second supervisor. I had the pleasure of following multiple courses from Prof. Dr. Schiele before starting my thesis. Considering his pleasant and informative teaching style and his expertise in maturity modelling and business operations, I was very eager for Prof. Dr. Schiele to help me during my thesis. Thank you for your analytical perspective and constructive feedback during the making of this thesis.

I would like to thank the entire team at Pernino Consulting for being so welcoming and providing such a great working environment these past months. Additionally, Pernino Consulting has enabled me to come into contact with a diverse set of specialists, willing to help me with any questions I encountered. This collaboration has enabled me to learn a lot about enterprise asset management, maturity modelling and consultancy. I especially want to thank Niels Hofman for introducing me to Pernino Consulting and Jos Smits for taking me on board and exploring/shaping my thesis subject. Furthermore, I want to express my gratitude to Ms. Femke Van Doorn, who guided me from the very start till the finish of my thesis. She was always quick to react to any questions I had and helped me extensively whilst creating and conducting the workshops. I also want to wholeheartedly thank all who participated in the workshops to evaluate the proposed maturity model, your input has been incredibly helpful and provided me with numerous new valuable insights.

Lastly, I would like to thank my family and friends for their advice and support during the last half year. In particular, I want to thank my girlfriend Anouk Boekhorst for her ongoing support and when necessary, sometimes kidnapping me away from my laptop to clear my head and start with a newfound focus the day after.

For now, I would like to invite you to read this thesis. I hope it will captivate your interest and present a thought-provoking viewpoint on maturity modelling for enterprise asset management.

Yours sincerely,
Bernard Verheijen

Executive Summary

Maturity Models (MM), over the years, have become an invaluable tool for businesses to systematically assess and document their maturity in specific domains. A Maturity Model is a model which assesses the maturity of a domain by evaluating it for various dimensions, based on a multitude of maturity levels. MM assessments can hereby help ease decision-making and effectively guide, as well as monitor, an organisation's progress towards an improved or fully mature state. Furthermore, MM assessments can also be used to compare the maturity of various domains or organisations and provide a common language for initiating discussions.

In this context, maturity is a dynamic state, which indicates how explicitly defined, managed, controlled and effective a business activity (or sequence of activities) is. Here, a fully mature state is considered to be complete and perfect. In the literature, these fully mature states are commonly referred to as best practices. What is considered to be a best practice may change over time, as it reflects the current state-of-the-art within a particular domain. It should be noted that depending on an organisation's industry, objectives and goals, varying levels of maturity for certain dimensions will be suitable. Progressing towards improved practices is about effectively balancing risk, performance and cost in an optimised manner.

To reap all potential benefits from using a MM, it is important to actively avoid or mitigate several pitfalls whilst creating a MM. Shortcomings identified in existing MMs range from a lack of clear structure, documentation and/or methodology, to failing to effectively address interoperability and the organisation as a whole. Furthermore, MMs are often not flexible enough to keep up with managing changes (whilst adhering to certain quality improvement principles) and the development of MMs tends to lack empirical assessment and evaluation.

An area for which such a maturity assessment and roadmap towards improvement can be especially beneficial is Enterprise Asset Management (EAM). EAM systems are concerned with all coordinated processes of an organisation that enable and ensure the cost-effective monitoring, management and optimisation of asset performance throughout the entire asset life-cycle. The larger and more asset-intensive an organisation becomes, the more crucial and beneficial it is to have an effective EAM approach in place. Effective EAM can help an organisation align its business objectives and goals with their use of assets. This can be done by, amongst others, efficient inventory management, implementing optimised maintenance strategies, and thorough risk identification and treatment. But also in a broader sense, an organisation's EAM approach should not only be limited to considering solely tangible assets. An asset is to be considered any “item, thing or entity that has potential or actual value to an organisation” according to the International Organisation for Standardization (2014). Furthermore, they add that the value of an asset can be “tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities. It can be positive or negative at different stages of the asset life.” This broad viewpoint, on what is considered to be an asset, opens up a new and, in the literature, rarely considered perspective for an organisation's approach to EAM.

The goal of this thesis is to help large-scale, asset-intensive organisations take a holistic view of their EAM processes and their respective performance and ease the decision-making towards improved EAM practices. The creation of a MM which is theory-backed and in-practice evaluated is chosen to achieve this goal.

By conducting an extensive systematic literature review (SLR), the topics of EAM and MM are explored in-depth. Relevant (working) definitions are documented to transparently communicate the intended scope of this research and an overview of the benefits and shortcomings for both topics are identified in the SLR and displayed in a grouped manner with supporting references.

Subsequently, by combining the seven-phased framework by Becker, Knackstedt and Pöppelbuß (2009) for systematically developing a new MM with the four-stepped approach for systematically comparing MMs by Lautenschutz et al. (2018), a new MM for improved EAM was created. This first MM proposal was evaluated (i) by conducting semi-structured interviews with 8 experienced practitioners in the field of EAM (in line with the guidelines as set out by Adams, 2015) and (ii) by conducting an individual questionnaire-based assessment. The latter consists of questions to evaluate the proposed MM dimensions based on the Unified Theory of Acceptance and Use of Technology (UTAUT) which helps evaluate the performance and effort expectancy of the MM as well as to gain insight into the associated social influences and facilitating conditions).

The results of both the semi-structured interviews and the questionnaire-based study were predominantly positive. Considering the various valuable insights and feedback points that were gathered with the help of the participating practitioners, a second iteration of the MM design was executed. This resulted in an improved MM proposal. Ideally, this second MM proposal will once again be tested to finalize the second iteration of the MM development loop and potentially be able to validate the MM. However, due to limitations in time, this was outside the scope of this thesis.

All of the aforementioned steps have been conducted in pursuance of answering the main research question of this thesis: *What are the key dimensions and sub-dimensions that make up a MM for comprehensively evaluating an asset-intensive organisation's approach to EAM?* The following key dimensions (also referred to as focus areas in this thesis, see the bold dimensions below) and sub-dimensions were determined to be necessary for comprehensively evaluating an asset-intensive organisation's approach to EAM:

Strategic Direction
- Capital Expenditure Planning
- Organisational Operational Plan
- Organisational Business Process Map
- Organisational Contingency Planning
- Process Transformation
- Stakeholder Management
- Contract Management
- Internal Co-ordination
- External Co-ordination
- Performance Review
- Business Culture

Asset Life Cycle Management
- Asset Policy
- Asset Acquisition
- Asset Registering
- Asset Planning
- Asset Operation Management
- Asset Maintenance
- Asset Disposal

Information Quality
- Information Quality Governance
- Information Quality Assessment
- Information Availability and Accessibility

Risk Management
- Safety
- Risk Identification
- Risk Analysis
- Risk Evaluation
- Risk Treatment

Security
- Information Security Management
- Information Access Control
- Secure Transmission of Sensitive Information
- Physical Asset Vulnerability

Human Capital
- Skill Management and Development
- Roles and Responsibility
- Leadership and Business Culture
- Qualified External Support

Asset Cost Optimization
- Financial Planning
- Life-cycle Costs
- Operational Costs
- Maintenance Costs

Information Collection and Dissemination
- Information Management
- Asset Data Monitoring and Recording
- Information Storage
- Communication
- Knowledge Management and Sharing

Corporate Social Responsibility
- Environmental Sustainability
- Social Impact
- Employee Well-being
- Inclusive Recruitment
- (Personal) Data Protection and Privacy

Tool Management and Standardization
- Formal Standards and Protocols as the Basis
- Consistency and Standardisation of Tools
- Conceptual Modelling
- Decision Support System
- Application Management

Compliance
- Law and Regulations
- Insurance Compliance
- Corporate Policy Compliance
- Contractual Obligations

With the newly created MM, this thesis makes several contributions to practice.The main contribution is are that practitioners in the field of EAM are now able to assess the maturity of an organisation's EAM approach with the help of a comprehensive and explorative MM which is applicable to any large asset-intensive organisation, regardless of industry / sector. Furthermore, the proposed MM should be able to be used by almost any practitioner, as has been confirmed by the evaluated UTAUT prompts which present that the model is perceived to have a low effort expectancy.

With the newly created MM, this thesis makec a few contributions to research. First, it provides an extensive SLR which presents the state-of-the-art of research on the topics of MMs and EAM from the past 10 years. Furthermore, the newly proposed MM for EAM is explorative and comprehensive with a unique perspective on the scope of what is to be considered an asset (by including a broad range of intangible assets as well), which is not only theory-backed but also evaluated by 8 expert practitioners in the field of EAM. From a research perspective, this MM can be considered as a theory (i.e. concepts and relationships among them) which could serve as a foundation for future empirical research studies on EAM in organisations.

The main limitations of this research are traceable to the scope of the conducted SLR. Although the SLR was conducted in a manner as comprehensive and thorough as possible, it can not be guaranteed that relevant sources were not overlooked since the SLR was limited to only the past 10 years and solely conducted by using SCOPUS as a digital library. Furthermore, both the MM dimension selection and the MM comparison phases in the MM development process required the author (who has limited practical experience in the field of EAM) to assess the relevance of elements, in a process which one may consider to be somewhat subjective. This may have skewed the outcome of the MM development process and limited the repeatability and thereby the validity of the research. To counter this risk, all steps of the research process have been transparently documented in this thesis.

The most meaningful next step, for this research to go forward, would be to complete the second iteration of the proposed MM by evaluating the proposed new MM version with a group of experienced practitioners in the field of EAM in order to determine the usability and usefulness of the MM. This may result in the acceptance of the proposed MM or may trigger yet another iteration to improve the MM further.

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List of Abbreviations

BIM	Building Information Modeling
BPM	Business Process Management
CMMI	Capability Maturity Model Integration
EAM	Enterprise Asset Management
ERP	Enterprise Resource Planning
FM	Facility Management
IQM	Information Quality Management
MM	Maturity Model
RQ	Research Question
SE	System Engineering
SLR	Systematic Literature Review
UTAUT	Unified Theory of Acceptance and Use of Technology

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1. Introduction

Maturity Models (MM) have become an increasingly meaningful and adopted tool for businesses. MMs are used to not only systematically assess and document current competencies but also to guide towards future organisational goals. An area for which such an assessment and roadmap to improvement can be significantly beneficial for organisations is Enterprise Asset Management (EAM). Effective and optimised EAM supports the exploitation of an organisation's assets through coordinated activity to maximize the return on investment, prolong the technical life cycle, and improve the security of assets. EAM can be crucial for achieving a company's goals. Maturity Models can aid in achieving these goals by identifying the current state and guiding an organisation towards an improved state. However, the current number of broadly applicable MM concerning EAM is limited, and most of the existing ones lack comprehensiveness as they do not consider EAM in all its facets.

This introductory chapter first describes the context of this thesis and the research problem (Section 1.1), subsequently, it presents the goal which is pursued (Section 1.2), and the related research questions addressed in order to achieve this goal (Section 1.3). Finally, the thesis structure is discussed briefly (Section 1.4).

1.1 Research Context and Problem

EAM is the process of managing the acquisition, maintenance and utilisation of a firm's assets. This process is concerned with ensuring that all company's assets, from buildings to equipment and data warehouses to intellectual property, are all optimally used and can support the company in achieving its strategic objectives. EAM systems (often part of an overarching Enterprise Resource Planning (ERP) system) are built and implemented to support the optimal usage of all assets. They can aid in the alignment of an organisation's goals and their use of assets by providing, amongst others, effective inventory management, the scheduling of (preventive and predictive) maintenance, inventory tracking, asset life cycle tracking and more. The larger and more asset-intensive an organisation becomes, the more important and beneficial it is to have effective EAM in place. Because the more diversified and asset-intensive an organisation's assets needs are, the more varied (service) needs become. Therefore growing companies are faced with increasingly complex asset management issues. To efficiently handle these asset management issues, an effective approach to EAM is crucial.

In the context of this research, we adhere to the definition of "large-scale" as set out by the Netherlands' Centraal Bureau voor de Statistiek (CBS), which considers large-scale organisations as organisations exceeding 500 employees.[1] Furthermore, asset-intensive organisations are considered to be all organisations that require an above-average level of long-term assets for their operations. Which in turn, causes the barrier to entry to these organisations' respective industries/sectors significant.

Pernino Consulting has experienced firsthand that the fit between asset-intensive firms and their EAM approach is often not optimally aligned. Which results in reduced performance

[1] https://www.cbs.nl/en-gb/news/2006/51/one-in-three-employees-do-company-course/company-size#:~:text=Small%20companies%20are%20companies%20with,have%20more%20than%20500%20employees.

and financial losses. This is especially problematic for asset-intensive organisations with high service needs. For an asset-intensive firm to be able to reach optimal performance, it is crucial to evaluate the fit between the firm and its implemented EAM approach. MMs can aid in this process. MMs not only offer a systematic and repeatable method for assessing and evaluating the maturity of an organisation concerning a specific domain but also are capable of presenting a path towards improvement and hereby can assist in decision-making.

The adoption of a MM is most useful/effective if the MM used (1) is capable of providing the required assessment levels, (2) is comprehensive enough to effectively scope the intended domain that needs assessment, (3) provides clear and repeatable measurements for dimensions and sub-dimensions, and (4) the creation process is backed up by theory. Furthermore, it would be best if the MM is validated not only by using literature sources but also by experts in the respective field or on the basis of convincing empirical evidence, to confirm its value in practice. Creating and evaluating such a MM is a challenging process, but if done correctly can reap significant rewards as it guides the implementation towards best practices (Wissotzki & Koc, 2013).

Next, we make the note that this thesis uses the term “best practice” as it is commonly refered to in the literature from the SLR and is also utilised in officially recognised management standards (for example in ISO 55000 of the International Organization for Standardization, 2014). One refers to a practice as being a “best practice” if it performs in some superior way as compared to all other practices for a specific dimension. To achieve the highest possible level of maturity in a domain, one must effectively implement the best practices for the domain in question. Considering that a best practice reflects the current state-of-the-art in a particular dimension, it should be noted that a best practice can change over time due to technological development. Furthermore, although implementing best practices enables an organisation to achieve the highest level of maturity, it may not always be in the best interest of the company. Depending on an organisation’s industry, objectives and goals, it might turn out to be highly uneconomical or even irrelevant for performance to implement best practices for certain dimensions. Thus, a best practice may not be *the best* for every organisation, therefore best practices perhaps should be considered successful practices or proven practices for a specific domain. For determining what practices are most suitable for an organisation in a particular domain, one must try to balance risk, performance and cost optimally for executing the respective EAM-related business activities. In this thesis. the term “best practice” will still be used going forward for clarity and consistency, but it is important to keep the aforementioned caveats in mind when encountering this term.

As indicated by Chen et al. (2021), Wissotzki & Koc (2013), and Mahmood et al. (2015), a multitude of studies have attempted to construct a measurement tool to achieve the benefits of effective EAM. Yet, the need for a comprehensive MM for all facets of EAM, backed up by theory and not only applicable to a niche set of organisations, still has not been realized. Pernino Consulting has experienced not only the misalignment of EAM approaches with organisational goals but also the lack of effective maturity assessment tools for the topic of EAM. This thesis tries to solve this problem. This is attempted by combining both theory and practice, as the research described in this thesis was initiated in tight collaboration with the University of Twente and Pernino Consulting. Where the University of Twente ensures soundness and theory behind the MM creation, Pernino Consulting will enable the effective evaluation and wherever necessary adaption of the model by testing the MM with an experienced group of consultants with expertise in EAM.

Pernino Consulting specializes in helping organisations realize their full potential since 2020. Based in the city of s’Hertogen-Bosch, Pernino Consulting is a consultancy agency specialising in the topics of business process improvement, programme and project management, digital strategy, IT architecture and design, IT selection processes, data

science and artificial intelligence implementations. Despite Pernino Consulting's relatively short history, Pernino Consulting brings over 300 years of combined business experience to the table, and through a diverse team of junior and senior process consultants, data and AI consultants, business architects and project managers Pernino Consulting adds value to their client organisations. The experience of the various consultants at Pernino Consulting will be a very valuable asset during this research, as it will help reflect and evaluate the new MMs' completeness and relevance.

1.2 Research Goal

The goal of this thesis is to help large-scale, asset-intensive organisations take a holistic view of their EAM processes and their respective performance and ease the decision-making towards improved EAM practices. In this context, an improved EAM practice is considered to be any approach / practice which balances risk, performance and cost in a more optimised manner for executing certain EAM related business activities. The creation of a MM which is theory-backed and in-practice evaluated is chosen to achieve this goal. This combination will allow the model to contribute to the scientific landscape of EAM by creating a MM with a diverse view of EAM by combining previous literature. Furthermore, the research is expected to contribute to the field of EAM in practice by enabling large-scale, asset-intensive organisations to repeatedly and systematically assess their EAM performance.

The envisioned MM should be able to give a broad and inclusive overview of the maturity of all areas affected by and related to an organisation's EAM maturity.

1.3 Research Questions

As already indicated, the goal of this thesis is to build a comprehensive, explorative MM for evaluating EAM performance. In line with this research goal, the following **main research question** (RQ) was chosen:

> *What are the key dimensions and* sub-dimensions *that make up a maturity model for comprehensively evaluating an asset-intensive organisation's approach to enterprise asset management?*

To answer this main research question several sub-research questions were formulated. These can be divided into multiple sections.

In the first section, the topic of Maturity Modelling is explored and in line with this the following sub-research questions are posed:

RQ1. *What is a maturity model?*
RQ2. *What maturity model characteristics are suitable for the proposed (new) maturity model on EAM?*

To explore these RQs in a comprehensive yet clear manner, they are split into multiple sub-sections. In these sub-sections the definitions of maturity and maturity modelling in the context of this thesis are expressed, an overview of the different types of maturity modelling approaches that exist are presented, and the various benefits, challenges and shortcomings

of maturity models are considered. These research questions and sub-sections are to be explored through a systematic literature review.

In the second section, the topic of EAM is researched to gain insight into the following question:

RQ3. *What is enterprise asset management?*

This RQ is also explored by a systematic literature review and split into multiple sub-sections. These sub-sections address defining the term enterprise asset management and the various benefits, challenges and shortcomings associated with it.

For the next section, both topics are combined in one, as the literature research focuses on identifying maturity models specifically aimed at EAM. To build a new maturity model it is important to analyse existing MM on EAM whilst asking oneself which elements of these existing models are relevant and indispensable. At this point, elements which are not contributing towards creating an explorative and comprehensive maturity model, for assessing an organisation's EAM approach, should be excluded. To create a MM in a systematic and comprehensively documented manner the methodological approach behind it must be sound. Achieving this, in the context of this thesis, is done by adhering to a combination of the work on maturity model creation by Becker et al. (2009) and Lautenschutz et al. (2018). For a more detailed description of what this entails and how this is utilised see Chapters 4 and 5. This approach leads to creating a new MM for EAM and hereby gives insight into the following posed RQ:

RQ4. *What dimensions and sub-dimensions from existing maturity models are transferable to the new model?*

The aforementioned questions, combined, will enable the creation of a new MM for EAM. This new MM, however, should not only be theoretically sound but should also hold up in a practical setting. Therefore, the newly created MM model will be presented to, and subsequently evaluated by, experts in the field of EAM. This evaluation will help answer the following and last research question of this thesis.

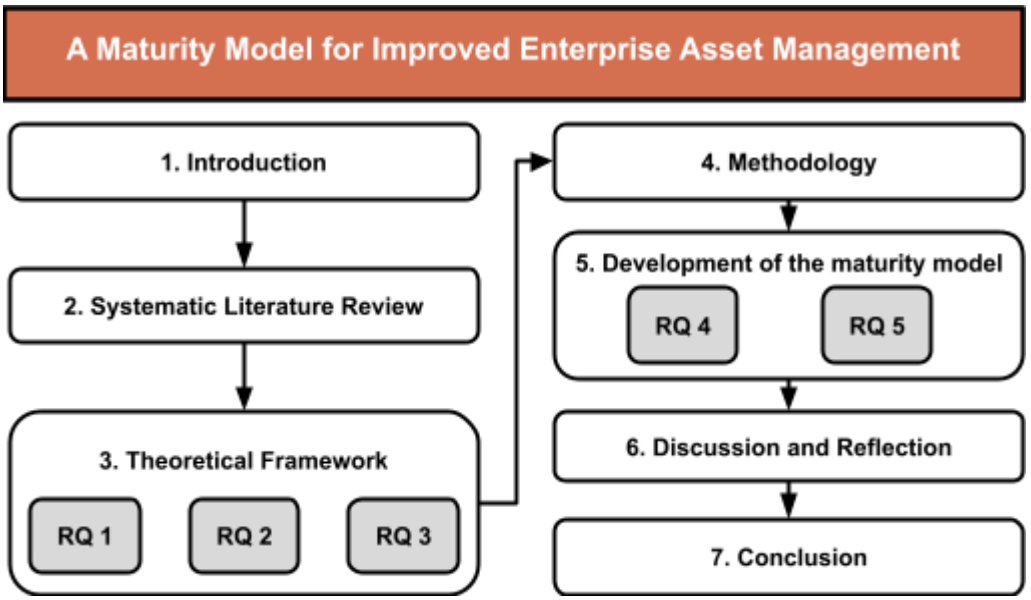
RQ5. *To what extent is the proposed maturity model usable and useful in practice?*

This final RQ will be answered by interviewing a multitude of experts in the field of EAM in workshop-style meetings. During these meetings, the model itself, its creation process and its vision are presented. After this, the participants will evaluate the model by filling in a questionnaire (partly based on the UTAUT model (Venkatesh et al., 2003) and participating in an open discussion to further elaborate on how the proposed MM is perceived.

1.4 Thesis Structure

Before exploring the topics in more depth, the structure of the thesis will be presented below (Figure 1.) in a visual manner to clarify the approach taken to this research project.

Figure 1. Visualisation of the Thesis Structure



The goal of this thesis is approached by first identifying relevant literature for the topics of maturity modelling, EAM and the combination of both these topics. This search is split into three sections to approach the diverse aspects of this research without limiting the scope by already combining the various topics.

First, the literature review focuses on gaining insight into the process of maturity modelling. In this section, we will explore questions such as: what approaches for maturity modelling are there? What are the benefits and drawbacks of these model approaches? How should one go about making or enhancing a maturity model? What models are well-regarded in the literature? This is done as preparation for tackling the main research goal of building a broad, inclusive and theoretically backed MM for the topic of EAM.

Second, a deep dive into the topic of EAM is presented. This topic is researched to give insight into current tried and tested approaches to effective asset management. This will help define the scope of what dimensions and sub-dimensions are relevant for assembling the final maturity model. Furthermore, researching the state of the art of asset management research will allow for detailed descriptive maturity level descriptions. It will enable not only to accurately describe, in practice, known maturity levels but also to give suggestions for, in the academia reported, future best practices. These will make the MM future-proof and show users what is needed to achieve the currently highest possible maturity level. In the last part of the literature review, the previously mentioned topics are combined in a final search to discover papers which consider both maturity modelling and EAM. This is done to list previously built models and identify the strengths and weaknesses of these models.

Subsequently, based on the acquired information in the systematic literature review RQ1, RQ2 and RQ3 are answered. In the methodology chapter (see Chapter 4), the approach for creating the new model is described, after which the development of the new MM is documented. In the discussion (Chapter 6), a reflection on the chosen research methodology and the MM is presented, the limitations of this research are described, and recommendations are made concerning future work. Finally, the thesis ends with some concluding remarks on the results of the research (Chapter 7).

2. Systematic literature review

This chapter focuses on the approach taken whilst conducting the systematic literature review (SLR). First, the adopted literature review methodology is explained to describe the design of the review. Then, the inclusion and exclusion criteria are defined, which expresses the scope of the review. Subsequently, the statistical results of the SLR are explained. And lastly, the literature reviews quality is evaluated, to ensure it represents the intended scope correctly and the gathered sources are of sufficient quality.

2.1 Systematic Literature Review Methodology

The SLR part of this thesis adheres to the guidelines set out by J.F. Wolfswinkel, E. Furthmueller and C.P.M. Wilderom (2013) in their paper "Using grounded theory as a method for rigorously reviewing the literature." In this article, the authors present a five-stage grounded-theory method for reviewing the literature to ensure a solid and systematic in-depth analysis. This five-stage process consists of the following stages:

1. **Define**
    - Define inclusion and exclusion criteria, areas of interest, and relevant sources and select appropriate search keywords.
2. **Search**
    - Conducting the search according to the defined search criteria.
3. **Select**
    - Refine the outcome of the conducted search.
4. **Analyse**
    - Analyse by employing open, axial and selective coding.
5. **Present**
    - Represent and structure the findings.

This process is iterative for narrowing down the search to gather the intended output. In the present Chapter, Stages 1, 2 and 3 are elaborated on, and Stages 4 and 5, namely, the analysis and presentation of the findings, are presented in Chapters 3 and 4.

2.2 Search keywords and inclusion/exclusion criteria

As described in Stage 1 of the five-stage process by Wolfswinkel et al. (2013), it is important to first define the inclusion and exclusion criteria of the search, identify areas of interest, relevant sources and to select appropriate keywords.

For this SLR, literature is sourced using the SCOPUS literature search engine and the search queries were focused on "Title, Abstract & Keywords." Furthermore, the inclusion and exclusion criteria maintained during all of the search queries are presented below. These choices were made in order to limit the scope of the search and to show relevant as well as contemporary research.

Inclusion Criteria:

- The top 100 sources per query, as presented by using the filter “Cited by (highest),” are taken into consideration for further selection.
- For part 1 of the SLR: only sources are included that address the topic of maturity modelling.
- For part 2 of the SLR: only sources are included that address the topic of (enterprise) asset management.
- For part 3 of the SLR: only sources are included that address both the topics of maturity modelling and enterprise asset management.

Exclusion Criteria:

- Non-English literature is excluded.
- Sources older than 2012 (≤10 years of age) are excluded.
- Grey literature is excluded, with the exception of grey literature as the result of snowballing.
- Duplicate literature is excluded.
- To ensure relevance, sources not corresponding to the intended query outcome are excluded.

With the inclusion and exclusion criteria defined and applied, stage two can be started: conducting the search. First, the topics of EAM and maturity models were searched broadly, only using these two terms themselves as keywords. Based on the results of multiple searches the keywords used in the queries were altered or more relevant keywords were added. After which the process was started again. This process of searching and refining the results (stage two and stage three) was iterated until the search results represented the intended outcome as accurately as possible. Finally, six queries were created. Two for each of the following topics: (1). Maturity Models, (2). Enterprise Asset Management and (3). the combination of both; Maturity Models and Enterprise Asset Management.

To approach this SLR with three different topics was a deliberate choice as it allowed the SLR to focus on the individual topics of maturity models and EAM in-depth, without unnecessarily narrowing the scope further. Yet also to identify the overlap between topics whilst exploring maturity models concerning EAM in the final combined search. This process resulted in the creation and subsequently, the search of the six queries as presented below in Table 1.

Table 1. Systematic Literature Review - Query Overview

	Systematic Literature Review Part I: Focus: Maturity modelling
Query 1	("maturity model") OR ("maturity modelling")
Query 2	(("maturity model") OR ("maturity modelling")) AND (("literature review") OR ("systematic review") OR ("overview"))
	Systematic Literature Review Part II: Focus: Enterprise Asset Management
Query 3	(("EAM") OR ("enterprise asset management") OR ("asset management"))
Query 4	(("EAM") OR ("enterprise asset management") OR ("asset management")) AND (("ERP") OR ("enterprise resource planning"))

	Systematic Literature Review Part III: Focus: Maturity modelling + Enterprise Asset Management
Query 5	(("maturity model") OR ("maturity modelling")) AND (("EAM") OR ("asset"))
Query 6	(("maturity model") OR ("maturity modelling")) AND (("ERP") OR ("enterprise resource planning"))

After applying these inclusion and exclusion criteria, and conducting the search with the previously defined queries, the top 100 results (or all results if less than 100 results were found at this stage) per query were taken into account for further selection/analysis. In total, six different queries were eventually used for the SLR. The selection of results of these queries then were processed by isolating all relevant titles. Subsequently, all abstracts were considered and only papers with, to this topic, relevant abstracts were selected. After this, duplicates (from other queries) and unavailable documents were removed. Lastly, the remaining selection was considered in full to decide on its relevance for this study.

An overview of the process described above is iterated and numbered in Table 2 below, these steps match with the steps as presented in the SLR results in the next section.

Table 2. Systematic Literature Review - Inclusion / Exclusion Steps

Search Engine: SCOPUS (Search within: Article title, Abstract, Keywords + Cited by highest). Search conducted during 12-2022

Step I	Total amount of documents found.
Step II	Filter out all documents older than 10 years (≥ 2012).
Step III	Filter out all documents that are not English.
Step IV	Limit to (if possible) the top 100 documents.
Step V	Filter the documents based on titles.
Step VI	Filter the documents based on abstracts.
Step VII	Remove duplicate documents.
Step VIII	Remove unavailable documents.
Step IX	Filter based on the full document.

The next section presents the outcome of these selection steps.

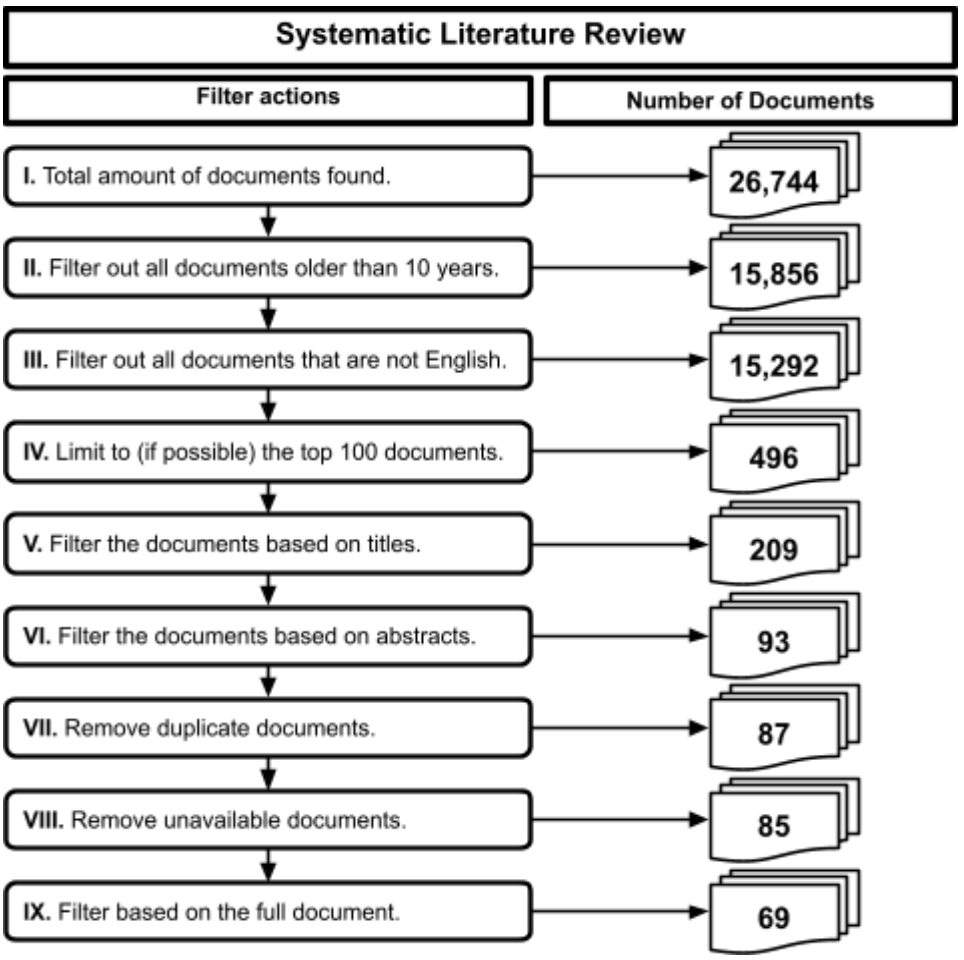
2.3 Source selection

With Stages 1, 2 and 3 of the 5-stage model completed, the final selection of literature has been composed. In the pursuit of transparency and repeatability of this research, Table A.1,

A.2, A.3, and A.4 presented in Appendix A, as well as Figure 2 presented below, shows the number of selected documents throughout the literature selection process.

Table A.1 (Appendix A) presents the literature search with a focus on maturity models, Table A.2 (Appendix A) with a focus on EAM and Table A.3 (Appendix A) with a combined focus on both these topics. Table A.4 (Appendix A) and Figure 2 present the statistics of the entire search process combined in one.

Figure 2. SLR Search Results
SCOPUS (Search filters: Article title, Abstract, Keywords + Cited by (highest))
Search conducted in December 2022



As indicated above, during the process of conducting the SLR, the total document selection was reduced from 26,744 to the 69 most relevant articles for this research. These articles form the basis of the literature research and the creation of the improved EAM MM.

2.3 Quality Assessment of the selected sources

In the five-stage approach by Wolfswinkel et al. (2013), one important Stage is missing which researchers find in the work of Petersen et al. (2015): quality assessment. According to Petersen et al. (2015) in their paper: “Guidelines for conducting Systematic Mapping Studies in Software Engineering: An update”, it is even essential to assess the quality of the

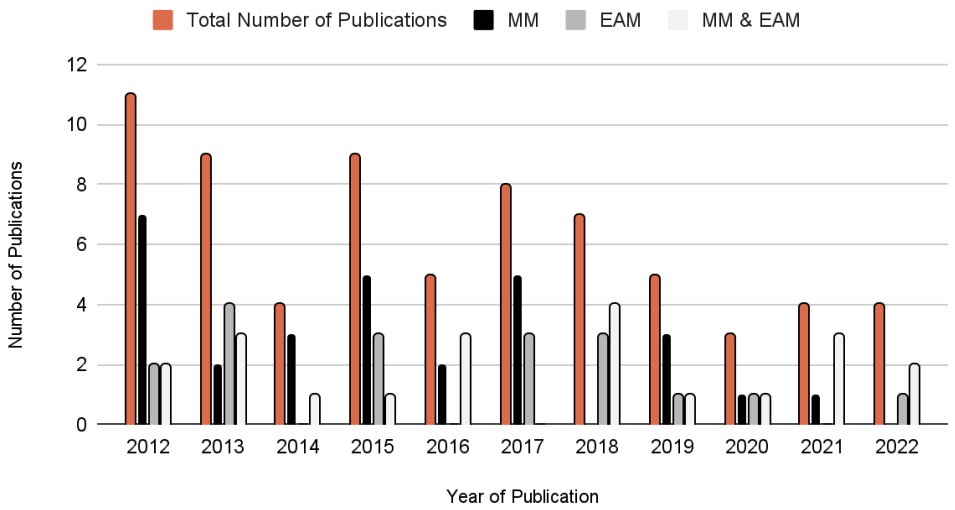
results in a systematic review, as this will ensure the rigour and relevance of the results. And thus a quality assessment can result in a certain level of quality assurance.

To verify the quality of the sources (i.e. the 69 selected papers) of the SLR in this thesis three approaches are taken to assess the quality. First, the timeline of the SLR is visualised. This is done to identify potentially abnormal gaps or extremes in the results. This can help recognise trends and spot inconsistencies. Second, the results are analysed with the help of VOSViewer. VOSViewer is a software tool developed by N.J. Van Eck and L. Waltman from the University of Leiden.[2] The tool is used for visualising bibliometric networks In the context of this thesis, VOSViewer is used to evaluate if the co-occurrence of the keywords correlates with the keywords used in the search queries. Furthermore, it may give useful insights into what keywords are closely related/linked this can give suggestions for potentially relevant extra keywords or topics to investigate. Next, VOSViewer is used to analyse the frequency and co-occurrence of authors. This is done to check the diversity of the group of authors, so the research is not excessively influenced by the perspective of a limited number of (collaborating) authors. Lastly, the journals of the findings are evaluated by exploring their respective SCImago Journal Rank (SJR) scores and their H-Index, to evaluate the impact of the publications.[3]

2.3.1 Demographics of the included papers

As presented below in Figure 3, we can see a decreasing trend in the number of publications if we consider the total number of publications. This is mainly due to the decrease in publications on the topics of MMs and EAM individually. The relevant search results of the combination of both these topics seem to have been relatively stable over the years. It should be noted that the decrease in documents over the years is likely explained due to the conducted search being conducted whilst sorting the papers by highest cited. Since older papers often have reached more citations, these are more prevalent in this research. So this trend in itself does not necessarily mean less research on the topics mentioned has been conducted in more recent years. Furthermore, no remarkable gaps in the timeline of the literature publication dates were found.

Figure 3. Demographics of the included papers



[2] //www.vosviewer.com/
[3] https://www.scimagojr.com/journalrank.php

2.3.2 VOSViewer Visualisation

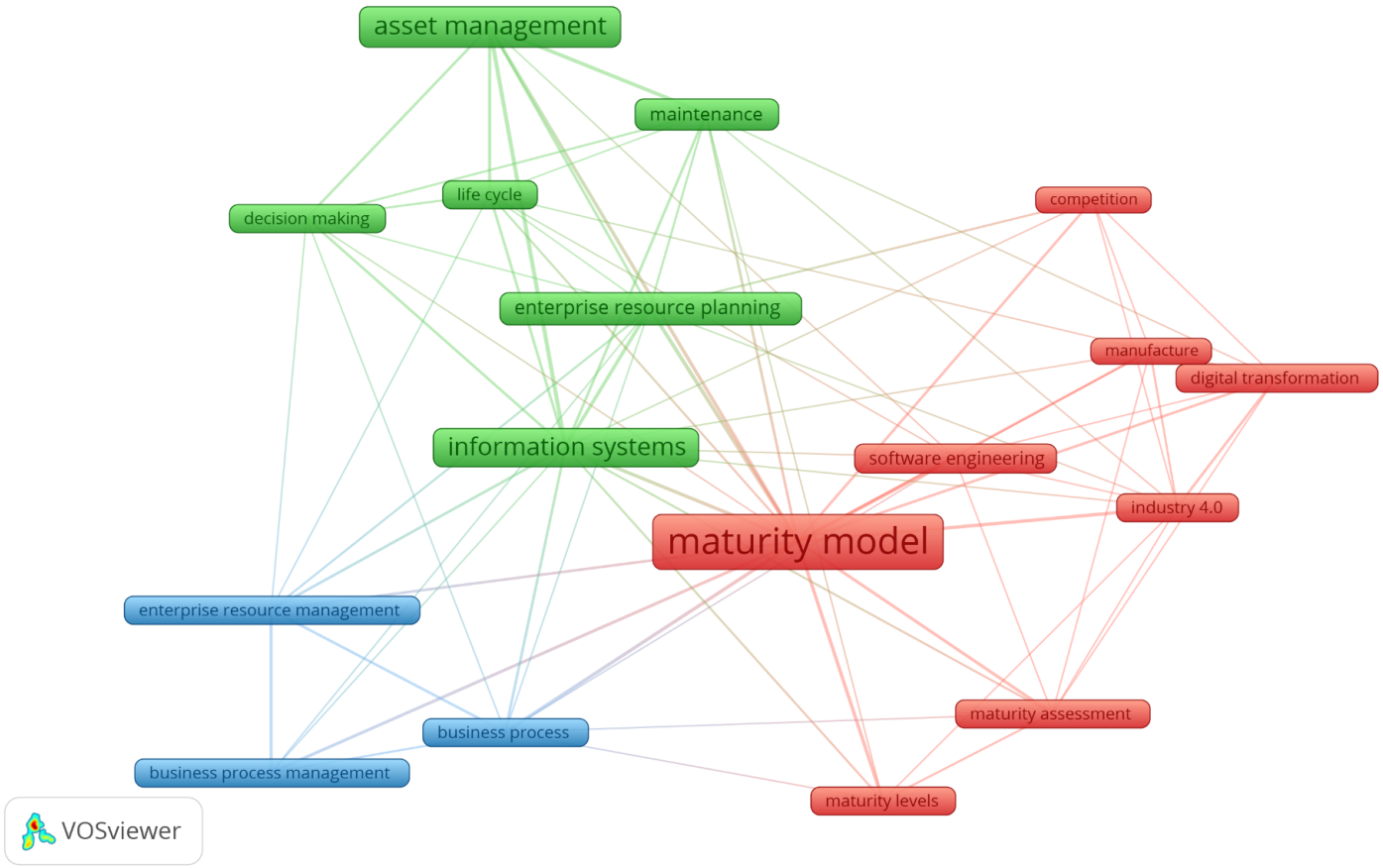
As mentioned previously, VOSViewer is a software tool created to visualise scientific landscapes. VOSViewer makes use of the visualisation of similarities (VOS) mapping technique. The generated map displays the recurrence of the most prevalent keywords and clusters them based on their relative strength. The smaller the distance between keywords, the greater the relative strength between them. For a more in-depth exploration of this technique please see (van Eck & Waltman, 2009).

In the context of this thesis, the tool is employed to evaluate if the co-occurrence of keywords from the final literature selection matches the applied queries and reflects the intended topics well. Additionally, it might point out relevant related topics (or clusters of topics) that have not been considered until this point. Lastly, the co-authorship analysis function is used to explore potential abnormalities regarding the (co-) authorship of the literature (Santos-Neto & Costa, 2019).

The VOSViewer output presented below (Figure 4), has been based on bibliographic data. More specifically, the bibliographic data of the final 69 selected documents from the SLR. The analysis presented is focused on the full counting of the co-occurrence of keywords. Full counting in this context means that every co-occurrence of keywords is considered to have the same weight. A VOSViewer thesaurus file is added to group keywords that represent the same term. The thesaurus file for example replaces the keyword "maturity models" with "maturity model" so a less fractionalized and more clear output could be generated. The occurrence threshold for keywords was set at 4.

Figure 4 shows that the keywords asset management and maturity model are most prevalent. Also, the keywords enterprise resource planning and maintenance are high in occurrence, which represents the used queries well. This confirms that the output of the queries matches the intended result. Two notable occurrences are the terms software engineering and industry 4.0. Their occurrence is likely to be explained as follows: software engineering is closely related to maturity modelling as the roots of maturity modelling started with the creation of the capability maturity model integration (CMMI) (Sauni et al., 2022). This MM variation was especially relevant/applicable in software development. The topic of Industry 4.0 is relevant due to its link with asset management. In recent years Industry 4.0 has been a popular research topic and has brought forth various approaches for more effective use of assets utilising increased interconnectivity and automation.

Figure 4. VOSViewer Bibliographic analysis of co-occurrence by full counting



As mentioned previously, VOSViewer can also be used to identify focal points or abnormalities concerning the (co-) authorship of the used literature. A bibliographic analysis is made by compiling all relevant data in a single Research Information Systems (RIS) file to be analysed by VOSViewer, and the co-authorship analysis is made using the full counting method. In this analysis, no VOSViewer thesaurus file was used. The maximum number of authors per document was set at 25 and the minimum number of documents by a single author was set to 1. The result is a map displaying all 210 authors, which clusters of authors have worked together and their interrelatedness. The analysis indicated that only 12 of the 210 authors were represented more than once in the literature used. These 12 authors contributed to 2 documents of the SLR result, which indicates a high diversity of sources.

Figure 5. VOSViewer Bibliographic analysis of authorship (co-)occurrence

As mentioned in the introductory part of this chapter, the SJR score and h-index are used to evaluate the impact of journals. Elaborating on this, the SJR score indicates the average number of weighted citations received in a selected year compared to the number of publications from the journal in the preceding three years. Whereas the H-index oftentimes is used as an author-level metric to measure productivity and citation impact, in this context it is used to evaluate the impact of the journal. The H-index, here, indicates a number that represents the minimal number of citations that all articles in the publication have achieved.

Presented in Appendix B, Table B.1 presents the full overview of all papers and their respective SJR Scores and H-Index. In Table 3, presented below, an overview/summary of these findings can be found.

Table 3. Overview - SJR Scores and H-Index - Overview

SJR Score	Number of publications
Unavailable	17
0.000 - 0.100	0
0.101 - 0.200	16
0.201 - 0.300	7
0.301 - 0.400	4
0.401 - 0.500	3
0.501 - 0.750	8
0.751 - 1.000	2
1.001 - 1.500	3
1.501 - 2.000	6
2.001 - 2.500	2
2.501 - 3.000	1
> 3.000	0

H-Index	Number of publications
Unavailable	9
0 - 10	3
11 - 20	5
21 - 30	11
31 - 40	4
41 - 50	4
51 - 75	9
76 - 100	7
101 - 150	11
151 - 200	3
201 - 300	1
301 - 400	0
401 - 500	2
> 500	0

Average SJR	0.651	**Average H-Index**	77.867

Considering the overview of Table 3, we can conclude that the average SJR score is <1.0, which indicates that the journals selected have a below average citation potential. The average H-Index signifies that on average the minimal number of citations of the selected journals is (rounded up) 78, which is respectable considering the highest H-Index journal score is 146 (according to Elsevier[4]). However, it should be noted that both values may be skewed as some scores/indexes were unavailable.

Overall, the results indicate that the journals found in the SLR results are, on average, relatively often cited, yet have a below-average citation potential. Although this in theory adds to the credibility of the sources, due to the spread of scores and unavailability of scores, every paper itself will still be critically evaluated when read in full to ensure the quality of the literature study.

[4] https://scientific-publishing.webshop.elsevier.com/publication-recognition/what-good-h-index/#What_is_a_good_H-Index_score_journal

3. Theoretical framework

In order to develop a new and improved MM for EAM, it is first important to explore those literature sources that are already present on the topic. Therefore, this chapter gives an in-depth inside into the findings from the SLR. The resulting 69 selected papers from the SLR were first summarised and categorised according to the subject (for example, MM or EAM but also, if applicable, the industry sector that the papers focussed on) and relevance (papers closely related to the intended research goal of this thesis were identified to identify commonalities and distinct features in their research approach). In this chapter, the findings from the SLR are structured and represented to answer three out of the four sub-research questions of this thesis. The following RQ will be discussed (in order of appearance):

RQ1. *What is a maturity model?*

RQ2. *What maturity model characteristics are suitable for the proposed (new) maturity model on EAM?*

RQ3. *What is enterprise asset management?*

The answers to these RQs help to build the theoretical framework needed for the latter development of a new model. These answers build on the previous SLR chapter as it presents Stages 4 (analyse) and 5 (present) from the five-stage process as presented by J.F. Wolfswinkel, E. Furthmueller and C.P.M. Wilderom (2013).

In what follows, each of the sections explores one of the three aforementioned RQs. However, depending on the topic, relevant themes, definitions, and questions are also explored to comprehensively address the overarching research question.

3.1 RQ1: What is a maturity model?

First, the topic of maturity modelling is explored. To give a thorough yet clear perspective of maturity modelling, this sub-research question is once again divided into parts. The research question is split into the following sub-sections (in order of appearance):

1. *Defining maturity.*
2. *Defining maturity modelling.*
3. *Types of maturity models.*
4. *Benefits of maturity models.*
5. *Shortcomings of (existing EAM) maturity models.*

3.1.1 Defining maturity

Before being able to define what a MM is and discover its functionality, an understanding is needed of what the underlying notion of maturity means. The importance of defining the key concept of maturity has been identified as a fundamental design principle by Röglinger, Pöppelbuß, and Becker (2012) in their influential work: Maturity models in business process management (BPM). Yet is seldom explicitly defined.

According to the Oxford Advanced Learner's Dictionary,[5] the noun maturity is defined as one of the following definitions:

1. *"The quality of thinking and behaving in a sensible, adult manner."*
2. *"The state of being fully grown or developed."*
3. *"Understanding and skill that an artist develops over a period of time."*
4. *"The time when money you have invested is ready to be paid."*

Within the literature, on maturity modelling, there is no standardized definition for maturity, and therefore no exact consensus over the definition of the term can be found, although it should be noted that the various given definitions are closely related. The definitions for maturity presented in the resulting literature from the SLR are presented to explore the adopted definitions, before choosing a comprehensive and fitting interpretation as a working definition for the context of this thesis.

The definition of "The state of being fully grown or developed" as stated by the Oxford Advanced Learner's Dictionary closely resembles the definition of maturity as described by Lahrmann et al. (2011) and Wagire et al. (2020), who describe maturity as a "state of complete, perfect or ready." Lahrmann et al. (2011) add to this that to reach this final state "an evolutionary transformation path from an initial to a target stage needs to be progressed." This definition was also adopted by Król and Zdonek (2020), Olszak (2016), and Teichert (2019). Wagire et al. (2020) add that achieving maturity can concern "improvements in the development of business processes, systems, technology and organisation as a whole." Furthermore, Wagire et al. (2020) explain the difference between readiness and maturity, as these terms sometimes are unrightfully used interchangeably. They refer to Pacchini et al. (2019) who describe readiness as a state of being equipped to achieve a specific task, whilst maturity is referred to as a level of progression in achieving a specific task.

Teichert (2019) focuses specifically on digital maturity and claims that digital maturity is not a static but holistic concept as technology is continuously changing and it reflects on technological and managerial aspects. Li, Wu, and Yen (2012) focus on maturity in yet another context, instead of digital maturity they focus on maturity in the context of knowledge management. In this context, they define maturity as "the extent to which a specific process is explicitly defined, managed, measured, controlled, and effective."

Mahmood et al. (2015), adhere to the notion of the CMMI Product Team (2002) that maturity, in the context of capability maturity models in various application areas, means "the extent to which an organisation has explicitly and consistently deployed processes that are documented, managed, measured, controlled and continually improved." This closely matches the definition presented by Gökalp, Şener, and Eren (2017), as they claim that maturity is used to "define, assess and form a guideline and a basis for evaluating the progress in the business."

García-Mireles et al. (2012) state that there is a common consensus in the literature for process maturity, which was described by Paulk, Weber and Chrissis (1995) as "the extent to which the process is explicitly defined, managed, measured, controlled and effective." Moradi-Moghadam, Safari, and Maleki (2013) translate the concept of maturity directly into a business perspective as it exemplifies the difference between mature and immature enterprises as follows: "mature organisations do things systematically while immature organisations achieve their outcomes as a result of heroic efforts of individuals using approaches that they create more or less spontaneously."

[5]https://www.oxfordlearnersdictionaries.com/definition/english/maturity?q=maturity

Proença and Borbinha (2016) acknowledge multiple perspectives from varying authors on what maturity is in pursuit of their exploration of the state of the art of maturity models for information systems. Among others, they refer to the work by Anderson and Jessen (2003), who define maturity as an enterprise's ability to achieve goals. Furthermore, they present the definition as given by Franz (2009) and Fitterer and Rohner (2010), who adopt a definition identical to the previously mentioned definition by Lahrmann et al. (2011), who claim that maturity is "the state of being complete, perfect and ready." This state can be reached by diverse paths, as identified by Amaral and Araújo (2008) but progresses from an initial state to an improved final state according to Mettler (2009) and Sen and Ramammurthy (2011).

Although not necessarily defining the term "maturity" itself, Bititci et al. (2015) comment on the relationship between the concepts of maturity and performance. Bitici et al. state that the "fundamental underlying assumption underpinning all these works is that higher maturity is associated with better performance. Evans (2004) confirms the relationship between the maturity of performance measures and improved performance, whereas De Leeuw and Van den Berg (2011), as well as Bitici et al. (2011), verify the relationship between the maturity of managerial practices and improved performance.

When considering all the above definitions found in the literature, most can roughly be sorted into *three groups*. Here, one group represents the definitions focusing on *maturity as being complete and perfect* (Lahrmann et al. (2011), Wagire et al. (2020), Franz (2009), and Fitterer and Rohner (2010)). Whilst the other group emphasises *maturity as a measurement of evaluating processes in regards to being systematically and explicitly defined, managed, controlled and effective* (Li, Wu, and Yen (2012), Mahmood et al. (2015), CMMI Product Team (2002), Gökalp, Şener, and Eren (2017), García-Mireles et al. (2012), and Moradi-Moghadam, Safari, and Maleki (2013)). Lastly, the third group considers *maturity to be a dynamic concept as maturity can improve/progress in various ways to reach a final mature state* (Lahrmann et al. (2011), Wagire et al. (2020), Król and Zdonek (2020), Olszak (2016), Teichert (2019), Teichert (2019), Amaral and Araújo (2008), Mettler (2009), and Sen and Ramammurthy (2011)).

To summarise, a clear overview of the varying interpretations/definitions of maturity is presented in Table 4, presented on the following page.

Table 4. Overview of the interpretations of "Maturity" from the SLR

Group	Definition focus	Source
I	Focus on maturity as a state of being complete and perfect.	● Lahrmann et al. (2011) ● Wagire et al. (2020) ● Franz (2009) ● Fitterer and Rohner (2010)
II	Focus on maturity as a measurement for evaluating if processes are systematically and explicitly defined, managed, controlled and effective.	● Li, Wu, and Yen (2012) ● Mahmood et al. (2015) ● CMMI Product Team (2002) ● Gökalp, Şener, and Eren (2017) ● García-Mireles et al. (2012) ● Moradi-Moghadam, Safari, and Maleki (2013)

III	Focus on maturity as a dynamic concept, considering maturity can improve/progress in various ways towards reaching a final mature state.	• Lahrmann et al. (2011) • Wagire et al. (2020) • Król and Zdonek (2020) • Olszak (2016) • Teichert (2019) • Teichert (2019) • Amaral and Araújo (2008) • Mettler (2009) • Sen and Ramammurthy (2011)

The most fitting description for maturity in the context of maturity modelling would be the combination of groups II and III (Table 4). Group I considers maturity as only the final mature state, however, in the context of maturity modelling, maturity levels can vary since maturity is a dynamic concept which can improve/progress in diverse ways. Yet the higher the maturity level, the more systematically and explicitly defined, managed, controlled and effective certain processes are. The working definition for maturity in the context of this thesis combines the various definitions, in pursuance of being comprehensive, as follows:

Working definition - Maturity:

> *Maturity is the dynamic state which indicates how explicitly defined, managed, controlled and effective a process is. This state is dynamic and can progress in various ways to reach an improved state. The final state/level of maturity is considered to be complete and perfect.*

It is important to note that the term “process” which is specified in this working definition of maturity, is intended to refer to any business activity or sequence of business activities in an organisation.

3.1.2 Defining maturity modelling

With the definition of maturity defined for this research, let us now consider how it can be used in the context of maturity modelling.

The origin of maturity modelling started in the software industry, from the 1970s onwards, as maturity models became an increasingly important tool for organisations in managing, evaluating and planning future development in software projects. These models mainly focussed on assessing process capability, but some models also were applicable to address business processes (Albliwi, Antony, and Arshed, 2014). Deemed by Sauni et al. (2022) as one of the original capability maturity models and by Helgesson, Höst, and Wyns (2012) and Cosic, Shanks and Maynard (2012) as the most famous of maturity models: the Capability Maturity Model Integration version 1.1 (CMMI) by Paulk et al. (1993) from Carnegie Mellon Software Engineering Institute, Pittsburgh has had a very significant impact on the software industry and the development of maturity modelling and software process improvement (Helgesson, Höst, and Wyns, 2012). Cosic, Shanks and Maynard (2012) add to this list of influential maturity models the growth model by Nolan (1973). These models have helped organisations streamline their process advancement and have laid the foundation for the development of many MM variants with varying characteristics and for a diverse set of application domains.

But what are maturity models and what exactly are they used for? The literature is divided on the definition of maturity models and no clear united definitions have been presented thus far

(Wendler, 2012). Some authors even bypass this question altogether in favour of describing their models' intended purpose instead (Olszak, 2016). This thesis does not ignore this issue and presents a working definition for the context of this thesis. To choose a fitting working condition, we now will first explore the findings from the literature on this matter.

According to a systematic mapping study by Wendler (2012), (*1). maturity models outline the conditions of specific objects which fulfil a final mature state. In this final/mature state, no further progress is possible.* This closely resembles the view presented by Mehairjan et al. (2016) whose perspective on maturity models is based on Volker et al. (2013) and Fraser, Moultrie, and Gregory (2002): (2). *"maturity models can be seen as a set of structured guidelines that describe how different domains within an organisation can contribute to a set of predetermined overall outcomes."* Olszak (2016) elaborates a bit further on this as she claims that (3). *maturity models are created and used to guide the transformation process from a non-mature state to an improved or final mature state*. Spruit and Pietzka (2015) make use of Becker et al. (2009) definition of maturity models which deems (4). *maturity models as "an artifact that aims at solving the problem of defining an organisation's current status regarding their capabilities and deriving means for improvements."*

Correia et al. (2017) also identify the lack of a common definition for maturity modelling and present three definitions put forward by other authors. Summarising, Correi et al. (2017) find the following definitions: Kohlegger, Thalmann, and Maier (2009) define (5). *maturity models as a representation of phases of "increasing quantitative or qualitative capability"*. This is done to be able to assess advances of specific elements in a certain focus area. Cuenca et al. (2013) add to this by emphasising a (6). *MM's ability to track elements' progress over time.* Lastly, Bitici et al. (2015) consider (7). *MMs to be matrixes of practices. Divided by focus area, these matrixes identify "the level of formality, sophistication, and embeddedness of practices."*

According to Caserio and Trucco (2018) elaborate more extensively on their perceived definition of maturity models. First, they adhere to the notion by Lahrmann et al. (2011) that the concept of (8). a *MM consists of a sequence of "multiple archetypal levels of maturity of a certain domain that can be used to assess the degree of the model development."* This way organisations can create an understanding of the overall development and more precisely the weak and strong points in a specific domain and what strategic alignment is needed to achieve an improvement. Due to the aforementioned functionalities, Grube (2018) deems (9). *maturity models to be "diagnostic tools."* Grube (2018), as well as Mehairjan et al. (2012), accentuate the ability of (10). *maturity models to generate an improvement plan and "monitor" the progress of these plans*. Wißotzki and Koç (2013) articulate their definition of the purpose of (11). *maturity models as "to identify a gap between actual and the intended organisational design which can be closed by succeeding development activities."*

Cosic, Shanks and Maynard (2012) are more precise about what this gap could potentially be. They use a combination of three sources to describe their definition of an information system maturity model, they characterise (12). *information system maturity models as "instruments that facilitate the assessment of the level of development of organisational capabilities (De Bruin, 2009), processes (Paulk et al., 1993) or resources (Nolan, 1973)."*

Another often recurring term encountered during the SLR is assessment model, however, it should be noted that this is not the same as the MM as described by Tarhan, Turetken, and Reijers (2016). The difference between maturity models and assessment models is deemed important by the authors because (1) *maturity models take a "guiding perspective," whereas assessment models take an "inquiring view"*, (2) *assessments made by maturity models can be made with a shifting scope, level of detail and precision*, (3) *the unclear distinction between the two models can cause confusion and may result in improper designs.*

As demonstrated in this chapter, maturity models can be created and applied to address a multitude of domains, take for example software process management (by Paulk et al., 1993), business intelligence (BI) (by Caserio and Trucco, 2018), business process management (by Grube, 2018), maintenance management (by Mehairjan et al., 2016), enterprise asset management (by Wißotzki and Koç, 2013), information systems (Cosic, Shanks and Maynard, 2012), and Correia et al. (2017) furthermore adds the domains amongst others human resource management, project management, supply chain management, and risk management. This shows the widely applicable and diverse nature of maturity modelling.

When considering all of the definitions found in the literature above, roughly three overarching definition groups emerge. The first group defines *(1). MMs with a focus on maturity models' ability to, in a structured manner, outline the condition of a final, fully mature state.* The following authors are considered to fit this description: Wendler (2012), Mehairjan et al. (2016), Volker et al. (2013), Fraser, Moultrie, and Gregory (2002), and Bitici et al. (2015). The second group defines a (2). *MM as having a multitude of maturity levels to assess specific elements, and by assessing these elements the MM can assist in decision-making and hereby guides the transformation process towards reaching an improved or fully mature state*. The following authors are considered to fit this description: Olszak (2016), Spruit and Pietzka (2015), Becker et al. (2009), Kohlegger, Thalmann, and Maier (2009), Lahrmann et al. (2011), Wißotzki and Koç (2013), Cosic, Shanks and Maynard (2012), De Bruin (2009), Paulk et al. (1993), Nolan (1973). Lastly, there is a group of authors that extend upon the previously mentioned group's definition by focusing on the ability of (3). *maturity models to monitor the progress of maturity levels of elements over time*. To this group belong the following authors: Cuenca et al. (2013), Grube (2018), and Mehairjan et al. (2012).

To summarise, a clear overview of the varying interpretations/definitions of the term maturity model are given in Table 5, presented below.

Table 5. Overview of interpretations of "Maturity Model" from the SLR

Group	Definition focus	Source
I	Maturity Models are models with the ability to, in a structured manner, outline the condition of a final / fully mature state.	● Wendler (2012) ● Mehairjan et al. (2016) ● Volker et al. (2013) ● Fraser, Moultrie, and Gregory (2002) ● Bitici et al. (2015)
II	Maturity Models are models that are characterised by having a multitude of maturity levels to assess specific elements, and by assessing these elements the MM can assist in decision-making and hereby guides the transformation process towards reaching an improved or fully mature state.	● Olszak (2016) ● Spruit and Pietzka (2015) ● Becker et al. (2009) ● Kohlegger, Thalmann, and Maier (2009) ● Lahrmann et al. (2011) ● Wißotzki and Koç (2013) ● Cosic, Shanks and Maynard (2012) ● De Bruin (2009) ● Paulk et al. (1993) ● Nolan (1973)

III	Maturity models extend upon the definition as described in Group II, by acknowledging a MM's ability to monitor the progress of maturity levels of elements over time.	• Cuenca et al. (2013) • Grube (2018) • Mehairjan et al. (2012)

Considering that the three found definition groupings add to one another, the last mentioned group can be considered to be the most comprehensive. Combining the definitions creates a comprehensive perspective of maturity models which allows for the full scale of benefits possible (for a more precise description of these benefits see Section 3.1.4 Benefits of maturity models), therefore the following MM definition is considered the working definition for this thesis.

Working definition - Maturity Model:

> *A Maturity Model is a model which assesses the maturity of a specific domain based on a multitude of maturity levels, doing this can assist in decision-making and be used to guide, as well as monitor, the transformation process towards reaching an improved or fully mature state over time.*

3.1.3 Maturity Model Types / Approaches

Not all maturity models are created the same, as indicated in the previous section. In fact, MMs can be applied to a wide variety of application domains. However, the models themselves and the approach to building such models can vary heavily as well. This section will explore the various MM types and approaches found in the literature. This is done to explore the possibilities for the development of a new MM for EAM later on in Chapter 6.
Based on the 69 selected papers from the SLR, six different approaches to maturity modelling have been identified resulting in different MM types (see Table 6). In order to create a thorough understanding of what approaches one can take when building a maturity model and how these varying approaches differ, the following section will analyse the various MM approaches and types. Below, the topics are first listed in order of appearance, and hereafter individually addressed and explained in more detail.

Maturity model types and approaches:

I. Descriptive, prescriptive, and comparative maturity models.
II. Progression models, capability models and hybrid models.
III. Fixed-level maturity models and focus area maturity models.
IV. The continuous representation approach and the staged representation approach.
V. Top-down maturity modelling approach and bottom-up maturity modelling approach.
VI. Qualitative measures, quantitative measures and a combination of both.

I. Descriptive, prescriptive, and comparative maturity models:

The most broadly known and applied way to form categories of MMs is based on the distinction between descriptive, prescriptive and comparative maturity models.

These three approaches are explained by different authors in various ways, however for the purpose of this work, this thesis adopts the explanation as presented by Wißotzki and Koç (2013). We start with it because of its clarity and straightforwardness. These authors indicate that descriptive maturity models are used to assess the current state, the "as-is", whereas prescriptive maturity models not only assess the current "as-is" state but also recommend guidelines and best practices to achieve a higher level of maturity. Prescriptive models also offer guidance towards improvement (García-Mireles, Moraga and García, 2012). Translated in design principles, Puparambil and Baghdadi (2019) claim that descriptive design

principles are: *(1) the ability to assess criteria for each level and (2) a focus on a "target group-oriented assessment methodology.*" Whereas the design principles for prescriptive use are: *(1) presenting a course of action for improvement, (2) decision-making support to choose a course of action, and (3) a focus on "target group-oriented decision methodology*." *Lastly, comparative maturity models are capable of assessing multiple organisations (or sectors or regions) so one can compare similar practices to one another.* Hereby comparative models allow for internal and external benchmarking (Correia et al. (2017)). Wißotzki and Koç (2013) add to this description that "descriptive and comparative maturity models by nature only identify problems but neither describe how to solve those nor offer detailed guidelines and toolkits to support practical adoption. Hence, it is not possible to develop the observed attributes incrementally." Only prescriptive maturity models are capable of doing this.

Some sources only consider descriptive and prescriptive MMs. Out of the 17 sources exploring this topic, we observe that 6 belong to this group, see Reis, Mathias, and de Oliveira (2017), Van Looy, De Backer, and Poels (2012), Pulparambil, and Baghdadi (2019), Teichert (2019), Tarhan, Turetken, and Reijers (2015 and 2016). The majority of sources (the other 11 papers' authors identified in the SLR) do also recognise the comparative MM as an extra variation. This group consists of the following authors: Wißotzki and Koç (2013), García-Mireles, Moraga, and García (2012), Santos-Neto and Costa (2019), Albliwi, Antony, and Arshed (2014), Correia et al. (2017), Cosic, Shanks, and Maynard (2012), Röglinger, Pöppelbuß, and Becker (2012), De Carolis et al. (2017), Klötzer, and Pflaum (2017), Rapaccini et al. (2013), and Wißotzki, and Koç (2013).

In the current body of literature, one will mostly find descriptive maturity models (Pulparambil and Baghdadi (2019), Teichert (2019), Tarhan, Turetken, and Reijers (2015 and 2016)). Santos-Neto and Costa (2019), even go as far as saying that this discrepancy in the availability of prescriptive models is limiting the widespread use and practical application of maturity models that support organisational change management. Depending on the domain and needs of the MM user, it might be most beneficial to create or use a descriptive, prescriptive, or comparative MM.

II. Progression models, capability models and hybrid models:

Errandonea et al. (2022) take another approach to dividing maturity models. This approach was also adopted by Caralli, Knight, and Montgomery (2012) and is based on the division of maturity models into three categories: progression models, capability models and hybrid models. These models are explained by Errandeonea et al. (2022) as follows: *(1) progression models are focussed on assessing maturity (similar to the aforementioned descriptive maturity models), (2) capability models are focussed on defining capabilities to achieve an improved level of maturity (similar to the aforementioned prescriptive maturity models), and (3) hybrid models which combine the previously mentioned models as they asses maturity yet also reflect the capabilities needed to acquire to transition between maturity levels. Thus by doing so, hybrid models provide a roadmap towards evolving to a more mature state.*

III. Fixed-level maturity models and focus area maturity models:

The aforementioned article by Wißotzki and Koç (2013) additionally differentiates between fixed-level maturity models and focus area maturity models based on Van Steenbergen et al. (2010). Fixed maturity models are models with a set amount of maturity levels (commonly five), while focus area maturity models have no such limitations. In focus area maturity models the number of maturity levels is domain-specific and can vary. This is especially relevant in models that assess a diverse set of specific capabilities.

IV. The continuous representation approach and the staged representation approach:

Laue et al. (2014) and Pulparambil and Baghdadi (2019) present the concept of continuous and staged representation maturity models. Here they define the continuous representation maturity modelling approach as making use of “capability levels to improve processes of an individual process area or a group of process areas.” Whereas the staged representation approach uses “maturity levels which represent a pre-defined set of process areas and so describe a path for improvement for the entire organisation.” So the difference in these approaches can be found in the level of granularity of the model’s maturity levels.

V. Top-down maturity modelling approach and bottom-up maturity modelling approach:

How should a MM be developed and applied? According to Grube (2018), Santos-Neto and Costa (2019), and Mettler (2011) this can be done in two ways: bottom-up or top-down. According to Grube (2018), all sources strongly indicate that the implementation of a MM (in the context of Grube's research, this focuses on a BPM maturity model) should be accomplished by senior management in a top-down approach. Grube (2018) argues that only by doing it this way the MM will get the support needed for a successful application. Grube (2018) adds to this that a bottom-up approach would be possible, but significantly more difficult to achieve. Santos-Neto and Costa (2019) elaborate more on the process itself instead of focusing on the executing party and state that in a top-down approach the maturity levels are first defined and subsequently evaluation items related to the maturity levels are defined. Whereas, in a bottom-up approach the evaluation items are defined first and afterwards the maturity levels are developed. The top-down approach would function best in relatively new and unversed domains, whereas the bottom-up approach would be best suited in a more explored and mature domain.

VI. Qualitative measures, quantitative measures and a combination of both:

Santos-Neto and Costa (2019), Guédrai, Naudet, and Chen (2013), Leal, Panetto, and Lezoche (2016), and Guédria, Naudet, and Chen (2013) further elaborate on the different ways one can categorise MMs. These authors focus on the type of measurement. They find that MMs can also be categorised along the dimension of the type of observations they use to assess maturity and the definition of variables they account for. In this respect, three different categories of models are recognised, MMs using (1). *qualitative observations*, (2). *quantitative measures*, and (3). *a combination of both qualitative observations and quantitative measures*.

The most widely used assessment type is the qualitative observation according to Guédria, Naudet, and Chen (2013). In a qualitative approach, the assessment is made by considering subjective assessment criteria; one matches a specific maturity level to a certain level of interoperability. Whereas a quantitative approach assessment is done through characterisation by numerical values which represent the assessed entity.

To summarise, there are various approaches one can adhere to whilst creating a maturity model. A clear overview of the various options one can adopt is presented in Table 6, presented on the next page.

Table 6. Overview - Maturity Modelling Approaches

No.	Maturity Modelling Approach			Description
I	Descriptive	Prescriptive	Comparative	● Descriptive MMs describe the "as-is" state of a single organisation. ● Prescriptive MMs describe not only the "as-is" state of a single organisation but also outlines guidelines for achieving a higher level of maturity. ● Comparative MMs are capable of assessing multiple organisations to compare them to one another, comparative models allow for internal as well as external benchmarking.
II	Progression	Capability	Hybrid	● Progression MMs are focussed on assessing maturity. ● Capability MMs are focused on defining. capabilities to achieve improved levels of maturity. ● Hybrid models assess current maturity yet also provide a roadmap towards an improved level of maturity.
III	Fixed-level	Focus area		● Fixed-level MMs have a set amount of maturity levels (for all assessed dimensions). ● Focus area MMs have no such limitations and the amount of distinctive maturity levels may vary depending on the assessed dimension.
IV	Continuous representation	Staged representation		● MMs with a continuous representation are used to improve/mature the capability of specific processes within an organisation. ● MMs with a staged representation are used to improve/mature the organisation as a whole.
V	Top-down	Bottom-up		● In a top-down approach, the maturity levels are first defined and subsequently, evaluation items related to the maturity levels are defined. ● In a bottom-up approach, the evaluation items are defined first and afterwards the maturity levels are developed.
VI	Qualitative	Quantitative	Combination of qualitative and quantitative	● In qualitative MMs the assessment is solely done by considering subjective criteria and matching them to specific maturity levels, according to the level of interoperability. ● In quantitative MMs the assessment is solely done by evaluating which numerical values represent the assessed entity and which maturity level matches certain numerical values. ● Some MMs use a combination of qualitative and quantitative inputs for assessing maturity.

3.1.4 Benefits of maturity models

After expressing the working definitions for maturity and maturity models, as well as describing various maturity model categories, this section will focus on answering the question: *Why should one use a maturity model?* To answer this question the present section reports the (potential) benefits of using a maturity model as described in the 69 documents selected in the SLR. After first giving a more detailed description of the, by authors, expressed benefits of MMs, an overview will be given at the end of this sub-section that summarises all findings (see Table 7).

According to Sauni et al. (2022), Olszak (2016), and Patríco and Almeia (2012), MMs lay a solid foundation for incremental, controlled and sustainable improvement towards best practices in the respective domain the MM concerns itself with. Kampker et al. (2018) and Olszak (2016) add to this that maturity models enable the development of a digital roadmap customised specifically for the organisation in question, this can effectively help in introducing new concepts and facilitate transformations. In the context of asset management, maturity models do not only allow for identifying competencies and best practices in a structured and repeatable manner, but they also give insight into the current capacity of an organisation to manage its assets (Mahmood et al., 2015). Mong et al. (2021) compare a ternary of performance improvement models (the balanced scorecard, EFQM Excellence Model and maturity model) and emphasise a maturity model's capability of "providing assessment, improvement, and comparison for better results and value to the organisation". Furthermore, it notes that maturity models can assist in effective and strategic management.

Cornu et al. (2012) list several benefits from the perspective of deployment by managers. They state that maturity models help managers identify weaknesses, make clear initial assessments and monitor progress, help in decision-making through prioritisation and support gradual improvement. Mehairjan et al. (2016) also focus on a maturity model's ability to monitor progress but also emphasise the benefit of maturity models as a way to provide a common language and a discussion starter.

All in all, this section presents various views by the authors of the papers included in our SLR on how the creation and application of effective maturity models can be of important use for organisations to assess, control, monitor, guide, prioritise, and improve their maturity in a specific domain. A clear overview of the various potential benefits mentioned above is reiterated in a summarised manner and displayed in Table 7 below.

Table 7. Overview of MM Benefits

Group description	Potential benefits of using a MM	Source
I. Improvement Roadmap	Can function as a roadmap to effectively introduce new concepts and facilitate incremental, controlled and sustainable improvement towards an improved or best practice in a specific domain.	• Sauni et al. (2022) • Olszak (2016) • Patríco and Almeia (2012) • Kampker et al. (2018) • Olszak (2016)
II. Gain insight into capacity and capabilities	Can assist in gaining insights into an organisation's current capacity and capabilities.	• Mong et al. (2021) • Mahmood et al. (2015) • Cornu et al. (2012)

III. Aid in decision-making	Can help (management) with decision-making by identifying weaknesses and providing prioritisation. This can assist in effective and strategic management.	• Mong et al. (2021) • Cornu et al. (2012)
IV. Comparisons	Can give insight into how organisations perform compared to other organisations / competitors.	• Mong et al. (2021)
V. Monitoring progress	Using a MM can enable an organisation to monitor progress over a certain period of time.	• Mehairjan et al. (2016) • Cornu et al. (2012)
VI. Common language	A MM can function as a common language to initiate a discussion.	• Mehairjan et al. (2016)

3.1.5 Shortcomings of (existing EAM) maturity models

The authors of the papers included in this SLR indicate that maturity modelling also comes with several challenges. These challenges, if not handled with care, may hinder effective usage and obstruct reaping the full potential reward of applying maturity models. These challenges then may result in shortcomings in the created MM, as illustrated in the selected 69 papers from the SLR presented below.

Wißotzki and Koç (2013) and García-Mireles, Moraga, and García (2012) identify a problem with the development of maturity models as they find that oftentimes maturity models are developed without being backed by a clear structure or methodology. This methodological challenge affects the quality of the MM creation process. Furthermore, Wißotzki and Koç (2013) and García-Mireles, Moraga, and García (2012) add to this that the development process of MMs itself is also oftentimes poorly documented, which affects MM quality. The lack of a clear structure and documentation for methodology and the MM development process is especially prevalent when focussing on the development process of maturity levels in the SLR. Often, papers do explain how the maturity levels should be interpreted and what source(s) they took inspiration or adopted the maturity levels from. However, the reasoning behind choosing specific maturity levels from a certain source oftentimes remains undisclosed. Also, ideally, when authors describe maturity levels, they would be able to provide empirical evidence for the link between the proposed maturity (levels) and the (associated) performance. However, a clear and structured report on empirical tests for evaluating the maturity-performance link is rarely found in the literature on MMs. Schiele (2007) presents an exception to this.

According to Becker, Knackstedt and Pöppelbuß (2009), it is to be expected that authors use maturity levels inspired by or adopted from previous MMs. Because the descriptions of individual maturity degrees can often be partially or even fully applied when using existing MMs as a starting point for the design process of a new MM since they cover the same relevant problem domain. Regardless of the approach taken, it is important to clearly document the steps taken as neglecting this negatively influences the repeatability of the conducted research.

Furthermore, Mahmood et al. (2015), Albliwi et al. (2014), and Sauni et al. (2022) state that even though there is a wide variety of maturity models with numerous application areas, most models fall short in considering all organisations as a whole. Most models fail to consider the broader organisation and address topics such as strategy, policy, governance and human resources in the context of asset management. Most existing MMs solely focus

on the evaluation of operational and technical levels of mainly asset management of physical assets. Mahmood et al. (2015) give some examples of domain-specific overarching and sometimes external factors that are overlooked. For example, in the context of EAM, environmental factors or community demand management.

Wißotzki and Koç (2013) identify that a lot of models are capable of describing the gap between actual and intended organisational design, however, are unable to illustrate how to fill or solve this gap. This relates to the previously identified lack of prescriptive maturity models and thus the inability to observe attributes incrementally as identified by Pulparambil and Baghdadi (2019), Teichert (2019), Tarhan, Turetken, and Reijers (2015 and 2016), and Santos-Neto and Costa (2019).

Another methodological issue is addressed by Pöppelbuß et al. (2011). They indicate three general shortcomings for the application of maturity models: "*(1) vastness of theoretical research, (2) an empirical assessment of maturity levels and (3) the lack of one linear sequence for development in practice.*" In line with the challenge concerning the empirical assessment of maturity levels, García-Mireles, Moraga, and García (2012) identify a lack of MM evaluation regarding validity, reliability, and generalizability. Mehairjan et al. (2012) also have identified the challenging nature of translating the goals of certain domains into varying maturity levels.

Moreover, Guédria, Naudet, and Chen (2008) express their concerns about most maturity models insufficiently addressing the potentiality of interoperability by exclusively accounting for a single facet of interoperability. Likewise, Wißotzki and Koç (2013) are concerned with maturity models not being flexible enough to keep up with managing changes whilst adhering to certain quality improvement principles.

Wendler (2012) points out another point of critique: the trend of researchers to, oftentimes, choose to create a brand new MM instead of first searching for suitable existing models to use, improve, extend or validate. This results in a high number of conceptually developed maturity models without any empirical validation. If proposed MMs lack empirical performance tests, this can cause a multitude of undesirable consequences as also pointed out by Pöppelbuß et al. (2011) and García-Mireles, Moraga, and García (2012). By developing a MM only conceptually, the authors may overlook relevant aspects one would encounter in practice and, subsequently, may derive inaccurate or incorrect conclusions by doing so. Not conducting empirical tests limits the validity, reliability and generalizability of the proposed MMs. And the trend of creating new conceptual MMs, without building upon previous empirically evaluated works, may slow down or even stifle scientific progress in the domain. One could even argue that this lack of empirical tests is especially detrimental in the field of maturity modelling, considering that a large number of the produced / proposed MMs are part of grey literature, which already poses quality control concerns in and of itself due to the scarcity of peer-reviewed articles.

All in all, this section showed various examples of shortcomings and pitfalls one can encounter whilst building a maturity model, as illustrated by the authors from the (69 papers in the) SLR. This is done to be mindful of them going forward during the development of the MM for improved EAM.

Table 8. Overview - Shortcomings of (existing EAM) MMs

Group	Shortcomings of (existing EAM) MMs	Source
I	Lacking a clear structure, documentation and / or methodology on the creation process. (This becomes especially prevalent when focusing on how maturity levels for MMs are chosen).	• Wißotzki and Koç (2013) • García-Mireles, Moraga, and García (2012)
II	MMs on EAM oftentimes fail to take into account the broader organisation as a whole and only focus on the evaluation of operational and technical levels of mainly physical asset management.	• Mahmood et al. (2015) • Albliwi et al. (2014) • Sauni et al. (2022)
III	MMs are oftentimes capable of describing the gap between actual and intended organisational design, yet unable to depict how to fill or solve this gap.	• Wißotzki and Koç (2013) • Pulparambil and Baghdadi (2019) • Teichert (2019) • Tarhan, Turetken, and Reijers (2015 and 2016) • Santos-Neto and Costa (2019)
IV	A lack of empirical assessment and evaluation. A number of conceptually developed maturity models lack empirical evaluation / validation. Authors often opt for creating new MM instead of using, improving, extending or validating already existing MMs.	• Pöppelbuß et al. (2011) • García-Mireles, Moraga, and García (2012) • Wendler (2012)
V	Challenging nature of translating the goals of certain domains into varying maturity levels.	• Mehairjan et al. (2012)
VI	Often maturity models insufficiently address interoperability by exclusively accounting for a single facet of interoperability.	• Guédria, Naudet, and Chen (2008)
VII	Maturity models often are not flexible enough to keep up with managing changes whilst adhering to certain quality improvement principles.	• Wißotzki and Koç (2013)

3.2 RQ2: What maturity model characteristics are suitable for the proposed (new) maturity model on EAM?

Considering all the definitions and MM approaches/categories described previously, as well as the respective benefits and challenges of maturity models, we now will discuss the decisions made for the new MM for improved EAM. It should, however, be noted that the chosen practices and approaches here cannot be considered the best suitable for all maturity model applications but solely best fitting for the context of this thesis: taking time and resource constraints into account.

First, to build any suitable MM it is of great importance to define the key concepts of maturity and maturity models to have a clear starting point of the meaning of these terms in the context of this research. To recapitulate, after considering all 69 papers included in the SLR the following definitions are used in the context of this thesis:

Working definition - Maturity:

> *Maturity is the dynamic state which indicates how explicitly defined, managed, controlled and effective a process is. This state is dynamic and can improve/progress in various ways to reach the final mature state. The final mature state is considered to be complete and perfect.*

Working definition - Maturity Model:

> *A Maturity Model is a model which assesses the maturity of a specific domain based on a multitude of maturity levels, doing this can assist in decision-making and be used to guide, as well as monitor, the transformation process towards reaching an improved or fully mature state over time.*

For the context of this thesis, the following choices regarding the various MM types/approaches are made: *the MM will be descriptive in nature*. This choice was made because it fits the goal of the MM, as the goal is to assess the current state of EAM in organisations from a comprehensive view. Prescriptive models would also guide the assessed organisation towards an improved maturity state, but building a MM prescriptive in nature is outside the scope of what is feasible in the timeframe of this thesis.

Concerning the choice between a fixed-level MM or a focus area-oriented maturity model: the literature does not reflect a clear choice as to which is more suitable. For the creation of the MM in the context of this thesis, it is my personal intention to *adhere to a staged representation* as described by Laue et al. (2014) and Pulparambil and Baghdadi (2019). This choice is made as it is to be expected that, with the help of experts, it will be possible to achieve an adequate level of granularity and this will increase the repeatability of the MM.

Due to the extensively available literature and the, if needed, accessibility of experts in the field of EAM, *a bottom-up approach is chosen for building the maturity model*. As this approach is best suited for an explored and mature domain according to Santos-Neto and Costa (2019), and as the scope of this research does not include the implementation of the maturity model, we decide against a top-down approach as suggested by Grube (2018). In this bottom-up approach, we first define the evaluation elements and subsequently decide on the appropriate maturity levels.

Although quantitative measures can, for some criteria, more accurately assess maturity, the choice was made to *focus on qualitative measures* instead. This choice was made to be as inclusive as possible for the application of the MM in asset-intensive organisations. As some organisations may not have access to extensive quantitative measurements of their business processes. Furthermore, many (intangible) assets are hard, if not infeasible, to quantitatively describe.

Moreover, to garner as much of the beneficial effects described as possible from the MM an emphasis is put on correctly handling the presented pitfalls and shortcomings. Firstly, the lack of a vast theory-backed clear structure and methodology (as described by Wißotzki and Koç (2013) and García-Mireles, Moraga, and García (2012), and Pöppelbuß et al. (2011)) is handled by basing the MM development on an extensive SLR as described in Chapter 2 and 3 and documenting the development process in detail. Secondly, to address the concerns of Mahmood et al. (2015), Albliwi et al. (2014), and Sauni et al. (2022) concerning the failure to consider all aspects of EAM, a potential new MM should be based on a variety of existing models and should be validated by several experts in the field. This is done to attempt to address gaps found in the comprehensiveness of the model. Furthermore, Wendler's (2012)

concerns regarding the trend of researchers creating new maturity models without considering using, improving and extending existing models are also addressed by the development approach of combining already existing models.

Besides the considerations from the SLR, some personal restrictions that influence this thesis and the MM creation process should also be taken into account / acknowledged. Due to the time restrictions associated with the making of this thesis, it will not be possible to address the pitfall pointed out by Pöppelbuß et al. (2011) and Wendler (2012) of not validating the MM with empirical evidence or empirical performance tests through case studies. The MM, however, will be evaluated by experts in the field of EAM to evaluate the MM not solely by literature but also in a practical setting. This pitfall will be addressed again in the future of work section of the discussion (see Chapter 7.4).

3.3 RQ3: What is enterprise asset management?

RQ3 posed in this thesis concerns itself with the second major topic besides maturity models: enterprise asset management (EAM). This topic is explored with a similar approach as the MM topic. First, an exploration of the topic, based on the 69 sources from the SLR, is presented. Here various sub-themes related to EAM are addressed. This is done to answer the question: what is enterprise asset management? The following sub-themes are addressed (in order of appearance):

1. *Defining enterprise asset management.*
2. *Benefits of enterprise asset management.*
3. *Shortcomings of enterprise asset management.*

3.3.1 Defining enterprise asset management

Enterprise asset management (EAM), often also referred to as simply asset management (AM), takes a holistic view of the entire lifecycle management of an organisation's assets. The concept of EAM has been used in public and private sectors, with varying interpretations and levels of understanding (Khaliq, Mahmood, and Das, 2016). Many of the leading asset management organisations experience difficulties in optimizing their asset performance (Woodall, Parlikad, and Lebrun, 2013). This can be caused by a wide range of issues, for example, due to improper planning, poor information quality management (IQM), or the implementation of ill-advised maintenance strategies. In the pursuit of optimizing the performance and life cycle of an organisation's assets, EAM emerged.

But what does the topic of EAM encompass? In this section, we will consult a wide range of sources from the SLR on this matter and give a comprehensive overview of the current state of the art in the field of EAM.

Before being able to consider this question in detail, another question arises: what is considered an asset? The answer to this question varies amongst authors. Alì et al. (2013) define an asset as “any type of element which contributes to the enterprise activity.” Nurmukhamet and Tick (2022) refer to an asset as “any valuable item possessed by a company”. They elaborate on this by claiming that assets can be tangible and intangible, furthermore, they explain that considering an asset's lifecycle, the economic value of an asset is spread over time. The British standard even goes as far as saying that an asset does not have to have value itself but is considered an asset an “item, thing or entity” which

has the potential to be of value to an organisation. Lastly, the definition of an asset given in the ISO55000: 2014 Asset Management book describes their definition of an asset in even more detail. Their description is very extensive and inclusive and will for this reason be adopted as the working condition of what an asset is, in the context of this research.

Working definition - Asset:

> *"Item, thing or entity that has potential or actual value to an organisation. Note 1 to entry: Value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities. It can be positive or negative at different stages of the asset life."*

- International Organization for Standardization (2014)

To clarify what is meant by tangible and intangible assets in this context, take for example a property or product of an organisation; this is considered a tangible asset. Whereas for example intellectual property or branding is considered to be an intangible asset, as it does hold value but it does not have any physical presence.

With this definition of an asset in mind, let us now consider the definition of EAM. The current market leader in enterprise application software: Systems, Applications & Products in Data Processing (SAP)[6] defines EAM as follows:

> *"Enterprise asset management (EAM) incorporates the management and maintenance of physical assets owned by a company throughout the entire lifecycle of an asset, from capital planning, procurement, installation, performance, maintenance, compliance, risk management, through to asset disposal."*

Although the definitions presented in the literature on EAM are mostly very similar to the one of SAP, there is an ongoing discussion on how far the scope of this topic should reach. Some authors argue that EAM is confined to only physical assets (SAP is part of this group as presented by the definition above), whereas others believe aspects such as intellectual property and human resources are also aspects that should be considered under the EAM umbrella. In this section, we will explore the various perspectives on what EAM is and how far certain authors believe the scope of EAM reaches. Finally, a working definition is decided on for EAM in the context of this thesis.

Khaliq, Mahmood, and Das (2016) present their used definition of EAM by first defining what they consider to be an asset. To explore this topic they present the definition of an asset according to the British Standard (2014) which defines an asset as "An item, thing or entity that has potential or actual value to an organisation." Regarding the definition of EAM, they present two definitions. The first of which is stated by the British Standard (2014), which defines it as the "coordinated activity of an organisation to realize value from assets." This definition was adopted by Woodall, Parlikad, and Lebrun (2013) as well. The second presented definition is by Tor and Shahidehpour (2005), their characterisation elaborates further on the topic by stating that "asset management is a process of attaining, utilisation and removal of assets to make the best out of it in terms of cost and output without compromising on risks involved during their whole life cycle." Khaliq, Mahmood, and Das (2016) warn about confusing EAM with portfolio management, as they consider bonds and stocks to fall outside the scope of EAM. Moreover, they differentiate between short-term asset management (which concerns operational issues), mid-term asset management (which concerns the maintenance of systems assets), and long-term asset management

[6] https://www.sap.com/insights/what-is-eam.html

(which concerns the strategic planning of distribution systems). Within these distinctions of timeframes, Khaliq, Mahmood, and Das (2016) have identified a list of key process areas. These represent groupings of activities for enhancing process capabilities. The key process areas consist of *(1) Asset policy, (2) Asset planning, (3) Asset creation and acquisition, (4) Asset disposal, (5) Environmental analysis, (6) Asset operations, (7) Asset maintenance, (8) Risk management, (9) Contingency planning, (10) Financial planning, (11) Capital expenditure, (12) Review of asset management system*. Similarly, Gökalp, Şener, and Eren (2017) also mention multiple key process areas, but in the context of asset management in Industry 4.0. They emphasise the *(1) IT system coverage of the organisation, (2) Technological readiness for Industry 4.0, (3) Adoption of emerging business technologies, and (4) Addressing smart technology security issues.*

Kortelainen et al. (2015) focus solely on physical assets in the context of EAM as they adopt the European Federation of National Maintenance definition, which states EAM concerns itself with: “the optimal life cycle management of physical assets to sustainably achieve the stated business objectives.” Similarly, Fouladgar et al. (2012) also solely focus on physical assets in their definition of EAM but emphasise the importance of decision-making in equipment management and operations. The definition by Deghanian et al. (2012) is mostly in line with the aforementioned definitions, however, due to the context of the paper (critical components in power distribution systems) highlight the need for being able to guarantee predefined service and security standards. Furthermore, Kortelainen et al. (2015) emphasise the importance of how data, collected in various information systems such as enterprise resource planning (ERP) and computerized maintenance management systems (CMMS) can be used to improve operational efficiency and help with investment decision-making. Aleksandrova, Vasiliev, and Letuchev (2018) consider EAM systems to be a “logical development of CMMS” and regard EAM as “a process equipment accounting and equipment maintenance and repair management system focused on reducing equipment maintenance costs and improving productivity.” In line with this focus on optimizing asset performance, Patríco and Almeia (2021) emphasise asset-related decision-making with a risk-based approach. Similarly, within the scope of EAM, Mehairjan et al. (2012) state, it is crucial for asset performance, and improved operative decision-making to implement effective and efficient maintenance and inspection strategies. These definitions are all articulated slightly differently but accentuate the need for taking risks into account for effective decision-making for efficient EAM.

Laue et al. (2014) believe that EAM should be embedded throughout an organisation’s time dimension (consisting of “*(1) strategic asset management and (2) operational asset management”), organisational dimension (consisting of “(1) technology and information management, (2) human factors management, and (3) organisational management*”) and spatial dimensions (consisting of “*(1) the management of the asset itself and the nearest environment; and (2) the management of the interaction of the asset with environmental factors*”). Amadi-Echendu et al. (2007) add another two dimensions to this: the statistical and measurement dimensions, but Laue et al. (2014) believe these are unnecessary for comprehensively characterising EAM. These views tend to be quite refreshing in the literature on EAM as they do extend their scope of EAM to some intangible assets. This view is seldom present but very relevant as intangible assets can also be crucial in an organisation's pursuit towards certain business goals. When considering the aforementioned BSI (2014) definition of an asset, we can see it does not exclude intangible assets, which they follow up on in their development of the PAS 55 framework: although PAS is primarily focussed on the management of physical assets they acknowledge that other categories of assets have a direct impact on the overall performance of assets. They even deem them critical to the success of optimised and sustainable asset management. Besides physical assets, PAS 55 also briefly pinpoints the importance of intangible assets such as leadership, motivation, culture, reputation, social impact, knowledge, communication, teamwork, and

experience. The acknowledgement of these critical but often overlooked EAM aspects should be considered to holistically approach the topic of EAM.

Considering all the aforementioned interpretations for EAM and how it should be implemented, managed and maintained, we see a diverse set of opinions. However, one clear distinction can be recognised: the authors either focus on solely physical/ tangible assets, whilst others consider the term asset to have a broader definition. These authors adopt a definition for the term “asset” either similar to or exactly from the International Organization for Standardization (2014). Table 9, presented below, reiterates this vital distinction and displays which authors adhere to which of these two groups.

Table 9. Overview of the interpretations for “EAM” from the SLR

Group	Definition focus	Source
I	EAM is concerned with the coordination of all activities that realize value from physical/tangible assets.	• Kortelainen et al. (2015) • Fouladgar et al. (2012) • Deghanian et al. (2012) • SAP (see https://www.sap.com/insights/what-is-eam.html)
II	EAM is concerned with the coordination of all activities that realize value from assets (as defined in the broad sense as set out by the International Organization for Standardization in 2014) for an organisation.	• Khaliq, Mahmood, and Das (2016) • Woodall, Parlikad, and Lebrun (2013) • Laue et al. (2014) • Amadi-Echendu et al. (2007)

Considering all the former stated definitions from the literature, several recurring aspects stand out. In favour of giving a comprehensive, yet clear definition of EAM the recurring aspects are included in the working definition, but too context-specific additional elements from other authors’ definitions are left out. For this working definition, we adhere to the previously stated working definition for an asset, as set out by the International Organization for Standardization (2014). Resulting in the following working condition of EAM for the context of this thesis.

Working definition - Enterprise Asset Management:

> *Enterprise Asset Management is the coordinated process of an organisation to cost-effectively monitor, manage and optimise asset performance throughout the whole life-cycle of the assets.*

3.3.2 Benefits of enterprise asset management

While some of the benefits of EAM have already been briefly touched upon, in this section a recap and a more elaborated view are given on why effective EAM can be crucial for organisations, this is especially relevant for asset-intensive enterprises.

Well-implemented and executed EAM will allow for improved decision-making and hereby improve productivity and enable extracting maximal asset performance by optimizing asset life cycles (Kortelainen et al., 2015). A well-implemented EAM system will enable the

improved transparency and visibility of an organisation's assets and asset-related activities, such as maintenance and inspection. Optimally, maintenance and inspection improvement plans are created whilst considering the organisation's goals, EAM will enable monitoring, control and align these plans and goals (Mehairjan et al., 2012). Pärn, Edwards, and Sing (2017) add that, if an EAM has a well-integrated Building Information Modeling (BIM) and Facility Management (FM), it can increase utility and data retrieval speed, enhance collaboration, visualise assets, increase asset lifespan and permit improve space/move planning.

Furthermore, it should be noted that EAM is widely applicable and thus can generate the aforementioned benefits for various sorts of assets. Although most of the authors from the SLR emphasise the application for mainly physical assets, for example, Laue et al. (2014) show that EAM can and should be embedded throughout the entirety of an organisation to reap optimal rewards. Laue et al. (2014) also touch upon the use cases for EAM for instance human factors. Moreover, environmental factors are considered (Laue et al., 2014; Bondarenke et al., 2018).

Bondarenke et al. (2018) even present some statistics EAM has the potential to achieve (in the context of oil and gas company property management). They state EAM can facilitate reducing maintenance costs by 25 to 30%, emergency work costs by 31% and equipment downtime by 20%.

The International Organization of Standardization lists a total of nine benefits that they consider effective EAM can realize, however, add to this that the benefits are not only limited to the mentioned benefits. The list of benefits includes: *(1). Improved financial performance, (2). Informed asset investment decisions, (3). Managed risk, (4). Improved services and outputs, (5). Demonstrated social responsibility, (6). Demonstrated compliance, (7). Enhanced reputation, (8). Improved organisational sustainability, and (9). Improved efficiency and effectiveness.*

A well-implemented and executed approach to EAM can help contribute significantly to an organisation's goals and success. Some of the more prevalent benefits from EAM, as mentioned in the SLR, are briefly touched upon in a summarised manner down below in Table 10.

Table 10. Overview - EAM Benefits

Group	Potential EAM Benefit	Source
I	Improved decision-making for asset utilisation / planning in line with overarching business goals.	● Kortelainen et al. (2015) ● Bondarenke et al. (2018)
II	Improved transparency and visibility of an organisation's assets.	● Mehairjan et al. (2012) ● Pärn, Edwards, and Sing (2017)
III	Improved asset value creation / asset performance throughout its entire lifecycle.	● Bondarenke et al. (2018) ● Pärn, Edwards, and Sing (2017)
IV	Enable accurate monitoring and control of assets.	● (Mehairjan et al., 2012) ● Pärn, Edwards, and Sing (2017)

All in all, the potential benefits of EAM are considered to be significant and therefore the implementation should be a point of focus for all organisations, especially those that are asset-intensive.

3.3.3 Shortcomings of enterprise asset management

The aforementioned benefits can, however, only be realized if the EAM approach is implemented and executed effectively. To achieve this, several pitfalls and shortcomings, as identified in the 69 papers from the SLR, need to be considered, avoided and/or overcome. This section will briefly touch upon a variety of these shortcomings. An overview of them is shown in Table 11.

First of all, good EAM is very dependent on the data available, therefore IQM is often a problem in EAM implementations (Kortelainen et al., 2015; Woodall, Parlikad, and Lebrun, 2013). Woodall, Parlikad, and Lebrun (2013) define IQM as a way for organisations to improve information quality “by implementing processes to measure, assess costs, of improve and control information quality.” This can be implemented by employing specific guidelines and educating staff on how to improve information quality.

Ho et al. (2015) elaborate on this issue as they state asset data are “often erroneous, lacking requisite detail and therefore not fit for decision support.” Alì et al. (2013) add to this that the data often is fragmented into several repositories and databases behave unreliably. Therefore, it is essential to consider data quality and data handling processes.

Another challenge mentioned by Kortelainen et al. (2015) is the alignment of an organisation's asset strategy with its respective strategic objectives. Monitoring performance indicators can help in addressing this challenge.

The size and complexity of EAM and all its corresponding aspects (such as presented in 3.3.2) become a challenge in itself for larger organisations (Khaliq, Mahmood, and Das, 2016; Cavka, Staub-French, and Poirier, 2017). Similarly, as complexity increases, interoperability also becomes a significant challenge (Kivits and Furneaux, 2013).

Jardine and Tsang (2013) identify further four shortcomings of (physical) EAM, described as (1) Emerging trends of operation strategies, (2) Toughening societal expectations, (3) Technological changes, and (4) Increased emphasis on sustainability. Brous, Janssen, and Herder (2020), accentuate the need for considerations in the cultural dimension for effective EAM. These authors emphasise that staff should be rewarded and can observe meaningful results to embed improvement behaviour in practice.

Mahmood et al. (2015) express their concerns for EAM implementations due to increasing concerns regarding (1) resource scarcity, (2) a degrading environment, (3) climate change, (4) more stringent regulations, and (5) a greater reliance on a multi-agency delivery model.

Table 11. Overview - Shortcomings of EAM approaches from the SLR

Group	Shortcomings of EAM approaches	Source
I	Lacking effective information quality management for the data supporting the implemented EAM approach.	● Kortelainen et al. (2015) ● Woodall, Parlikad, and Lebrun (2013) ● Ho et al. (2015) ● Alì et al. (2013)
II	Lacking alignment of an organisation's asset strategy with strategic objectives / goals.	● Kortelainen et al. (2015)
III	Lacking the ability to effectively manage the increasing complexity of a larger organisation's EAM. Which can cause interoperability issues.	● Khaliq, Mahmood, and Das (2016) ● Cavka, Staub-French, and Poirier (2017) ● Kivits and Furneaux (2013)
IV	A lack of accounting for emerging trends, changing external environments and societal expectations.	● Jardine and Tsang (2013) ● Mahmood et al. (2015)

So to conclude, although there is a lot to gain from a well-implemented EAM, there are several pitfalls and shortcomings that need to be overcome to achieve an effective EAM. Therefore being aware of these shortcomings is an important step towards avoiding or finding solutions for them.

4. The Methodology for Maturity Model Design

Previously the methodology of the conducted SLR has been covered in detail, in this section, the methodology for the creation of the MM for EAM will be explained in detail. This chapter will solely cover the methodology itself and not present the creation process as conducted during the work of this thesis – we note that our MM creation process will be presented later, in Chapter 5. For the approach of creating the new MM, the guidelines for MM creation, as set out by Becker, Knackstedt and Pöppelbuß (2009), are adhered to. The work of Becker, Knackstedt and Pöppelbuß (2009) builds upon the work of De Bruin et al. (2005) and it presents a theory-backed approach for creating and comparing MMs. De Bruin et al. (2005) presented a more generic framework of development phases for maturity assessment models, consisting of the following phases (in sequential order): *(1) Scope, (2) Design, (3) Populate, (4) Test, (5) Deploy, and (6) Maintain.* Becker, Knackstedt and Pöppelbuß (2009) elaborated on this design by formulating *six* MM development *requirements* which are spread over *seven phases*. This approach was created as a response to the – till that point mainly – insufficiently documented and non-methodically substantiated MM evaluation and creation. This framework has had a great impact on the research topic of maturity modelling and has been adopted by a large group of authors (for example, from the SLR of this thesis: Duque and El-Thalji, 2020; Wagire et al., 2020; Spruit and Pietzka, 2015; and Wißotzki and Koç, 2013).

The aforementioned framework by Becker, Knackstedt and Pöppelbuß (2009) consists of seven phases, these phases are described in sequential order below:

1. *Problem definition*
2. *Comparison of existing MMs*
3. *Determination of development strategy*
4. *Iterative MM development*
5. *Conception of the transfer and evaluation*
6. *Implementation of transfer media*
7. *Evaluation*

In the following sections, these steps will be individually elaborated upon. Per section, a description will be given of (1) what these steps entail generally and (2) how this will shape the MM creation in the context of this thesis. In Chapter 5 of this thesis: the actual results of these proceedings will be presented. This chapter is solely intended to explain the steps themselves and some of the reasoning behind them. Moreover, this thesis primarily focuses on the earlier phases of the framework, as due to time limitations the final phases will be outside of the scope of this research, nevertheless, an explanation will be given to be complete and to preliminary indicate potential future work. Furthermore, wherever applicable, the framework is supplemented with relevant theory on how these steps can be brought into practice.

4.1 Problem definition

During the problem definition phase, Becker et al. (2009), first off emphasise the need to identify the problem's relevance for researchers and/or practitioners. And secondly, they focus on the need for the problem to be defined, this is done by describing the prospective application domain, the conditions for its application and the intended advantages of the model before the start of the design.

The problem and its relevance, application domain and intended advantages have already been elaborated on within the introduction chapter of this thesis (see Chapter 1.1) but will be repeated here in a concise manner for clarity.

Problem statement
Firms can lose out on significant amounts of asset performance and thus capital by having a lacking or non-aligned approach to EAM.

Relevance of the problem statement
For scholars, this problem is relevant to address since the current literature has yet to realize a systematic and repeatable method for assessing EAM which comprehensively covers the topic, is backed by theory, and is evaluated by relevant practitioners.

For practitioners, this problem is relevant to address since organisations can gain in asset performance if they improved upon their EAM approach/practices.

Prospective application domain
While improving EAM is applicable and useful for all organisations, it is considered especially relevant for asset-intensive organisations as EAM becomes increasingly more complex the more asset-intensive an organisation becomes. The broad view presented in this MM is especially relevant for consultants identifying and evaluating those dimensions that are of interest for improving the maturity of the assessed organisation.

Conditions for application
To correctly apply the intended MM to an organisation, it is necessary to have all the relevant information needed to assess the various maturity dimensions and sub-dimensions, to accurately rate their maturity level. This may require a multitude of practitioners to evaluate the entire set of diverse dimensions presented in the MM. Depending on the type and size of the organisation the MM assessment may differ in usefulness/applicability, as the MM is most suitable for large, asset-intensive organisations.

Intended advantages
For a more extensive overview of the goal of this MM and the advantages one can gain with a maturity modelling approach, we refer readers to Chapter 1.2. To sum up: the MM is developed with the intention to enable organisations to extensively evaluate their current maturity levels regarding a comprehensive list of EAM dimensions/sub-dimensions. This will enable them to identify strengths and weaknesses in their EAM approach/practices and hereby support improved decision-making to guide the organisation towards improved maturity levels. This is done in pursuance of optimizing a firm’s asset performance.

4.2 Comparison of existing maturity models

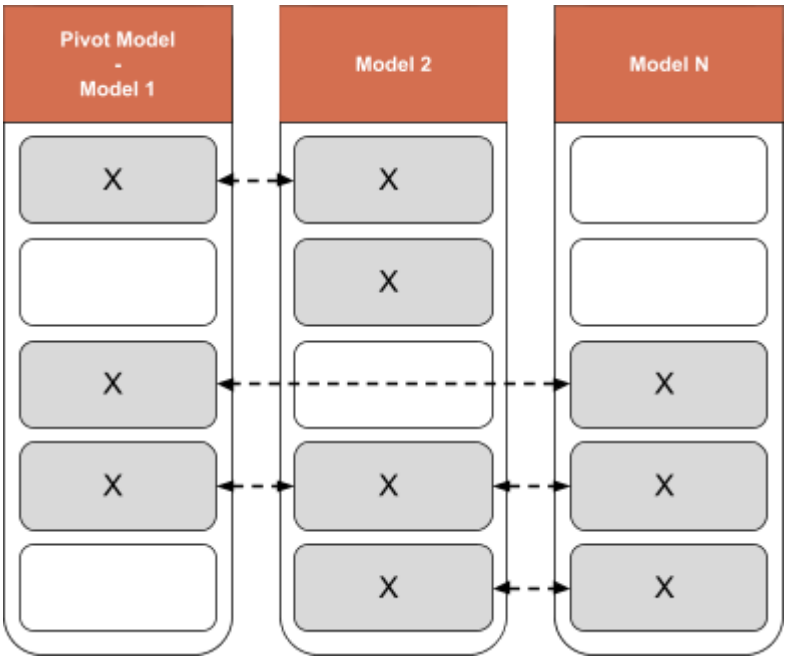
According to Becker, Knackstedt and Pöppelbuß (2009) one must first compare various existing models to assess the need for creating a new MM or if one can use or improve upon a previously developed MM. This phase is in preparation for the decision of the development strategy in phase 3 and focuses on analysing related works. This phase takes place with the help of the previously described SLR, specifically, the results of the queries that combine the topics of MMs with EAM are used. As a result of these queries, a list of MMs related to the topic of EAM has been created. These are then analysed and considered in full on their relevance and utility. A final selection is made by applying inclusion/exclusion criteria.

To validate if an existing model does already fully suffice the intended goal of the MM envisioned in this thesis, the four-step approach for comparing MMs by Lautenschutz et al. (2018) is used. Depending on the outcome of this comparative analysis, the development strategy will be determined. The approach of Lautenschutz et al. (2018) includes these steps:

1. *Conduct a SLR of related MMs.*
2. *Create a construct diagram to evaluate the identified models and create a metamodel.*
3. *Select a pivot model to compare to.*
4. *Compare the models systematically to identify common and unique constructs.*

In this process, it is irrelevant which model is chosen in step three as the pivot model, as it solely serves the purpose of being compared too. The choice of which model to use as a pivot model does not influence the eventual outcome, however, it is most convenient to choose the most extensive/complete model as a pivot model as it will simplify the process of step 4: comparing the model systematically. Step four is crucial. In this step, the selected models are compared to identify commonalities and/or unique constructs present in the various models. An illustration of what this comparison will look like is illustrated below in Figure 6, this example is representing the model comparison (in the case that no one single model already represents all dimensions/sub-dimensions).

Figure 6. Illustration of the systematic comparison of MMs



4.3 Determination of development strategy

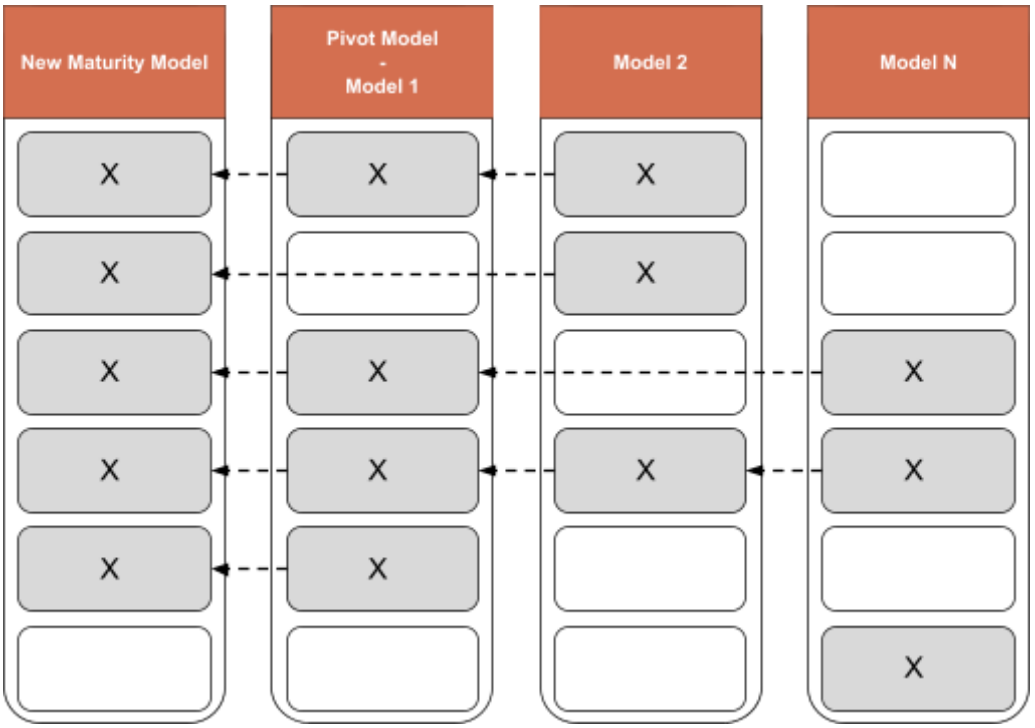
As mentioned above, this phase is closely related to the previous phase. Based on the comparison made in the previous phase, the decision is made if one or multiple MMs in the literature already suffice the goal set out for the envisioned MM in this thesis. If this turns out to not be the case, a decision will need to be made to either construct a completely new MM or improve upon the existing MMs by combining already existing models.

If the creation of a new model is desirable, the creation process is best conducted by qualitative content analysis considering no standardized terminology is used across MM on EAM. One can go about this process in two different ways: employing deductive reasoning or inductive reasoning. Applying deductive reasoning is best suitable if the new model intends to further describe the dimensions/sub-dimensions in a more detailed description. Whereas, deciding on an inductive reasoning approach will be best to combine more detailed descriptions to create a more generalized description.

Considering the intended goal of creating explorative and inclusive MM to assess an organisation's EAM maturity, the model creation process will take an inductive reasoning approach. This approach will result in the creation of an overarching MM which will be built up by generalized dimensions based on previously identified MM commonalities, yet will also include unique constructs if considered to add to the inclusive nature of the new MM.

The illustration process is illustrated below in Figure 7. As one can see, in rows one, three and four, the new model includes a dimension/sub-dimension by absorbing inputs from other models (in a generalized manner). However, the model may also include unique dimensions/sub-dimensions if deemed beneficial for the explorative and inclusive nature of the model (see rows two and five for example). But there can be made exceptions, see the last row. Here the dimension or sub-dimension is not included in the new model, this can occur if a dimension or sub-dimension is deemed too industry/sector/application specific. These will not be added to the new model as they will not be relevant or even applicable when applied to other industries, thus causing the model to lose its explorative and inclusive nature.

Figure 7. Illustration of the MM creation process



4.4 Iterative maturity model development

In line with the framework of Becker, Knackstedt and Pöppelbuß (2009), the development of a MM must be done iteratively. In this iterative loop, one goes through the phases of selecting a design level, selecting a development approach, selecting a design model, and testing your results to see if they are satisfactory, if this is the case move on to the next phase, if not, restart the cycle.

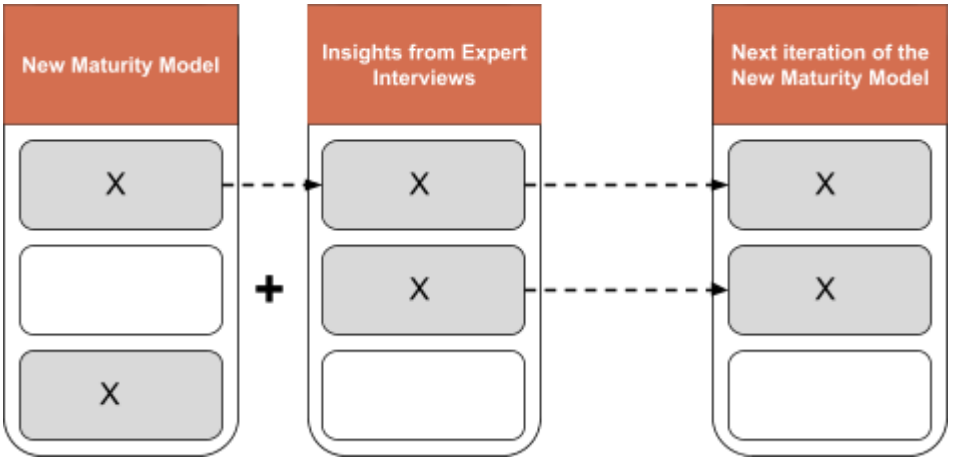
This iterative MM development process takes place by evaluating and, based on the feedback gathered, adjusting/improving the MM based on expert (semi-structured) interviews. This choice was made because the evaluation of the MM will require posing close-ended and multiple open-ended questions. Furthermore, some questions require potential follow-up questions to gain a deep understanding of what is meant by the various individual interviewees. This approach fits the strengths of a semi-structured interview method best (Adams, 2015). Furthermore, due to the collaboration with Pernino Consulting, access to experts in the field of EAM (internal and external) is available. This valuable source of knowledge should not be left unutilised as it is a valuable source for extending, improving and evaluating the literature-based MM. It will also add to the validity of the model as this way extensive, in practice grounded, inputs will be considered during the creation of the MM.

The semi-structured interviews will take place in a workshop-style meeting, where first some background information and the model itself will be presented, and then a survey will be filled out individually. Finally, the meeting will end up with an open discussion to gain a more detailed perspective on certain questions and to facilitate deliberation between participants. The full presentation and the outcome of these meetings will be presented and analysed in detail in Chapter 5.

It should be noted, however, that semi-structured interviews do have several drawbacks as well, for example being very time and labour-intensive. Furthermore, they require a tactful interviewer. To conduct effective and useful semi-structured interviews the guidelines as described by Adams (2015) are considered throughout the entirety of the interview process. From the preparations, the interview itself, to the analysis of the interviews afterwards. Furthermore, the beforehand set-up evaluation questions in the survey/questionnaire are created with the UTAUT model in mind (Venkatesh et al., 2003). These questions give insight into the performance expectancy, effort expectancy, social influence and facilitating conditions associated with using the proposed new MM for EAM.

These interviews are intended to add to the MM development in two ways, first, by identifying and potentially adding previously unidentified gaps in the model and second by evaluating the relevance of the dimensions and sub-dimensions of the created model dimensions and sub-dimensions from a practical perspective, this may even result in removing dimensions or sub-dimensions from the previously created model. This process is illustrated below in Figure 8. In the first row, the presented aspects in the created MM are confirmed by the experts and therefore included in the next iteration of the MM. In the second row, the discovery of unidentified gaps in the model by experts is illustrated, these newly identified aspects are also included in the next iteration of the MM The last row represents the scenario where an aspect is represented in the MM but deemed irrelevant by experts, because of this feedback from the experts the decision is made to not include them in the MM going forward.

Figure 8. Illustration of the evaluation/adaptation of the MM by expert interviews



4.5 Conception of the transfer and evaluation

During the conception of the transfer and evaluation phase, the MM development process focuses on the development and evaluation of the MM by employing one of several well-founded research methods (Becker, Knackstedt and Pöppelbuß; 2009). García-Mireles, Moraga, and García (2012) suggest that one could use various of these research methods, among others: case studies, card-sorting workshops, and an analytical hierarchy process. We make the note, however, that evaluating the practical application of the created model in a real-world context is considered to be outside of the scope of the timeline of this thesis. Instead, there will be a perception-based evaluation study with experts concerning the perceived usefulness and the applicability of the proposed MM in this thesis.

4.6 Implementation of the transfer media

The implementation of the transfer media phase in the MM development procedure concerns itself with making the MM and its transfer media accessible to the, earlier decided-upon, targeted user group (Becker, Knackstedt and Pöppelbuß, 2009). This phase, however, is also outside of the scope of this thesis.

4.7 Evaluation

Lastly, in the final phase of the MM development procedure by Becker, Knackstedt and Pöppelbuß (2009) the model is evaluated. This evaluation is concerned with all principles and premises of the development but also extends itself to evaluating the usefulness, quality and effectiveness of the model. Overall, the evaluation will establish if the MM can provide the intended advantages to the respective application domain it was designed for. If during the evaluation phase, it turns out the developed MM is in any way insufficient, another iteration of the development process should be initiated or the model should be rejected. If the model is sufficient and up to standard, the model development procedure is ended. However, evaluating the MM in all its facets is outside of this thesis's scope.

5. Development of the maturity model

With the approach for achieving the intended goal of this thesis described in detail in Chapter 4. Maturity Model Methodology, it is now time to start assessing if a previously created MM already satisfies the set-out vision or if the development of a new MM is desirable. Presented below are all steps described in the methodology chapter, yet now their respective outcome is described as utilised during the MM development process.

5.1 Problem definition

The problem definition has previously been described in detail, please see Chapter 1.1 and Chapter 4.1. However, for legibility, the problem statement will be briefly reiterated here. The problem statement for this MM is defined as follows: firms can lose out on significant asset performance and thus capital by having a lacking or misaligned approach to their EAM. To combat this issue the EAM in an organisation should be assessed and where applicable plans for improvement should be made and implemented. The envisioned MM will create an explorative and inclusive overview for organisations to discover their EAM approach's strengths and weaknesses. This should help with decision-making towards an improved EAM approach. The new MM should be able to assess a broad range of EAM topics, be created in a theory-backed and well-documented manner and be evaluated by experienced practitioners in the field of EAM.

5.2 Comparison of existing maturity models

The comparison of existing MMs serves as a preparation for the MM development process as it assesses if there is the need for creating a new MM and if so if this can be done by improving upon previous work or should be started from scratch. To determine this, one first identifies relevant related works. These works are identified, described, analysed, compared and grouped in the following sections. In this thesis, this process is shaped by the four-step model for comparing MMs as described by Lautenschutz et al. (2018). The following sub-sections describe these steps and how they have been executed in detail.

5.2.1 SLR of related maturity models

To explore if existing models already suffice in the intended goal of the MM of this thesis, first a SLR of related MMs is conducted. For the process of identifying related MMs in the academic literature, the third SLR query group is used. This query group combined the topics of MMs and EAM. The exact queries used, the number of results generated from these queries and the inclusion and exclusion criteria for selection are described in Chapter 2.2 and Appendix A.

As a result of this SLR (and the process of snowballing where deemed necessary), a total of 18 different MMs were found. This selection of MMs displays the diverse approaches authors take when assessing an organisation's EAM approach. Furthermore, it displays the various domains/industries where EAM MMs can be of help. To prepare for the exploration of these MMs, the models were first analysed and described in more detail. This started by

listing the models and their sources (as can be found in Appendix D, Table D.1), then creating a brief text-based description of the various MMs (as can be found in Appendix C), and lastly by giving a more detailed overview in the form of a table describing the MMs' basic descriptive information, title, authors, year, research content, number of maturity levels, maturity levels, dimensions and sub-dimensions (see Appendix E).

After first identifying a diverse set of MMs on the topic of EAM and gaining a deeper understanding of these selected models, it becomes clear that to create an insightful model comparison to evaluate if an existing MM fits the intended MM vision or for the potential creation of a new MM, the model selection needed to be defined further. This was necessary, not only, to make the model comparison process itself more manageable, but also to exclude too industry or sector-specific MMs as they do not fit the MM vision and will negatively affect the potential creation of an inclusive MM.

The inclusion criteria which were upheld during the selection of the 18 identified MMs from the SLR are displayed below:

Inclusion criteria:

1. The MM selected must fit the definition of a MM as defined in Chapter 3.1.2.
2. The MMs identified must be the result of the SLR conducted at the start of this thesis, for the SLR process and the exact queries used please see Chapter 2. However, snowballing (the act of tracking down references within the found sources) from the identified relevant literature is allowed.
3. The MMs identified must have a clear link with the topic of EAM.

In the interest of narrowing down the scope of the MM comparison, several exclusion criteria were set up to narrow down the MM selection going forward. These additional exclusion criteria, and the reason for upholding the criteria, are listed below.

Exclusion criteria:

1. MMs solely applicable for utilisation in a specific industry or sector.
    - MMs with a non-generalizable focus on a specific industry or sector are excluded going forward. This choice was made as these MMs are not deemed suitable, as they do not fit the envisioned MM goal and hereby could decrease the inclusiveness of the model. An example of such a MM is MM12 by Mehairjan et al. (2016). Mehairjan et al. (2016) focus on the development and implementation of a MM for professionalising maintenance management for infrastructure. Evaluated criteria in this MM such as "Medium Voltage Substations" and "Sub-transmission grid" for example, are elements that are deemed to be specific and non-generalizable for the vision of the intended MM for EAM. However, it should be noted, that even though a MM may clearly display a focus on a specific industry, the MM may still be deemed fit for consideration if the dimensions described in the MM are generalisable and thus also applicable and relevant outside of the industry / sector of focus. Take for example MM16 by Sauni et al. (2022). This MM has a clear focus on railway (track) asset management, yet is included going forward as the dimensions from the MM such as "Roles and Responsibilities" and "Acquisition and Disposal" are relevant dimensions to consider in any organisation's approach of EAM.
2. MMs with a too high level of granularity.
    - Some of the discovered MMs do, due to their highly detailed nature, not fit the envisioned explorative nature of the intended MM. Including MMs with too many detailed dimensions would (1) make the comparison of the MM unnecessarily complex and extensive and (2) including too detailed

dimensions would decrease the inclusive and explorative nature of the resulting MM and thus is not desirable. MM13 by the National Audit Office, Office of Government Commerce and PricewaterhouseCoopers (2014) displays multiple dimensions that ought to be too detailed, such as the “Cross Organisation/Family” dimension within “Governance” and “Intelligent Client Function”.

3. MMs which are deemed too general.
    - Where some MMs are not suitable due to their high level of granularity, others are deemed unsuitable due to their too general approach to creating dimensions. These MM’s dimensions for example only loosely present four broad dimensions of EAM. Considering the complexity of the topic of EAM, these broad dimensions are not able to be assessed clearly and thus provide useful insights into the maturity of an organisation’s EAM practices. An example of such a MM is MM8 by Kampker et al. (2018). This model assesses an organisation solely by (1). Technology (consisting of (1.1) Machine Data and (1.2) Order Data, (2). Organisation, and (3). Culture. These broad dimensions are deemed too general to be in line with the scope of the envisioned MM. Including too general dimensions will also negatively affect the repeatability of the MM, as they are difficult to score objectively.

Reconsidering the aforementioned list of MMst with these exclusion criteria in mind brought us to 10 suitable MMs to be used from here on out. Before the following steps are presented, first a brief textual overview of the 10 selected MMs is presented below.

MM Selection:

- **MM 2 - [Ref. 17]:** The MM created by Chen et al. (2021) concerns itself with testing the maturity of digital twin implementations and guiding organisations towards improved digital twin implementations to support their asset management endeavours. The model consists of three dimensions, which are divided into nine groupings and twenty-seven sub-dimensions, named “rubrics”. These dimensions were examined by a team of 40 experts and the model was evaluated by a twofold of case studies.
- **MM 3 - [Ref. 19]:** The MM as described by Cornu et al. (2012) focuses on the implementation of system engineering (SE) to improve business process efficiency. The created MM is to be used before the SE deployment processes. The MM differentiates between five maturity levels and considers three dimensions (with six sub-groupings) described by twenty-two sub-dimensions. The proposed MM is submitted to a group of design office experts of an aviation manufacturer for validation and has been applied to an organisation to validate and improve its content. However, it should be noted that no clear approach or outcomes of these endeavours have been documented in the article itself.
- **MM 4 - [Ref. 29]:** Errandonea et al. (2022) created a MM specific to industrial maintenance in the context of the railway sector. This model defines guidelines to evolve within various maintenance strategies towards prescriptive maintenance from a blanket perspective. This MM differentiates into four maturity levels and three dimensions divided into eighteen sub-dimensions. The model is built from an in-depth literature review. Before presenting the main conclusions, the article presents a case for the applicability of the proposed Maintenance Maturity Model (M3) in the railway domain. However, the paper only tackles the applicability theoretically and no empirical research is conducted.
- **MM 5 - [Ref. 36]:** The MM created by Gersonius et al. (2017) concentrates on asset management in the context of flood protection (specifically across the North Sea Region). This is of importance as where, when and how much to invest in assets is critical in ensuring flood protection. The MM differentiates between five maturity

levels and seven dimensions. The proposed MM is tested by assessing the maturity of 5 flood protection asset management organisations (in Belgium, Sweden, Denmark, Germany and The Netherlands). Subsequently, the results from these assessments are analysed and compared.

- **MM 6 - [Ref. 37]:** Gökalp et al. (2017) present a MM which concerns itself with the topic of Industry 4.0 and provides a MM to guide the transition of organisations towards Industry 4.0 in a systematic and repeatable manner. The presented MM is based on seven previously existing MMs and is built with 6 maturity levels in mind. The model differentiates between five dimensions. The paper does not document any empirical evidence to evaluate or validate the usability and performance of the proposed MM.
- **MM 9 - [Ref. 49]:** Khaliq et al. (2016) present a MM which focuses on asset management in the context of electrical power distribution organisations. The MM is built with the intended goal of benchmarking and improving asset management. The model evaluates aspects based on a set of thirteen grouped activities which are referred to as key process areas and seven key attributes as adopted from the British Standard Asset Management System (2014). These key attributes are evaluated for each of the key process areas. Maturity levels are split into five: from initial or ad hoc to optimised. The proposed MM is evaluated by conducting case studies at 2 different organisations specializing in electrical power distribution. However, it should be noted that the documented findings are referred to as preliminary findings, yet no paper describing the decisive findings could be discovered.
- **MM 14 - [Ref. 75]:** Patrício and Almeia (2021) present a MM intending to create a common risk framework for assessing risk management processes in the context of road and rail infrastructures. This model differentiates six maturity levels, from innocent to excellent and assesses an organisation's maturity based on eight dimensions. The proposed MM has been empirically evaluated by conducting a case study of a public infrastructure organisation which manages both the Portuguese national road and railway networks.
- **MM 16 - [Ref. 90]:** The MM as described by Sauni et al. (2022) has a clear focus on railway (track) asset management. This model takes five levels of maturity, from ensuring safety to vision. These are applied to six dimensions. The MM has been evaluated by conducting semi-structured expert interviews with 22 interviewees from 8 organisations and has been successfully applied to railway asset management in Finland.
- **MM 17 - [Ref. 68]:** The Office of Government Commerce MM on property asset management defines five individual maturity levels, from unawareness to excellence and has split its assessment into eight different dimensions. The proposed MM is developed based on 50 conducted questionnaires at various departments, executive agencies and non-department public bodies. Followed by 32 interviews and a developmental workshop.
- **MM 18 - [Ref. 111]:** The MM presented by Woodall et al. (2013) focuses on understanding an organisation's approach to IQM in the context of asset management and providing guidance towards improved IQM practices. Maturity is evaluated in a five-staged maturity level assessment from chaotic to optimising. The MM creation process does include the evaluation of seven previously existing MMs on the topic of IQM and is split into thirteen process areas and forty-five critical success factors (CSF). The occurrence of these process areas and CSF are linked to the various maturity levels. The MM is tested in a case study by evaluating 10 U.K.-based organisations.

To review this selection of 10 MMs more in-depth, the occurrence of the shortcomings (as mentioned in the overview of section 3.1.5) will be evaluated / described here. Some of the mentioned shortcomings, however, are difficult to accurately evaluate without being an

experienced practitioner in the relevant field of work, industry or organisation the MM concerns itself with. For example, evaluating to which extent a MM sufficiently addresses interoperability or is flexible enough to keep up with managing changes whilst adhering to certain quality improvement principles. Whereas other shortcomings, such as a lack of empirical tests or a lack of clear documentation when describing the (systematic) approach for creating or adopting maturity levels, are identified more candidly.

Considering that a potential, newly created MM may be based on these previous 10 selected works, it is relevant to identify the occurrence of shortcomings within this selection. Because these MMs form the base on which the new MM will be built. Therefore, presented below in Table 12, an overview is given of the ten selected MMs being evaluated on (1) the presence of an empirical test to evaluate and potentially support the proposed MM and (2) if the article's quality has been assessed by means of a peer-review.

Table 12. Analysis of the shortcomings of the 10 selected MMs from the SLR - Part I

MM No. and Reference	(Supporting) Empirical Testing	Peer-reviewed	Source Type
MM 2 - [Ref. 17]	✓	✓	Article published in journal (Multidisciplinary Digital Publishing Institute - Sustainability)
MM 3 - [Ref. 19]	✓	✓	Conference Paper (6th IEEE International Systems Conference, SysCon)
MM 4 - [Ref. 29]		✓	Article published in journal (Multidisciplinary Digital Publishing Institute-Applied Sciences)
MM 5 - [Ref. 36]	✓	✓	Article published in journal (Multidisciplinary Digital Publishing Institute - Infrastructures)
MM 6 - [Ref. 37]		✓	Conference Paper (17th International Conference on Software Process Improvement and Capability Determination)
MM 9 - [Ref. 49]	✓	✓	Conference Paper (IEEE PES Asia-Pacific Power and Energy Engineering Conference)
MM 14 - [Ref. 75]	✓	✓	Conference Paper (14th World Congress on Engineering Asset Management)
MM 16 - [Ref. 90]	✓	✓	Article published in journal (Built Environment Project and Asset Management)
MM 17 - [Ref. 100]	✓		Grey Literature Research Study (Office of Government Commerce)
MM 18 - [Ref. 111]	✓	✓	Article published by journal (Engineering Asset Management Review)

As displayed in Table 12 and also elaborated on in the aforementioned MM descriptions, the analysis shows that 8 out of the 10 selected MMs have been empirically tested. Furthermore, 9 out of the 10 selected articles proposing a MM have been peer-reviewed before being published / shared. This is a fairly good score, considering both a lack of

empirical tests and a lack of peer-reviewed articles in the field of maturity modelling were identified as prevalent shortcomings in section 3.1.5.

Another frequently occurring MM shortcoming is the lack of clear structure or documentation concerning the MM development process, specifically when focussing on the motivation behind choosing certain maturity levels. Some authors create / propose new maturity levels, whereas others rely on adopting or being heavily inspired by previously created maturity levels by other authors. These aforementioned scenarios and their occurrence is tested on the 10 selected MMs from the SLR and the results are presented below in Table 13.

Table 13. Analysis of the shortcomings of the 10 selected MMs from the SLR - Part II

MM No. and Reference	Empirical test for evaluating the maturity-performance link	Clear and structured explanation / motivation for the chosen maturity levels	Creating / proposing new maturity levels	Maturity levels adopted from or inspired by other sources
MM 2 - [Ref. 17]				✓
MM 3 - [Ref. 19]			✓	
MM 4 - [Ref. 29]				✓
MM 5 - [Ref. 36]				✓
MM 6 - [Ref. 37]				✓
MM 9 - [Ref. 49]			✓	
MM 14 - [Ref. 75]				✓
MM 16 - [Ref. 90]				✓
MM 17 - [Ref. 100]			✓	
MM 18 - [Ref. 111]				✓

As displayed in Table 13, the analysis shows that none of the selected sources has included an empirical test to evaluate the maturity-performance link. Furthermore, although it is a somewhat subjective criterion to be judged, in the author's opinion none of the selected 10 MMs presented a clear and structured explanation or motivation for their respective choice in maturity levels.

From the 10 sources, 3 sources decided to create / propose new maturity levels (without stating a source of inspiration), whereas the remaining 7 did state one or multiple sources from which they directly adopted the maturity levels or, in some cases, took inspiration from. It should also be acknowledged that the selected sources vary in describing and defining their chosen maturity levels as well. Where some do only mention a “catchphrase” illustrating the typical mindset of people in the organisation which is assessed at a specific maturity level (see MM 3 - [Ref. 19]), others do extensively document the definitions / interpretations of their respective chosen maturity levels (such as MM 6 - [Ref. 37]**)** or describe how the maturity levels are linked to certain critical success factors in particular focus areas (see MM 18 - [Ref. 111]). Considering the severe lack of any clear and structured explanation / motivation for the chosen maturity levels, it becomes clear that this previously identified shortcoming is not only very prevalent but also a potentially interesting topic for the future of work.

5.2.2 Make a construct diagram and create a metamodel

Now the MM selection has been further narrowed down, the models will undergo a final preparation step, the grouping of (sub-)dimensions, before step two of the four-step process for comparing MMs as per Lautenschutz et al. (2018) will be conducted. As can be seen in Appendix E, the MMs have numerous dimensions and sub-dimensions. Combined, the 10 selected MMs consist of a total of 208 dimensions and sub-dimensions. To create a construct diagram, and a metamodel and prepare for the pivot model comparison, a set of inclusion and exclusion criteria are also applied to narrow down the scope of the dimensions used. The inclusion and exclusion criteria applied to the 208 dimensions and sub-dimensions are presented in a brief manner down below (these criteria are closely related to the criteria described in subsection 5.2.2).

Inclusion criteria:

- The dimensions / sub-dimensions identified must be part of the previously selected 10 MMs from the SLR.
- The dimensions / sub-dimensions must have a clear link with the topic of EAM.

Exclusion criteria:

- Dimensions / sub-dimensions solely applicable for utilisation in a specific industry or sector.
- Dimensions / sub-dimensions with a too high level of granularity.
- Dimensions / sub-dimensions deemed too general.

For transparency, the complete dimension and sub-dimension selection process as described above can be found in Appendix H (here exclusion criteria 1 and 2 are indicated in red and exclusion criteria 3 is indicated in yellow). This process results in a final selection of 111 dimensions and sub-dimensions from the previously selected 10 MMs.

With all relevant dimensions selected, the dimensions are now sorted into groups to organise the comparison process. This group selection is done by evaluating every dimension on its relevance to other dimensions. This is done by iteratively comparing dimensions and colour-coding-related dimensions. This process is repeated until all dimensions are placed in a group. Subsequently, the groupings are re-evaluated to make sure all dimensions in the various groups have some relation to one another. Lastly, the groups, which are to be called Focus Areas from now on, are given a name fitting to the dimensions it includes. This process forms the metamodel of the selected MMs, as can be found in Appendix F. This metamodel displays the underlying structure of the selected MMs

by having identified relevant groupings / focus areas. It should be noted, however, that the metamodel still does contain several overlapping dimensions at this point. These overlapping dimensions will be removed in the upcoming step described in sub-section 5.2.4.

The process, described above, resulted in the creation of a total of 9 focus areas. The name of each focus area, as well as the number of dimensions included in each focus area at this point, are presented in Appendix F, but also briefly presented below (in no particular order):

1. Human Resources (8 Dimensions)
2. Risk management (8 Dimensions)
3. Information quality (9 Dimensions)
4. Cost management / Financial Planning (4 Dimensions)
5. Security (7 Dimensions)
6. Asset life-cycle (21 Dimensions)
7. Information Collection and Dissemination (19 Dimensions)
8. Strategic Direction (19 Dimensions)
9. Tool Management and Standardisation (16 Dimensions)

To evaluate if one of the existing models already assesses all of the focus areas, a construct table is created to compare the inclusion of the focus areas in the 10 selected MMs. It also displays the number of dimensions representing each focus area. See Table 14 below.

Table 14. Construct Table - Comparing the MM selection

Construct Table - Displaying the differences in Focus Area inclusion of the 10 selected MMs

Focus Area Nr.	Focus Area	(01). Chen et al. (2021)	Nr.	(02). Cornu et al. (2012)	Nr.	(03). Errandonea et al. (2022)	Nr.	(04). Gersonius et al. (2020)	Nr.	(05). Gökalp et al. (2017)	Nr.	(06). Khaliq et al. (2016)	Nr.	(07). Patrício and Almeia (2021)	Nr.	(08). Sauni et al. (2022)	Nr.	(09). OGC (2007)	Nr.	(10). Woodall et al. (2013)	Nr.	MM Vision
(1).	Human Resources	✓	3	✓	2		0	✓	1		0	✓	1		0		0	✓	1		0	✓
(2).	Risk management		0		0	✓	2		0		0	✓	1	✓	4		0		0	✓	1	✓
(3).	Information quality	✓	4		0		0		0	✓	1		0		0		0		0	✓	4	✓
(4).	Cost management / Financial Planning		0		0	✓	3		0		0	✓	1		0		0		0		0	✓
(5).	Security	✓	2		0		0		0		0		0		0		0		0	✓	5	✓
(6).	Asset life-cycle	✓	1		0	✓	7		0		0	✓	6		0	✓	2	✓	4	✓	1	✓
(7).	Information Collection and Dissemination	✓	7	✓	3	✓	3	✓	1		0	✓	1	✓	2		0	✓	1	✓	2	✓
(8).	Strategic Direction	✓	2		0		0	✓	4	✓	2	✓	4	✓	1	✓	1	✓	2	✓	3	✓
(9).	Tool Management and Standardization	✓	3	✓	7	✓	2		0	✓	1		0		0		0		0	✓	3	✓
	Total number of dimensions	22		12		17		6		4		14		7		3		8		19		

As indicated in Table 14, none of the ten selected MMs can assess an organisation in all of the focus areas. Thus, none of the ten selected MMs can create a broad and inclusive assessment of an organisation's approach to EAM.

5.2.3 Pivot model comparison

In this sub-section, steps three and four of the four-step process for comparing MMs as per Lautenschutz et al. (2018) are conducted: the selection of a pivot model and the systematical comparison of models to identify common and unique constructs.

As indicated in Chapter 4.2, it is irrelevant which model is chosen as the pivot model as it does not influence the result. However, it is most convenient to choose the most extensive/complete model to have a solid basis to compare the other models against. In line with this reasoning, the MM as presented by Chen et al. (2021) is chosen to be the pivot model for this comparison.

As described in Chapter 4.2, the comparison of the MMs takes place by systematically comparing the pivot model to another model to find commonalities and unique dimensions. Once this comparison is done, the next model is considered and compared to the previous results. This comparison is split for each of the focus areas to make the process more clear and manageable. The complete outcome of this process is documented and presented in Appendix G for transparency and repeatability. Here every column represents one of the selected MMs and every row is utilised to map similar dimensions/sub-dimensions from the various models. Rows with only a single cell filled display unique constructs and rows with multiple cells filled display commonalities amongst the selected MMs.

5.3 Determination of development strategy

As already concluded in sub-section 5.2.2, none of the 10 previously selected MMs from the SLR are capable of assessing an organisation's EAM approach in all of the focus areas. This leads to the conclusion that none of the selected MMs from the SLR is capable of fulfilling the intended MM's goal: creating an explorative and inclusive MM for assessing an organisation’s approach to EAM. However, the previous steps have indicated that a combination of the selected MMs would be able to accomplish such an assessment.

Considering (1) the strong basis these existing selected MMs bring to the table, (2) the timeframe set out for this MM creation, (3) my personal limited experience in the field of EAM and, lastly, also (4) taking into consideration Wendler’s (2012) concerns regarding the trend of creating new MMs without considering improving or extending existing work first, the decision was made to create a new MM by building upon the previous 10 selected MMs from the SLR. These are the models created by Chen et al. (2021), Cornu et al. (2012), Errandonea et al. (2022), Gersonius et al. (2020), Gökalp et al. (2017), Khaliq et al. (2016), Patrício and Almeia (2021), Sauni et al. (2022), OGC (2007), and Woodall et al. (2013).

5.4 Iterative maturity model development

Becker, Knackstedt and Pöppelbuß (2009) describe the MM development process as an iterative loop. In this loop first design choices are made for the MM, a creation approach is selected, the model is created and lastly, the created MM is evaluated. If the results of the evaluation are satisfactory the loop is ended, if not, the process is started over.

5.4.1 MM design choices and approach

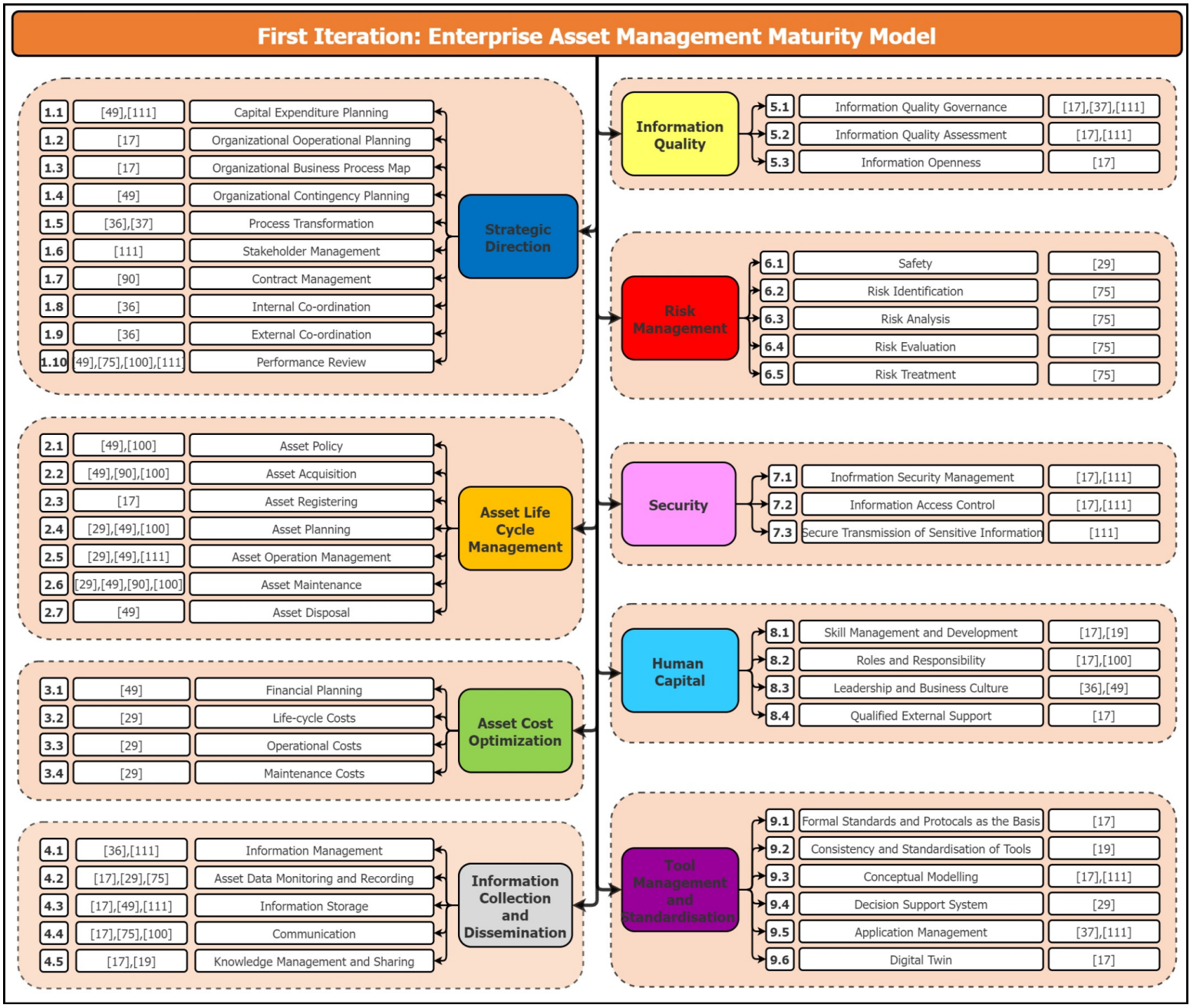
In Chapter 3.2 the design choices for the creation of a potential new MM have already been described, as well as the reasoning behind it. The new MM will be descriptive in nature, will asses maturity on a fixed-level basis, will be created with a bottom-up approach and maturity is assessed using qualitative measures. As described in Chapter 4.3, the model will be created using the previously conducted pivot model comparison.

5.4.2 MM development - First iteration

For the creation of the new MM we make use of the pivot model comparison. All found dimension commonalities discovered in this systematic comparison are included in the new MM, as commonalities indicate that multiple authors ought the described dimension to be of importance in the context of EAM. If commonalities are named differently, either one of the existing names is adopted or a fitting name is created that covers both descriptions of the authors. Unique dimensions or sub-dimensions are considered individually and only added if deemed to be relevant and contributing towards the explorative and broad nature of the new MM.

Appendix G shows the full pivot model dimension comparison in detail. After conducting the creation process as described above, a new list of MM dimensions is obtained. Below, Figure 9 presents an overview of the new MM and its dimensions.

Figure 9. The first iteration of the new MM for improved EAM: Focus areas and their related dimensions



To make sure the MM is understandable and assessment can be done in an accurate and repeatable manner, descriptions of all included dimensions are added to the MM. All focus areas and dimensions, including their descriptions, are presented below in Table 15. Therein, each focus area is coloured in the same colour as in Figure 9.

Table 15.a Content overview of the first iteration of the new MM for improved EAM

No.	Dimension	Description
1	**Strategic Direction**	Strategic Direction refers to the overarching enterprise-wide approach of an organisation towards business goals and objectives. Strategic Direction consists of various internal and external processes that are concerned with developing, planning, and prioritising asset activities to be aligned with the organisation's strategic vision.
1.1	Capital Expenditure Planning	Capital Expenditure Planning refers to the enterprise-wide planning of an organisation towards achieving long-term needs, requirements, and goals.
1.2	Organisational Operational Plan	The Organisational Operational Plan outlines a roadmap with specific actions towards achieving business goals / objectives. The plan describes in detail all actions, resources, and stakeholders / departments / teams involved.
1.3	Organisational Business Process Map	Organisational Business Process Mapping is the process of creating a clear visual representation / overview of certain business activities in an organisation.one in order to identify strengths and weaknesses in the respective process or business activity.
1.4	Organisational Contingency Planning	Organisational Contingency Planning refers to the planning of a course of action if unexpected events or situations occur.
1.5	Process Transformation	Process Transformation refers to the proactive change and improvement of business processes to increase efficiency and performance. This process typically consists of process analysis, design, implementation, monitoring, and improvement.
1.6	Stakeholder Management	Stakeholder management is the process of creating, monitoring, improving, and maintaining relationships with stakeholders. This is done to build robust relationships where the expectations of stakeholders are managed and aligned with organisational goals / objectives.
1.7	Contract Management	Contract Management refers to all processes regarding the creation, execution, and negotiation of contracts to maximize operational and financial performance, whilst reducing (financial) risks.
1.8	Internal Co-ordination	Internal coordination refers to all processes that ensure the ability of relevant internal departments / stakeholders to be effective and unified in their approach to tackling business objectives.
1.9	External Co-ordination	External coordination refers to all processes that ensure effective collaboration with external stakeholders / organisations to execute business activities that are aligned with relevant organisational goals / objectives.
1.10	Performance Review	Performance review refers to the process of evaluating an organisation's operations, this can be done at various levels of granularity: for example at the department, project or employee level. The goal of Performance Review is to assess how well an organisation operates and identify opportunities for improvement.

Table 15.b Content overview of the first iteration of the new MM for improved EAM

No.	Dimension	Description
2	**Asset Life Cycle Management**	Asset Life Cycle Management refers to all processes involved with ensuring an asset is effectively utilised during the entirety of its life cycle: from acquisition to disposal.
2.1	Asset Policy	Asset Policy refers to all rules and guidelines that are upheld for the utilisation and organisation of assets during their entire life cycle. The goal of the asset policy is to ensure the effective usage of assets to achieve organisational goals / objectives.
2.2	Asset Acquisition	Asset Acquisition is the process of procuring an asset and integrating it into an organisation's operations with the goal of contributing to the envisioned organisation's goals/objectives. Effective asset acquisition considers financial and planning requirements thoroughly to enable maximal asset value.
2.3	Asset Registering	Asset Registering refers to the process of recording ownership of an asset after acquisition. This process identifies and documents all assets within an organisation, including their respective attributes and location which supports the planning of asset operations. Furthermore, this process is important for establishing and protecting ownership rights and, wherever applicable, ensuring compliance with mandatory rules and regulations.
2.4	Asset Planning	Asset Planning concerns itself with allocating asset resources optimally over time to contribute to long-term value creation from the organisation's assets. Asset planning considers the timelines of asset acquisition, registration, operation, maintenance, and disposal.
2.5	Asset Operation Management	Asset Operation Management refers to all processes involved in ensuring effective and efficient day-to-day operations of an organisation's assets. Asset performance is closely monitored and wherever/whenever deemed necessary interventions are executed for example when assets fail to function as intended.
2.6	Asset Maintenance	Asset Maintenance is an integral part of effective asset life-cyle management and refers to all processes that are involved with keeping assets in optimal working condition. This is done to maximize asset lifespan and minimise downtime for optimal value creation.
2.7	Asset Disposal	Asset Disposal concerns itself with the removal of assets that no longer serve a purpose to the organisation in an effective and responsible manner. The goal of Asset Disposal is to remove the respective assets in a manner that minimizes cost and operational impact.

Table 15.c Content overview of the first iteration of the new MM for improved EAM

No.	Dimension	Description
3	**Asset Cost Optimization**	A major consideration in cost-effectively managing assets, whilst maximising asset performance throughout their life cycle, is cost. In order to implement the most cost-effective strategies for utilising assets a thorough analysis of expected costs needs to be made. As this analysis will enable improved decision-making towards achieving the lowest cost of ownership whilst maximising value creation.
3.1	Financial Planning	Financial Planning refers to the strategic development of a financial plan, which takes the various types of costs associated with owning, operating, and maintaining assets, into consideration. The goal of financial planning, in the context of enterprise asset management, is to ensure the alignment of cost-effective asset utilisation with envisioned company goals.
3.2	Life-cycle Costs	Life-cycle Costs refer to the total cost of acquiring, operating, maintaining and disposing of an asset. By being accurately informed about life-cycle costs an organisation can make informed decisions on the benefits or drawbacks of new asset acquisition or optimal asset management strategies for specific assets.
3.3	Operational Costs	Operational Costs refer to all costs associated with utilising an asset in routine operations.
3.4	Maintenance Costs	Maintenance Costs refer to all costs associated with keeping an asset in good working condition.

Table 15.d Content overview of the first iteration of the new MM for improved EAM

No.	Dimension	Description
4	**Information Collection and Dissemination**	Information Collection and Dissemination refers to all processes involved in collecting, storing, distributing, and analysing information/data. This process supports informed decision-making and enables the internal, as well as, external distribution of information/data.
4.1	Information Management	Information Management is the organisational practice consisting of all activities related to creating, capturing, monitoring, analysing, sharing and disposing of information/data.
4.2	Asset Data Monitoring and Recording	Asset Data Monitoring and Recording refers to the process of capturing data such as asset performance, maintenance, and operation timelines. This information can be gathered by a variety of tools and techniques, such as manually written reports or sensors. Monitoring and recording this data can help in making informed decisions for optimal asset utilisation (for example what maintenance strategy would suit a certain asset best).
4.3	Information Storage	To enable the effective collection and dissemination of information/data a centralized platform for storing data is required, this can be done in various ways depending on the organisation's needs: for example on-site or cloud-based. To effectively manage this centralized storage of information/data it is best to have standardized rules / practices in place for storing the various types of data needed for business activities. All information stored should adhere to these standardized rules / practices. By doing so stored information should be complete, accurate, (easily) accessible and analysable for relevant users.
4.4	Communication	The ability to effectively communicate information/data is crucial for keeping all relevant stakeholders informed and supporting informed decision-making throughout the organisation. To ensure the effective communication of information/data, the appropriate communication channels need to provide (instant) access to the relevant information at the correct point in time. Furthermore, the communication channels need to enable informing other stakeholders without delay.
4.5	Knowledge Management and Sharing	Knowledge management focuses on the creation and subsequently, the intentional / strategic distribution and utilisation of knowledge across an organisation, to support attaining specific business goals / objectives.

Table 15.e Content overview of the first iteration of the new MM for improved EAM

No.	Dimension	Description
5	**Information Quality**	Enterprise Asset Management decision-making is significantly reliant on / influenced by the captured asset performance data. Therefore, it is crucial that the data captured is accurate, complete, and relevant to ensure that one can confidently rely on the respective information.
5.1	Information Quality Governance	Information Quality Governance refers to all processes of regulating implemented policies and procedures that are concerned with safeguarding the data quality within an organisation.
5.2	Information Quality Assessment	Information quality assessment is the act of evaluating the quality of captured information/data compared to previously defined criteria or standards.
5.3	Information Openness	Information openness refers to the availability and accessibility of captured data. Effective information openness ensures the permanent availability and accessibility of data to authorized users.

Table 15.f Content overview of the first iteration of the new MM for improved EAM

No.	Dimension	Description
6	**Risk Management**	Risk management concerns itself with the identification, prioritisation, monitoring, and management of risks with the goal of maintaining acceptable risk levels to balance risk and asset exploitation to optimise the cost-effective usage of assets whilst reducing liabilities.
6.1	Safety	To ensure a safe working environment, wherever necessary, safety policies and procedures should be in place. Assets with safety concerns should accurately be defined and documented to ensure these respective assets are handled in a fitting / safe manner. This should be done in order to protect personnel, provide safe working conditions and protect assets.
6.2	Risk Identification	Risk identification is the process of documenting any risk that may hinder an organisation's operations towards achieving its intended business goal / vision. Risk can come in various forms, for example, operational risk or financial risk.
6.3	Risk Analysis	Risk analysis concerns itself with analysing the probability of risk occurrence and the potential impact / consequences the occurrence of certain risks can have. This can be done in various ways, for example by conducting a failure mode and effects (criticality) analysis or a fault tree analysis. Effective risk analysis should give an organisation insight into which assets, in case of failure, will cause certain consequences.
6.4	Risk Evaluation	Risk evaluation takes the knowledge gained in the risk analysis into consideration and, based on this knowledge, determines what an adequate level of risk is that the organisation is willing to take.
6.5	Risk Treatment	Risk treatment is the process of implementing adequate risk management / mitigation strategies for risks that were deemed important based on the previously conducted risk evaluation.

Table 15.g Content overview of the first iteration of the new MM for improved EAM

No.	Dimension	Description
7	**Security**	Data assets can be crucial for facilitating business activities and generating actionable insights, sensitive data therefore is an important asset. To ensure the safe and controlled transmission of sensitive data, robust security measures should be implemented and upheld.
7.1	Information Security Management	Information Security Management is the process of implementing and maintaining policies and best practices to ensure data safety, reliability and integrity.
7.2	Information Access Control	Information Access Control is concerned with ensuring data assets can only be accessed, changed, and/or deleted by authorized users. This is done to ensure the security and confidentiality of data assets.
7.3	Secure Transmission of Sensitive Information	Secure Transmission of Sensitive Information is a data asset security concern that needs to be adequately addressed to assure the confidentiality and integrity of data. Various strategies can be applied to achieve the secure transmission of data assets, for example requiring digital signatures.

Table 15.h Content overview of the first iteration of the new MM for improved EAM

No.	Dimension	Description
8	**Human Capital**	Human capital is often considered to be one of, if not the most important asset of an organisation. Employees are not only the driving force behind business activities but are also considered to be valuable assets due to their distinctive skills and knowledge.
8.1	Skill Management and Development	Employees have different skill sets, and to utilise these skills optimally the organisation should be able to perform efficient skill management. This involves identifying, developing and retaining skills with the goal of expanding/improving the skillsets of employees, as well as, assigning employees to projects that fit their abilities best. If done effectively, this can create value and maintain or gain a competitive edge compared to competitors.
8.2	Roles and Responsibility	Roles and responsibilities of employees should be defined explicitly and these definitions should be transparently communicated/shared across the organisation.
8.3	Leadership and Business Culture	The leadership and business culture in an organisation should contribute to the creation and execution of asset management policies and objectives. These policies and objectives should be aligned with an organisation's overarching vision/goals. Furthermore, (top) management / team leaders should proactively create and maintain support for the created policies and objectives within the relevant teams.
8.4	Qualified external support	If needed, the organisation should consciously attract external expertise to contribute towards an envisioned business goal. For example, through hiring external consultants.

Table 15.i Content overview of the first iteration of the new MM for improved EAM

No.	Dimension	Description
9	**Tool Management and Standardisation**	Effective Tool Management and Standardisation in the context of EAM refers to adopting the right tools to improve asset performance in a systematic, efficient, cost-effective and repeatable manner.
9.1	Formal Standards and Protocols as the Basis	Formal standards and protocols as the basis help business activities / operations ensure interoperability, work efficiency, compliance with rules and regulations, reduce cost and improve safety.
9.2	Consistency and Standardisation of Tools	Consistency and Standardisation of Tools refers to the enterprise-wide uniformity of tools used to ensure interoperability, work efficiency, compliance with rules and regulations, reduce cost and improve safety.
9.3	Conceptual Modelling	The goal of Conceptual Modelling is to gain / provide clarity, structure and understanding of the relationship between assets and stakeholders in various business processes. This insight can aid in improved / informed decision-making and thus can lead to improved efficiency and cost-effectiveness.
9.4	Decision Support System	A Decision Support System is a tool that can help an organisation determine their best course of action. This is done by a computer-based information system which analyses large amounts of data and compiles / extracts useful information from this process.
9.5	Application Management	Application Management refers to all processes concerned with the management of (software) applications throughout their life cycle.
9.6	Digital Twin	A Digital Twin is the creation of a virtual representation of an asset to simulate asset behaviour and analyse, monitor and optimize potential outcomes. This can boost asset performance, reduce costs, and express potential risks / issues beforehand.

Once the MM's focus areas and their related dimensions are formulated and described, it is now time to decide on appropriate maturity levels. Considering the broad range of EAM dimensions represented in the MM, the maturity levels must be applicable to a wide range of business activities. Furthermore, they must express continual growth towards a mature state in which asset performance and value creation are optimised. The maturity levels, of the ten selected MMs, from the SLR are taken into consideration. An overview of these maturity levels is presented below in Table 16.

Table 16. Overview of the maturity levels of the selected MMs

Selected MM Maturity Levels

Maturity levels (in ascending maturity)	Chen et al. (2021)	Cornu et al. (2012)	Errandonea et al. (2022)	Gersonius et al. (2020)	Gökalp et al. (2017)	Khaliq et al. (2016)	Patrício and Almeia (2021)	Sauni et al. (2022)	OGC (2007)	Woodall et al. (2013)
Maturity Level 1	Unaware	Initial	Preventive	Ad hoc	Incomplete	Ad hoc / Initial	Innocent	Ensuring safety	Unawareness	Reactive
Maturity Level 2	Identifiable	Low	Condition-based	Repeatable	Performed	Repeatable organization	Aware	Monitoring track quality	Awareness	Aware
Maturity Level 3	Aware	Neutral	Predictive	Standardised	Managed	Defined organization	Developing	Track geometry management	Knowledge	Quantified
Maturity Level 4	Communicative	Good	Prescriptive	Well managed	Established	Controlled organization	Competent	Optimising track geometry	Competence	Managed
Maturity Level 5	Interactive	Excellent	N/A	Optimised	Predictable	Optimized organization	Optimizing	Vision	Excellence	Optimizing
Maturity Level 6	Instructive and Intelligent	N/A	N/A	N/A	Optimizing	N/A	Excellent	N/A	N/A	N/A
No. of Maturity Levels	6	5	4	5	6	5	6	5	5	5

With the MM model's vision and the need for assessing a diverse set of dimensions in mind, at this stage, suitable maturity levels will be selected. As previously mentioned, according to Becker, Knackstedt and Pöppelbuß (2009), it is to be expected that authors can use maturity levels inspired by or adopted from the previously selected MMs. Because the descriptions of individual maturity degrees can often be partially or even fully applied when using existing MMs as a starting point for the design process of a new MM. This is often the case since the MMs cover the same relevant problem domain. After thorough consideration of the diverse sets of maturity levels, it was decided that Chen et al. (2021), Cornu et al. (2012), Gökalp et al. (2017), Patíco and Almeia (2021), OGC (2007) and Woodall et al (2013) were unsuitable for the envisioned MM, as the author perceives the barriers between the various levels as indistinctive. On the other hand, the maturity levels as adopted by Errandonea et al. (2022) and Sauni et al. (2022) were perceived as too specific. The maturity levels chosen by Errandonea et al. (2022) are solely applicable for evaluating maintenance strategies and the maturity levels chosen by Sauni et al. (2022) are only relevant for railway asset management applications. Lastly, the maturity levels as utilised by Gersonius et al. (2020) and Khaliq et al. (2017), were both deemed to be fit for evaluating a wide range of organisations regardless of sector. Eventually, it was determined that the maturity levels as described in the MM by Khaliq et al. (2016), were most appropriate as the varying maturity levels were deemed more distinctive in their naming as compared to Gersonius et al. (2020).

Presented below in Table 17 a detailed description for each of the maturity levels, taking inspiration from its source, was created. These descriptions were created to make the MM more clear and assessments more accurate and repeatable. The maturity levels are presented in ascending order of maturity and built upon one another.

Table 17. Overview of the maturity levels for the new MM for improved EAM (First iteration)

Maturity Level	Description	Score
Ad hoc / Initial Organisation	Business processes are unorganised, undefined, unstandardized, unaligned with business goals and created / adopted on an ad hoc basis.	**0**
Repeatable Organisation	Business processes are organised and consistently repeated, yet undefined, unstandardized and unaligned with business goals.	**1**
Defined Organisation	Business processes are organised, repeated, and defined yet unaligned with business goals.	**2**
Controlled Organisation	Business processes are fully controlled, defined, documented / monitored and aligned with business goals.	**3**
Optimised Organisation	Business processes are fully controlled, defined, documented / monitored, optimised for performance, flexible and adjustable if necessary, and aligned with business goals. Best practices are utilised for maximal value creation.	**4**

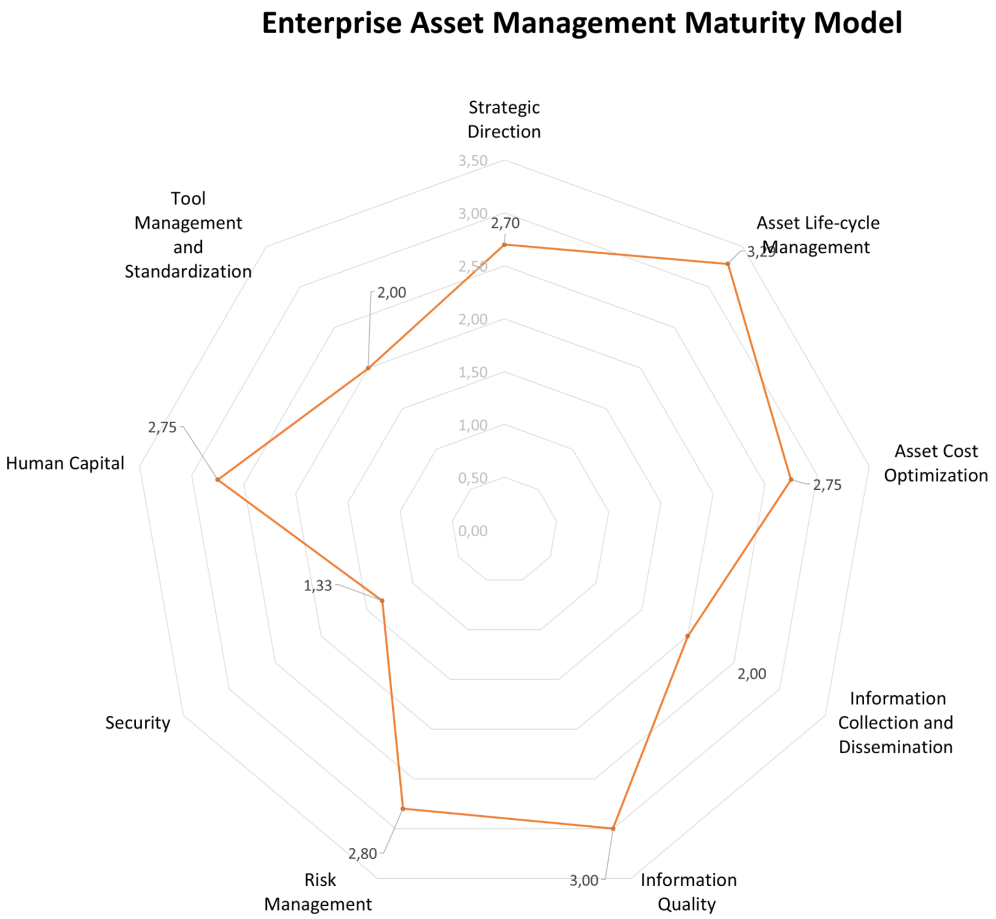
The scores generated are expressed in a numerical value, as shown in the maturity level table presented above. These scores are used to generate a visual representation of how the various dimensions perform compared to one another. This way, a quick, first impression can be given of the strengths and weaknesses within the assessed organisation.

This is done by generating a spider chart based on the maturity level assessments of all the dimensions for each focus area. Scores are calculated by calculating the average score of

the dimension for each focus area. In this manner, all dimensions and focus areas are deemed equally as relevant. This, however, may not be an accurate representation of the organisation in question. Depending on the industry, country, business strategy and various other factors, an organisation might want to prioritise certain focus areas or dimensions. Exploring the various weights and prioritisations different dimensions may have for certain organisations will make for an interesting task for the future development of this MM.

An example of such a spider chart is presented below in Figure 10. This spider chart is based on fictional / dummy data and thus does not represent any existing organisation and is solely created for demonstration purposes. As one can see, the spider chart displays an organisation whose best-performing focus area is Asset Life-cycle Management and whose least-performing focus area is Security. This might indicate that the organisation may benefit from doing a more detailed analysis of its EAM approach in the context of Security, as there is still a lot of room to improve towards a more mature state in this focus area.

Figure 10. First Iteration MM for EAM - Spider Chart (Based on fictional data)



With the first iteration of the new MM for improved EAM created and fully documented, we can now answer RQ4.

5.4.3 RQ4: What dimensions and sub-dimensions from existing maturity models are transferable?

The dimensions and sub-dimensions from existing MMs that are deemed relevant to take into consideration when assessing an organisation's EAM approach in a comprehensive and explorative manner are all displayed in the previously presented Figure 9 and Table 15. All the described dimensions were extracted from existing MM and have their respective sources next to them. These dimensions have been selected by applying a combination of the model comparison and model creation processes as described by Becker, Knackstedt and Pöppelbuß (2009) and Lautenschutz et al. (2018).

In the upcoming section, this (first iteration) MM is evaluated by practitioners in the field of EAM. After analysing this evaluation in a quantitative and qualitative manner, a second iteration of the MM, with changes based on the outcomes of the conducted interviews, will be presented.

5.4.4 MM evaluation

As described in more detail in Chapter 4.4, this evaluation stage took place by conducting semi-structured interviews (as described by Adams, 2015) and surveys in a workshop-styled meeting with experts in the field of EAM. Before inviting any participants, the interview questions were prepared in full and sent to the Ethics Committee of BMS for approval. After implementing some minor tips/suggestions, the interview setup was approved and invitations were sent out to potential participants.

In total, eight experts agreed to be interviewed for the purpose of evaluation. These experts have been interviewed in three sessions, one in person (05-05-2023) and two – online (16-05-2023 and 17-05-2023). The participating EAM experts were selected based on their work experience in the field of EAM. A minimum of three years of experience working in the field of EAM was required to participate. The interviewed participants were selected from three different organisations and their respective job titles ranged from director, to project manager, consultant and hard service specialist.

The goal of the semi-structured interviews is twofold: (1). To evaluate the new MM and gain valuable insights on how to improve the model further and (2). To assess the acceptance of the new MM by evaluating the performance expectancy, effort expectancy, social influence and facilitating conditions of the MM. This is done by adapting the Unified Theory of Acceptance and Use of Technology (UTAUT) framework as described by Venkatesh et al. (2003) in the article: User acceptance of information technology: Toward a unified view. The UTAUT framework was chosen because it is widely utilised in design science research and enables the effective evaluation of the MM's acceptance.

To make sure that all meetings were conducted in a similar fashion and all participants were equally informed, the interviews were carried out adhering to the following interview protocol:

1. **Preparation:** Three days before the meetings, all participants were sent a digital copy of the first iteration of the MM and a brief explanation of what to expect from the meeting. They were politely asked to, if possible, familiarize themselves with the MM by reading the documentation to allow for a more streamlined meeting.
2. **Presentation:** All meetings were accompanied using the same presentation and questionnaire, no intermediate changes were made between meetings. All slides

presented and questions asked in the questionnaire, as well as the answers by the participants, can be found in Appendix I, J and K, respectively. The meetings were recorded after first establishing verbal consent to do so. The meetings were split up into four sections:

2.1 Introduction: First informed consent for recording the meeting is established. Subsequently, the thesis topic, thesis goal, meeting goal and some relevant working definitions are introduced.

2.2 MM: A brief explanation is given of how the MM was created and what the MM evaluates / consists of.

2.3 Individual questionnaire: First the participants are asked if any questions on the MM remain at this stage. After addressing any unclarities about the MM the participants are sent a link to an online questionnaire to, individually, fill out. This questionnaire can be found in Appendix J and is to be filled out, in full, by all participants. The questionnaire starts of with some basic opening questions, followed by evaluating questions for every focus area and dimension. Lastly, the participant is prompted to evaluate questions inspired by the UTAUT model which evaluate performance expectancy, effort expectancy, social influence and facilitating conditions.

2.4 Open discussion: Lastly, the opinion of the participants is asked regarding a multitude of open questions. Not all questions are necessarily answered by each participant, but the questions are presented to guide the discussion. Whenever the discussion stalls or goes off-topic, the interviewee will intervene by trying to politely steer the discussion back to the presented accompanying questions for this discussion.

The questions accompanying the open discussion of the interviews are displayed below:

- What is your opinion on using a MM assessment to identify strengths and weaknesses in EAM implementations?
- Do you think the focus area(s) are logically divided? If not, which one(s) and why?
- Do you think any focus area(s) are missing? If so, which one(s) and why?
- Do you think any focus area(s) mentioned are not necessary? If so, which one(s) and why?
- Do you think the dimensions in the MM are representing the most important aspects of EAM in a comprehensive manner?
- Do you think any dimension(s) are missing? If so, which one(s) and why?
- Do you think any dimension(s) mentioned are not necessary? If so, which one(s) and why?
- Do you think the granularity of the maturity levels is adequate for the purpose of the MM? If not, why?
- Do you think the maturity level descriptions are clear in communicating the maturity stage of the presented dimensions? If not, why and what improvements do you suggest?

After conducting this interview protocol a total of three times, with a total of eight participants from three different organisations, all recordings were transcribed and all survey data was exported to a local save file. To create meaningful results from the conducted interviews we will now analyse the findings of the questionnaire utilising quantitative data analysis. Afterwards, the open discussion is analysed employing qualitative data analysis.

5.4.5 Quantitative Data Analysis

When analysing the results of the interview questionnaire we encounter the following noteworthy outcomes:

- **Current job/function:** Out of the 8 participants, 4 describe themselves as consultants, 3 as managers and 1 as Hard Service Specialist.
- **Years of experience:** The minimum number of years of experience is 3 and the maximum is 25. On average the participants have 13 years of experience in the field of EAM.
- **Experience with MMs:** Out of the 8 participants, 6 have previous experiences with using a MM as an assessment tool.
- **Most acquainted domain/area in EAM:** Only two participants' domains of experience in EAM overlap, both are most acquainted with “Information”.
- The relevance of all focus areas and individual domains are displayed in detail in Appendix K. To keep the text here readable, the relevant information will not be included in full here. However, we will present some noteworthy observations from the results gathered, as follows:
    - Based on the questionnaire, none of the included focus areas or dimensions in the first iteration of the MM are deemed ‘unnecessary’ for creating a broad and inclusive MM for EAM.
    - The dimensions which were scored at least necessary to include (with an average score of 1.75, where the rating of ‘1’ means ‘necessary’, ‘2’ means ‘neutral’ and ‘3’ means ’unnecessary’) are:
        - Organisational Business Process Map
        - Stakeholder Management
        - Asset Disposal
        - Qualified external support
        - Decision Support System
    - The dimension Decision Support System caused the most divide amongst the participants. As 5 participants deemed it necessary, 0 participants perceived it as neutral and 3 participants deemed this dimension to be unnecessary.
    - The dimension which was deemed most necessary to include in the MM was: Asset Operation Management. All 8 participants scored this dimension as necessary.
- The results from the UTAUT Questions in the survey are presented below in Table 18:

Table 18. UTAUT Question Analysis

Performance expectancy	Minimum	Mean	Median	Maximum
I would find the maturity model useful for assessing an organization's EAM Maturity.	3	4.250	4	5
Using the maturity model enables me to accomplish an EAM maturity assessment more quickly.	3	4.000	4	5
Using the maturity model will improve my understanding of an organization's current EAM practices.	3	3.875	4	5

Effort expectancy	Minimum	Mean	Median	Maximum
Without explanation, my interaction with the maturity model would have been clear and understandable.	2	3.125	3.0	5
I would find the maturity model easy to use.	3	3.625	3.5	5
It would be easy for me to become skilful at using the maturity model.	3	3.750	4.0	5
Learning to use the maturity model is easy for me.	3	3.750	4.0	5

Social influence	Minimum	Mean	Median	Maximum
People who influence my behaviour would think that I should use the maturity model.	2	3.375	3.5	4
Senior management of my organization will support the use of the maturity model.	3	4.125	4.0	5
In general, my organization will support the use of the maturity model.	3	3.875	4.0	5

Facilitating conditions	Minimum	Mean	Median	Maximum
I have the resources necessary to use the maturity model.	2	3.125	3.0	4
I have the knowledge necessary to use the maturity model.	1	3.375	4.0	4
A specific person (or group) is available for assistance if I encounter difficulties with the maturity model.	2	3.500	4.0	5

The answers to the UTAUT questions from the questionnaire give valuable insight into RQ5, as it shows to what extent the proposed MM was perceived as *usable* and *useful* in practice. Therefore, a more in-depth analysis of these results will be given in section 5.4.7. In this section, RQ5 will be answered, but before doing so, we will discuss the results of the qualitative data analysis first, in section 5.4.6. This is necessary because section 5.4.6. also provides insights helping to answer RQ5. The following qualitative data analysis was created based on the recordings of the open discussions with 8 participating experts in the field of EAM.

5.4.6 Qualitative Data Analysis

For the purpose of the qualitative data analysis of the conducted open discussions, the recordings were first transcribed. These transcripts are then analysed through qualitative inductive coding (Newcomer et al., 2015). This included multiple reading cycles of the transcripts as follows: A first initial read-through is done to get a feel for the data and important sections are highlighted. The second read-through is a line-by-line read-through where important sections are not only highlighted but also shortly summarised. Lastly, the summarised excerpts are coded from my perspective. The codes generated differentiate between excerpts of text that are deemed either (1) affirmative / validating, or (2) Pointing to gaps in the current MM, or (3) Indicating points of improvement / unclarities or lastly, (4) pointing to ideas for future of work. Due to the fully coded transcript sometimes giving away personal information or information about an organisation, it is not added as an appendix to this thesis.

However, summarised notable takeaways from the process of coding the interviews, categorised by their coding groupings, are presented below. For clarity, we identify the evaluation study participants as P1, P2, P3, P4, P5, P6, P7 and P8.

(1). Affirmative / validating:

- Participants P3 and P8 state that he/she believes that the current MM can assess a very broad range of relevant business processes.
- Interviewees P1, P2, P3, P4, P5, P6 and P7 agree that the level of granularity displayed in the presented focus areas and dimensions is okay from their point of view.
- Participant P7 confirms that all focus areas mentioned are important to be assessed. This participant strongly confirmed that he/she does see the need for such a broad MM for management to effectively be able to manage dimensions, also those outside of their expertise.

(2). Gaps in the current MM:

- Participant P2 deems it important that a consistent business culture is adopted throughout the organisation as a whole. This participant values that colleagues have a shared consistent focus and mindset. Hence, in the view of this participant, the dimension of shared focus should be more explicitly represented in the proposed MM. Participant P1 also confirms this.
- Participants P1, P2, P4, P7 and P8 believe that the MM is lacking a focus area on Corporate Social Responsibility. They add that this can be an internal responsibility towards employees but also external as in social and environmental responsibilities.
- Participant P4 states that misses a dimension on the physical security of assets. He/she gives the vulnerable nature of an oil pipe as an example.

- Participant P7 adds to the inclusion of the focus area CSR, that this focus area should also be concerned with how data is treated and for example the inclusivity of the hiring process of employees.
- Participant P7 states that the proposed MM is missing compliance. This can be considered a focus area that is built up by dimensions on law and regulations, insurance, company guidelines and contractual obligations. This participant further thinks that the MM should also include a dimension dedicated to the construction of KPIs for various assets.

(3). Points of improvement / unclarities:

- It remains unclear to four Participants P2, P4, P7 and P8 what exactly is to be considered 'a best practice'. These participants considered this to be a dynamic term because what is a best practice in a certain domain or for a specific industry may not be the same as for a competitor. Furthermore, it is important to consider that a best practice can be dependent on an organisation's business goals.
- Participants P4 and P7 experience the dimension of information openness as vague. Participant P7 would like it to be replaced with Information Availability and Accessibility.
- The participants (P4 and P7) had reservations about the inclusion of Digital Twin as a dimension. Participant P7 perceives it as random. In the view of P4, the dimension Digital Twin should be removed as it is an example of a Decision Support System..
- Participant P7 thinks the MM could benefit from the ability to assess the dimensions not by the presented maturity levels but by splitting the maturity levels into multiple, separately graded evaluation criteria. In the experience of this participant, a business activity might be completely ad hoc, yet very much in line with the business goal. The current maturity levels do not allow for making such a differentiation. In line with this, P7 suggests having all the dimensions assessed on their documentation, repeatability, monitoring, level of standardisation and alignment with business goals separately. A dimension can be monitored perfectly, yet not in line with business goals, and vice versa.
- Participant P7 deems information quality part of information collection and dissemination.
- Participant P7 thinks that too many used dimensions overlap with one another and would preferably like to see distinctive / exclusive dimensions only.

(4). Future of work:

- Participant P1 expressed interest in further elaboration of the proposed MM. In the view of P1, the dimensions in the MM can benefit from being supplemented with a question for assessment.
- Participant P2 explains that it might be interesting to research if the order in which the focus areas are presented and assessed influences the outcome of the assessment. P2 believes that bringing up cost at the start of the assessment may influence the ratings people give for the dimensions afterwards.
- Participants P1, P2, and P4 are convinced that it would be interesting to have the MM filled out by varying industries to examine the differences of focus in EAM across industries.
- Participant P2 pointed to the missing ability of the MM to display relationships between dimensions and how they influence one another. For example how one acts on information within asset lifecycle management.
- Participant P7 states that it might be interesting to arrange the dimensions in a manner where they are divided by the officials that are responsible for them, he/she gives the example of documentation belonging to quality and standardisation officers and strategic goals belonging to managers.
- Participant P7 thinks that the MM could benefit from examples for each dimension.

The insights, documented above, have been gathered during the conducted open discussions with experts in the field of EAM. These insights will be of great use when creating the second iteration of the MM. Implementing and modifying the MM with these suggestions from experts will make the MM more solid and grounded on real-world practice, in addition to the solid academic basis that the MM has right now. However, it should be noted, that to verify the suggested changes, the proposed second iteration of the MM should be re-evaluated by practitioners once again. This needs to be done in to complete a full second iteration. This unfortunately will be outside of the scope of this thesis. However, an improved version of the MM in a second iteration, taking into account the feedback gathered from experts in the field of EAM, will be presented in subsection 5.4.8, to include the suggested changes.

With the quantitative and qualitative analysis of the MM evaluation conducted and documented, we will now address RQ 5.

5.4.7 RQ5: To what extent is the proposed maturity model usable and useful in practice?

To answer RQ5, we will first focus on what insights the quantitative analysis has generated and how these can be interpreted, subsequently, we will consider what insights the qualitative analysis has generated and what this means for RQ5.

From the answers gathered in the questionnaire, the following overview of the UTAUT categories and their respective scores have been calculated (see Table 19). These scores show the minimum, mean, median and maximum scores of all performance expectancy, effort expectancy, social influence and facilitating conditions questions combined per category.

Table 19. UTAUT Overview

Overview UTAUT Model Evaluation	Minimum	Mean	Median	Maximum
The overall performance expectancy.	3	4.444	4.0	5
The overall effort expectancy.	2	3.500	4.0	5
The overall social influence.	2	4.095	4.0	5
The overall facilitating conditions.	1	3.455	4.0	5

Considering the overall score on performance expectancy, it can be concluded that the proposed (first iteration of the) MM is perceived by the eight participants as a *useful model*. Most participants agree the proposed MM would be useful for assessing an organisation's EAM and doing so in a quick manner. Most participants also agreed that using the MM could improve their understanding of an organisation's EAM practices. With a minimum score of 3 and a maximum of 5 across all three performance expectancy statements, we can conclude that none of the participants feel negative about the MM's performance expectancy and considering the 4.444 mean score, most participants even strongly believe in the MM's ability to be of use.

As for the effort expectancy of the MM, with an overall mean of 3.5, the participants are slightly leaning toward a positive evaluation of the effort expectancy. This is mainly due to the low score on the first prompt: "Without explanation, my interaction with the MM would have been clear and understandable", which scores a mere 3.125 on average. The other prompts for effort expectancy all score an average of 3.625 or above, indicating that the proposed first iteration of the MM can still benefit from becoming more clear. This could be

achieved by improving the model's layout, creating more detailed descriptions of dimensions and potentially adding practical questions to start the discussion for each dimension. The ease of using, learning to use and becoming skilful at using the MM are evaluated fairly high, indicating that the learning curve for using the MM is perceived as low.

As for the social influence prompts, the overall score in this category is also fairly high, as it scored 4.095 on average. When dissecting the scores, the lowest scoring prompt in this category is the “people who influence my behaviour would think that I should use the MM,” scoring only slightly towards a positive evaluation with a mean score of 3.375. However, the following two prompts, which ask about the support from senior management and their respective organisation as a whole, scored significantly higher with 4.125 and 3.874 on average. This indicates that the participants do anticipate that their organisation might want to support the use of the proposed MM.

Lastly, the proposed MM scores an average of 3.455 on the overall facilitating condition prompts. Which is once again slightly leaning towards a positive attitude. However, this is the first category where a prompt scored a minimum score of 1 in one of the prompts. This prompt was the following: “I have the knowledge necessary to use the MM.” This means that at least one of the participants strongly disagreed with this statement. A follow-up with this participant will be useful in order to evaluate why this score was given here and how the MM can be improved to improve this facet of the model. It should be noted that this opinion was also not shared amongst the group of participants, as the average score on this prompt was 3.375, with 5 out of 8 participants scoring it a 4 (which translates to agree). The prompt “I have the resources necessary to use the MM,” also scored relatively low with a score of 3.125 on average. This may be the result of the broad and explorative nature of the model, but further interviews should be conducted to figure out what resources specifically could help improve this score.

As presented in section 5.4.6, the qualitative analysis has also generated various insights into how the interviewees perceived the model and collected diverse opinions on how to improve the MM. The gaps and points of improvement / unclarities identified in the MM are clear indications that the MM could benefit from an extra iteration. Likewise, the future of work suggestions also indicate suggestions of how the MM could be extended in the future, to add extra functionalities and explore potentially interesting new approaches for conducting a similar maturity assessment. Yet, the affirmative / validating comments by the participants, as described in grouping 1 in section 5.4.6 also indicate that the proposed (first iteration) MM already provides value. Two participants, for example, explicitly expressed that they believe the proposed MM would already be able to assess a very broad range of relevant business processes. Nearly all participants also agreed that the proposed MM presents the right level of granularity, one fitting the intended broad and explorative scope of the MM. Interviewee 7 also pointed out that there indeed is a need for a MM, like the proposed MM, in practice.

All in all, considering the feedback from the open discussion, the questionnaire and specifically the feedback gained from the UTAUT model scores, *it is to be concluded that the first iteration of the MM is well-received and considered to be useful according to the 8 interviewed EAM experts.* There is, however, definitely room for improvement. Therefore a second iteration of the MM is created with the feedback received in mind. The next subsection will develop and present this second iteration of the MM.

5.4.8 MM development - Second iteration

Before considering what changes can and should be made to the MM itself, it is important to acknowledge the feedback on the theoretical side of the MM creation process as well. During the presentation for gathering feedback, some background information about the MM creation process was presented. This included the presentation of the working definitions, as defined in the theoretical framework of this thesis. However, based on the feedback gained from the interviews, it turns out that the term “best practice” could also benefit from having a clear working definition.

During the interviews, various definitions of “best practice” were discussed. Based on this discussion the following working definition for the term best practice was chosen.

Working definition - Best practice:

> *Best practice is a dynamic term. What is considered to be a best practice may change over time and may differ depending on dimensions, industries, business goals and more. A practice is considered to be a best practice for a specific dimension if it is able to balance risk, performance and cost in an optimal manner.*

Let us now focus on the MM itself. Considering the feedback from the interviews and the following quantitative and qualitative analysis (Sections 5.4.6 and 5.4.7), a second iteration of the MM for improved EAM is created. This second iteration adopts many of the suggestions made by the experts (participating in the first evaluation of the MM proposal), as this will help increase the usability of the MM in practice. Unfortunately, not all suggestions made were possible to implement considering the timeframe of this thesis and the expertise necessary to do so. For example, displaying the various relationships dimensions and focus areas may have, or how the sequence of presenting the focus areas and dimensions influences the created assessments.

Figure 10 presents the result of the second iteration in the development of the MM for EAM with all manageable modifications, as suggested by the participants in the evaluation. The MM is extended with two new focus areas: **Corporate Social Responsibility** and **Compliance**. Corporate Social Responsibility consists of six dimensions: *Environmental Sustainability, Social Impact, Employee Well-being, Inclusive Recruitment and (Personal) Data Protection and Privacy*. Next, the newly added focus area Compliance consists of four dimensions: *Laws and Regulations, Insurance Compliance, Corporate Policy Compliance and Contractual Obligations*.

Furthermore, as suggested in the group discussion, the dimension of *Business Culture* is added to the Strategic Direction focus area. The dimension of *Physical Asset Vulnerability* is added to the Security focus area. And the dimension of *Information Openness*, previously part of the focus area Information Quality, is renamed to *Information Availability and Accessibility* as it was deemed a more clear and understandable name for this dimension. Lastly, even though the dimension *Digital Twin* did not reach a majority vote for being deemed unnecessary in the context of this MM, two interviewees did specifically note that they did not find it necessary or even logical to add this dimension in the model as it is a specific tool and not a general dimension. Furthermore, they consider it to be part of the dimension: Decision Support System. After a more in-depth discussion on this topic after the interviews with one of the interviewees that felt this way, it was decided to drop this dimension in the second iteration of the MM. In Figure 10, below, the second iteration of the MM is presented. Here new dimensions and focus areas suggested by interviewees are indicated with [EO] as the source, which stands for Expert Opinion.

Figure 11. Second iteration of the new MM for improved EAM

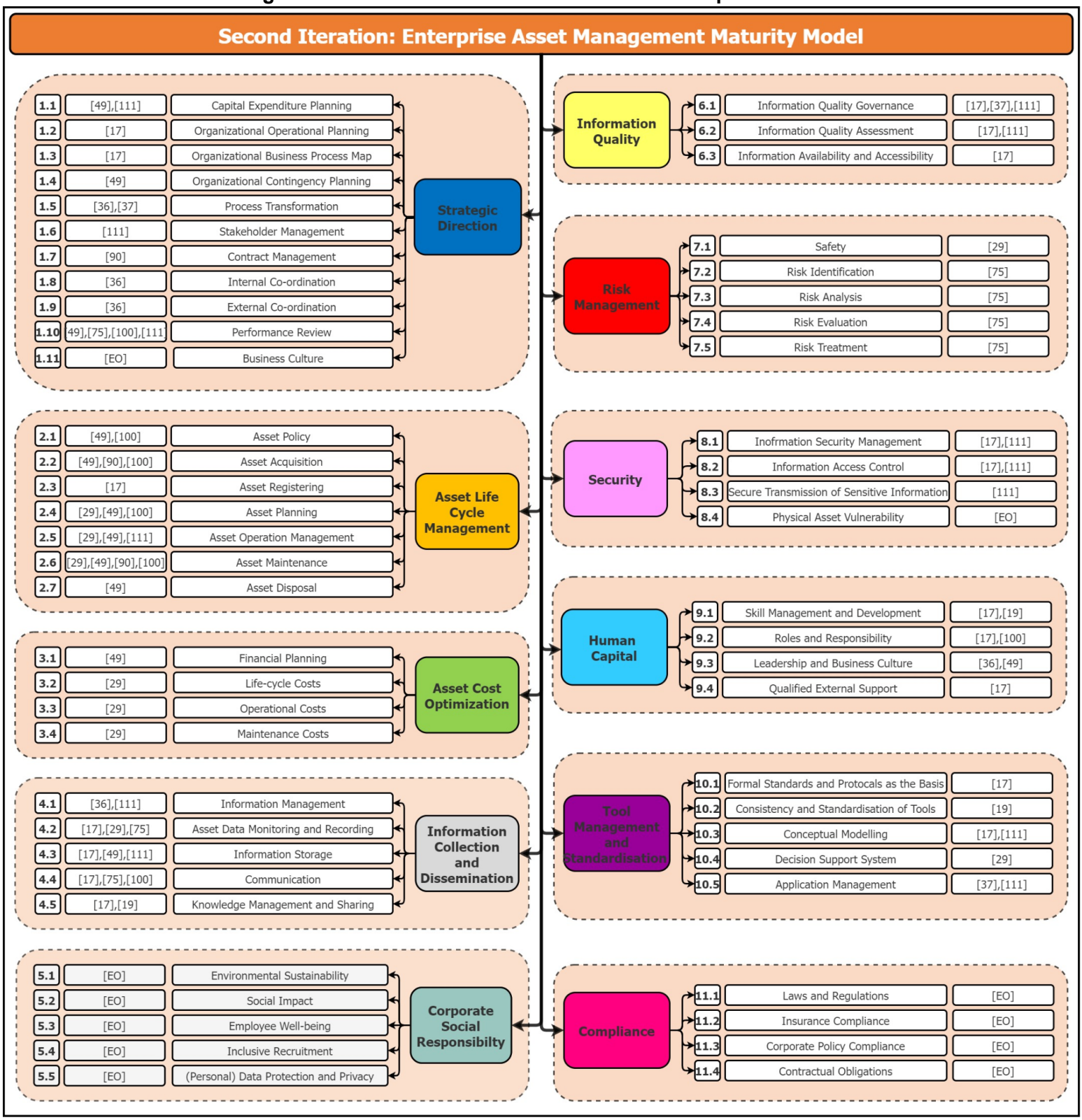


Table 20.a Overview of extra focus areas/dimensions in the second iteration of the MM

No.	Dimension	Description
1	**Strategic Direction**	Strategic Direction refers to the overarching enterprise-wide approach of an organisation towards business goals and objectives. Strategic Direction consists of various internal and external processes that are concerned with developing, planning, and prioritising asset activities to be aligned with the organisation's strategic vision.
1.11	Business Culture	Business Culture forms an essential dimension of an organisation, as it impacts an organisation's strategic direction. Business Culture concerns itself with workplace behaviour and the business vision. It is important that all employees embrace the business culture. This can help enable effective collaborations and a consistent focus on business goals throughout the various departments of an organisation.

Table 20.b Overview of extra focus areas/dimensions in the second iteration of the MM

No.	Dimension	Description
5	**Corporate Social Responsibility**	Corporate Social Responsibility focuses on taking responsibility for the impact an organisation may have on various aspects: environment, employees, society, and more. It is important to have a conscious and sensible approach towards all that is influenced by your organisation's activities. Doing so can improve sustainability, minimise risks and enhance branding.
5.1	Environmental Sustainability	In the context of Environmental Sustainability in EAM, it is important to be aware of your assets' influence on their surroundings. This includes but is not limited to, recycling, increasing energy efficiency, responsible asset disposal and sustainable sourcing.
5.2	Social Impact	It is important to be aware of what impact your organisation's various business activities may have on an economic and social level. As a responsible organisation, it is important to address preferably prevent/resolve any negative impact one might have and strive to provide value wherever possible.
5.3	Employee Well-being	Oftentimes, employees are a company's most valuable assets. They should be treated accordingly: with respect, recognition and care. This care should not only be focussed on physical and mental / emotional well-being.
5.4	Inclusive Recruitment	An organisation should be inclusive and unbiased in their recruitment process, not leaving anyone behind. This way the organisation can prosper from all benefits associated with a diverse workforce which offers a diverse set of perspectives.
5.5	(Personal) Data Protection and Privacy	Responsible data management is of the utmost importance, especially for organisations responsible for processing large amounts of personal data. It is important to always be aware of what data is really necessary and that it is processed, stored and transferred in a secure and responsible manner. Negligence in this dimension can have a severe impact on people's lives and therefore seriously impact how an organisation is perceived by the public.

Table 20.c Overview of extra focus areas/dimensions in the second iteration of the MM

No.	Dimension	Description
8	**Security**	Assets can be crucial for facilitating business activities and generating actionable insights, it is important to handle sensitive assets with care. To ensure the safe and controlled handling of sensitive assets, robust security measures should be implemented and upheld.
8.4	Physical Asset Vulnerability	When considering the security of assets, it is also important to consider the physical vulnerability of an asset. Especially assets crucial to business operations. If the vulnerability is high, it might be wise to consider adding extra security measures to limit risks, ensure safety and safeguard uptime.

Table 20.b Overview of extra focus areas/dimensions in the second iteration of the MM

No.	Dimension	Description
11	**Compliance**	When handling a large number of diverse assets, it is important to be aware of and adhere to all laws, regulations, policies, contracts and standards one must adhere to. Especially as failing to do so might have dire consequences.
11.1	Laws and Regulations	When conducting any business activities it is vital to adhere to the laws and regulations applicable. Failing to do so may result in fines, getting sued or having licences / privileges suspended.
11.2	Insurance Compliance	Insurance can facilitate a strategic approach to protecting an organisation, mitigating certain risks, and maintaining financial stability. But to be covered, one needs to adhere to the terms and conditions set out by the insurance provider. Therefore insurance compliance is crucial.
11.3	Corporate Policy Compliance	Corporate Policy Compliance concerns itself with how an organisation ensures ethical conduct and legal compliance by employees.
11.4	Contractual Obligations	Contractual Obligations compliance refers to the process of ensuring that each party of a contract meets their agreed-upon obligations and performance. Examples of such contractual obligations can come in the form of service/maintenance contracts, warranties, and supplier contracts. Not only can failing to do so have financial consequences, it may also hurt relationships and or have legal consequences.

With the updated dimensions and focus areas of the second iteration of the MM described, this iteration nears its completion. But before completing the iteration, it is important to reconsider the chosen maturity levels for the MM.

In general, the participants perceived the previously chosen maturity levels as fairly clear and useful for evaluating the maturity of the presented dimensions. However, participant P7 disagreed with this. This participant thought the MM could benefit from splitting the maturity levels into multiple, separately graded evaluation criteria. P7 argued that the proposed maturity levels were unable to represent certain scenarios. Take for example a dimension which is implemented completely ad-hoc. The process is unorganised, undefined, not standardised and adopted on an ad-hoc basis, this however, does not necessarily mean that it would also have to be unaligned with business goals. Furthermore, an industry best practice may be implemented, but this does not necessarily mean it is aligned with the business goals.

This thesis's author thinks that Participant P7 is right in arguing that the proposed maturity levels are unable to express these scenarios, which negatively affects the accuracy of the evaluations. P7 proposes splitting the ratings into multiple criteria, scored separately, instead of using the proposed maturity levels. No examples or supporting literature for assessing maturity in this way, have been found in the (69 papers from the) SLR. But considering the valid arguments Participant P7 brought up, it will be interesting to test the usability of this new approach. Added that this approach would not only give a more accurate description of the maturity of the dimension but also would help identify what causes certain maturity scores and who may be able to improve the respective scores.

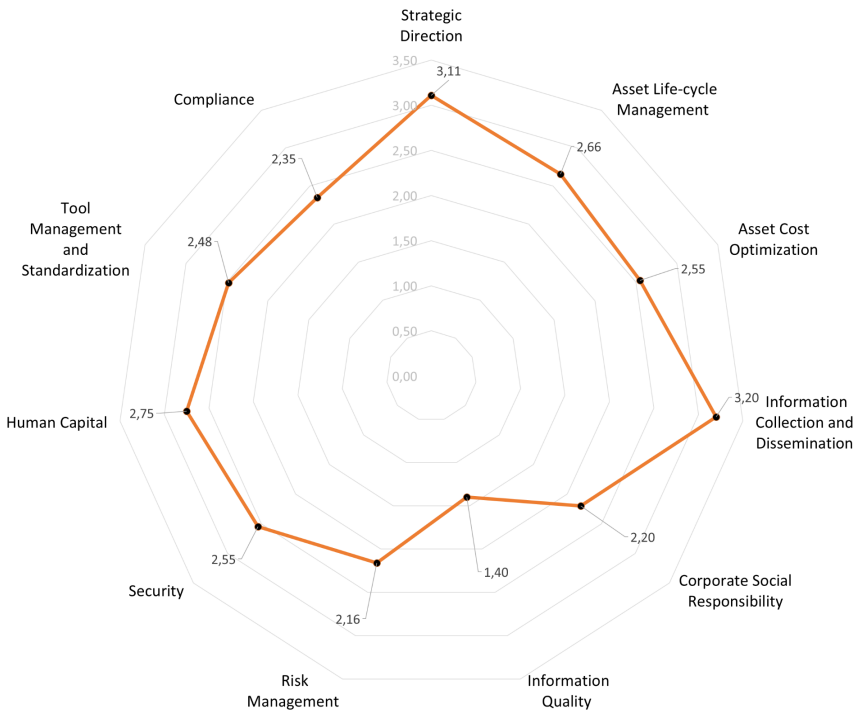
Therefore, for the second iteration, the chosen criteria to be evaluated for each dimension are (1) Organisation, (2) Definition, (3) Standardisation, (4) Monitoring and (5) Business Goal Alignment. Each of these five criteria will from now on be scored separately based on how the criteria is implemented in the organisation for the specific assessed dimension. The maturity levels used for evaluating the aforementioned criteria are inspired by the maturity levels of Cornu et al. (2012) and consist of the following levels:

- Initial (Scoring a 0)
- Low (Scoring a 1)
- Neutral (Scoring a 2)
- Good (Scoring a 3)
- Excellent (Scoring a 4)

Based on the assessments, average scores will be calculated to determine the organisation's overall maturity level for either a specific dimension, focus area or criteria. Doing so can help sketch a more accurate picture of the strengths and weaknesses of an organisation's EAM approach. And hereby should be able to generate a more detailed roadmap towards improved EAM practices.

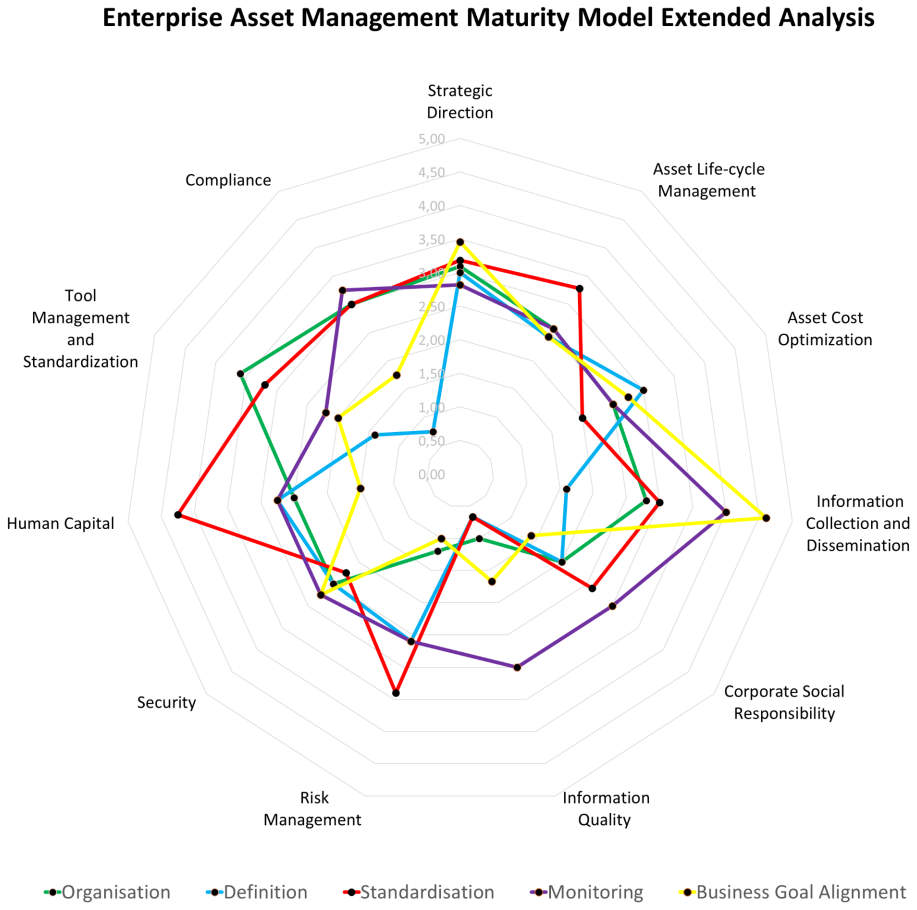
After generating the model in Excel and filling it with fictional / dummy data, a new spider chart is also generated. This time around, the spider chart is not made up of 9 series, but 11 series. An example of the generated spider chart is shown below in Figure 12.

Figure 12. Second Iteration MM for EAM - Spider Chart (Based on fictional data)



But, as described above, the second iteration calculates its maturity score based on the average score of the 5 criteria: (1) Organisation, (2) Definition, (3) Standardisation, (4) Monitoring and (5) Business Goal Alignment. These scores per focus area can also be shown separately, to sketch a more detailed picture as to what criteria perform well and which perform less. An example of such an analysis, in the form of a spider chart, is shown below in Figure 13.

Figure 13. Second Iteration MM for EAM - Extended Spider Chart (Based on fictional data)



This completes the creation process of the second iteration of the new MM for improved EAM. To sum up, this iteration improves upon the first iteration in a variety of ways: (1) new focus areas and dimensions are added, (2) some old dimensions are renamed or removed, and (3) the approach to assessing maturity is changed. Clearly, this improved MM needs its proper evaluation through follow-up empirical studies. Before evaluating and testing it, no statements can be made about the usability and usefulness of the adopted changes.

If, after a thorough evaluation of the second iteration of the proposed MM, the MM would be accepted, then subsequently phases 5, 6 and 7 of the framework by Becker, Knackstedt and Pöppelbuß (2009) are to be fulfilled. These three phases are concerned with the industrial transfer and evaluation in real-world applications. Unfortunately, the three phases are outside of the scope and timeline of this thesis. However, they will be touched upon in the future work section of this thesis.

6. Discussion and Reflection

In this chapter, the results of this thesis will be discussed and reflected upon. This is done in four subsections which, respectively, treat (1) the contributions to practice, (2) the research contributions, (3) the research limitations and (4) some suggestions for future work endeavours.

6.1 Contributions to Practice

The research in this thesis makes several practical contributions. First, practitioners in the field of EAM are now able to assess the maturity of an organisation's EAM approach with the help of a comprehensive and explorative MM. This MM is applicable for any large asset-intensive organisation, regardless of industry / sector and may serve as a benchmarking and self-assessment tool. The MM can identify the strengths and weaknesses of the current EAM approach, as the MM is descriptive. And by doing so the MM can help ease decision-making. The generated assessment can be the starting point from which organisations can either decide to conduct a more detailed exploration or start building a plan towards improved EAM practices in a specific domain.

Second, as for Pernino Consulting, and consultancy firms alike focussing on EAM, the created MM can function as an initial tool to explore in which dimensions it can be of assistance to a client. The proposed MM can be used during a first introduction and may be able to get a foot in the door of a potential client, as it may provide a clear and structured manner to open up a discussion about the various EAM practices in an organisation.

Third, the created MM should be able to be used by almost any practitioner, even with fairly limited EAM experience, and the effort to do so is fairly low. This was confirmed by the evaluation of the MM with the help of the evaluated UTAUT prompts. The scores of the UTAUT questions about the model, filled in by 8 experienced practitioners in the field of EAM, reflect this statement.

6.2 Contributions to Research

This thesis makes three research contributions. First, the thesis provides an extensive SLR which presents state-of-the-art research on the topics of MMs and EAM. It not only provides an analysis of the various relevant working definitions adopted by the authors of the 69 included articles but also gives a clear overview of the benefits and shortcomings identified by researchers in assessing maturity in EAM using MMs.

Second, the thesis presents a unique MM for EAM. Considering no current literature (as found in the SLR) has yet tackled the challenge of creating a comprehensive and explorative MM for EAM, applicable for a multitude of industry sectors and taking a broad perspective on what is considered to be an asset by not only focusing on physical assets but also considering a broad range of intangible assets. This is a unique selling point for the created MM, which was not found in any other MM in the SLR. Lastly, this thesis contributes to research by building upon existing MMs and not only presenting a conceptual MM solely based on literature but also taking feedback from practitioners into account when creating

the MM. The proposed MM is the result of two iterations, leveraging both the state-of-the-art knowledge from the SLR and the insights of the eight practitioners included in the first evaluation study.

Third, the proposed MM is a theoretical contribution. It is a conceptual model composed of concepts (namely, focus areas, dimensions, and maturity levels) and relationships among these. These relationships can be considered as hypotheses to be tested and evaluated in follow-up empirical studies by other researchers in a variety of real-world contexts. In this way, our MM can serve as a foundation for planning future empirical research that is necessary to further expand our understanding of the EAM phenomenon from a maturity standpoint.

6.3 Research Limitations

This section describes the limitations of the research conducted in this master's graduation project. The limitations are also concerned with the threats to the validity of this research. To ensure transparency and make readers aware of potential pitfalls, the limitations of this research will now be presented in chronological order in which they were encountered whilst conducting this research.

First, the limitations of the conducted SLR. Although the SLR was conducted in an as comprehensive and thorough as possible manner (even taking various precautions by assessing the quality of the SLR selected sources), it cannot be guaranteed that whilst performing the search for sources, potentially relevant keywords have been overlooked. Not including relevant keywords in the queries that form the paper selection, can negatively impact the results of the SLR as potentially relevant papers may have been left out. Furthermore, on the topic of limitations in the source selection of the SLR, the conducted SLR could have been more inclusive by using less strict inclusion and exclusion criteria. For example, by allowing sources older than 10 years and not solely using SCOPUS as a literature search engine but also using alternatives such as Web of Science and Google Scholar. Furthermore, the number of papers that were considered based on their title first, then on their abstract and eventually on the full paper versions also represents a limitation. The maximum number of sources to be considered for each of the 6 queries was 100 and therefore may have limited the scope and thus the validity of this research.

Another set of limitations becomes apparent when considering the MM creation process. First of all, similar concerns as the ones described above concerning the SLR are applicable here. This is because the MM creation process is dependent on the existing MM selection process and this process is based on part of the SLR. So if keywords are overlooked in the queries of the SLR potentially useful MMs may not have been taken into consideration for the MM development.

The selection process within the MM development process, to narrow down the number of MMs to consider for the systematic pivot model comparisons, as well as the selection of dimensions that are deemed relevant, to make the dimension comparisons more manageable, are both processes that were shaped by a selection process. For these processes, inclusion and exclusion criteria were created and documented transparently, as reported in Chapter 5.2.1 and Chapter 5.2.2. However, the inclusion and exclusion criteria focused on selecting the right level of granularity in MMs and their respective dimensions. One may think of this process as somewhat subjective. Although this process was conducted with the utmost care and whilst carefully considering the various MMs and presented dimensions, it is difficult to assess the degree to which this process was executed

fittingly, especially considering the author's limited practical experience in the field of EAM. This stage of the selection process could have benefited from the expert opinion of practitioners in the field of EAM.

Moreover, the process of comparing dimensions, as described by Lautenschutz et al. (2018) is limited in its ability to make comparisons, as it only works for making domain-specific comparisons. This means that one can only effectively compare dimensions from different MMs if they are similar in domain and level of detail. In the dimension comparison step described in Appendix G, this limitation is handled by displaying dimensions that could not be compared to other dimensions in separate rows, presenting them as unique constructs. These unique constructs are subsequently all evaluated individually to determine if they would aid in creating a comprehensive and explorative MM for improved EAM. If so, they are used in the making of the new MM, if not, these dimensions are dropped and not taken into further consideration.

The evaluation of the MM also presents some limitations to be mindful of. First of all, the sample size of the expert interviews. In total, eight experts in the field of EAM were interviewed. This most definitely has resulted in numerous valuable insights, but the MM evaluation would have benefitted from more expert evaluations. The workshop styled-meetings have been very useful in conducting the semi-structured interviews, but the varying group size and varying relationships between the interviewees (for example groups with colleagues as compared to strangers) may have affected the outcome of the interviews. Especially in the open discussion. As one, for example, might not speak as freely with your superior in the room. Furthermore, more introverted participants may not have been able to express their opinions as easily in a group with expressive extroverted participants present. Although the author has actively tried to prevent this from happening by steering the conversation wherever necessary, and asking specific questions to interviewees who had not yet expressed their opinion, it still is a limitation of conducting the semi-structured interviews in a group setting.

Next, it should be noted that some of the participating experts could potentially have a slight bias concerning the research as the author has become acquainted with some of the interviewees, as they have worked in a collegial setting for approximately half a year. This potentially may positively affect the evaluations given by the interviewees.

An important validity threat in the evaluation study is related to the generalizability of the findings. Would it be possible to obtain similar findings, if the eight participants were different experts in the same organisation? Following (Ghaisas et al, 2013) and (Seddon and Scheepers, 2011), the author of this thesis thinks that it might well be possible to collect similar perceptions from different experts who share the same contextual settings as the participants involved in the evaluation. This is because the similarity of contexts could possibly create similar organisational mechanisms that lead to experiencing similar aspects of the same phenomenon by the people sharing the context. One might wonder: would the results be different if the participants were drawn from other similar but different organisations? Again, this might be possible. For example, if the organisations have the same level of interest in EAM, willingness to assess their maturity in EAM, level of commitment to systematically improve EAM, and also similar process-oriented thinking, sense of priorities and understanding of the various focus areas and their respective dimensions.

Moreover, another threat to the validity of this study is the absence of any empirical test for evaluating the chosen maturity levels' maturity-performance link. Although the motivation for choosing the respective maturity levels has been documented in detail, it remains a predominantly subjective process which may negatively affect the validity of the MM.

The iterative MM development steps, described in this thesis, show the creation and evaluation of the first iteration of the new MM for improved EAM, which led to the second iteration. This iteration of the MM development is documented and created. The resulting MM has 2 new focus areas and several new and modified dimensions (Chapter 5.4.8). However, due to the scope definition and the pre-set duration of this project,, it is not possible to evaluate the second iteration of the MM as well. This, however, forms a line for future research.

6.4 Future Work

This research has achieved its goal of creating a new comprehensive and explorative MM for improved EAM, and by doing so, has created a solid basis to start to work on improving the MM for improved EAM even further. This section will therefore not focus on the various limitations that were encountered during this research but will focus on the various potentially interesting future work endeavours that were identified.

First of all, as indicated previously, the iterative MM development process has completed its first iteration by creating the first MM iteration and evaluating it with the help of 8 experts in the field of EAM through workshop-styled semi-structured interviews. These interviews have provided a lot of feedback on the proposed MM, which (after analysis) has helped immensely in improving the MM and creating a second iteration of the MM. The creation process has been documented in Chapter 5.4.8, yet to complete this second MM development iteration completely, this new second iteration of the proposed MM should once again be evaluated by experts. This would be a meaningful next step in improving the MM further.

From the author's perspective, this step has become particularly interesting, as the newly adopted suggestion of evaluating maturity based on multiple criteria, that are scored separately, instead of using a more conventional 5 fixed staged maturity levels may be an interesting and useful development going forward. The arguments provided by one of the participants in the evaluation study for doing so were perceived as very logical, yet they should be tested with a multitude of experts (and preferable in practice by conducting a case study as well) to determine their actual benefit / value.

Subsequently, depending on the outcome of the evaluation of the second iteration of the MM, the MM development loop should either be iterated once more or if the outcome is satisfactory phases 5, 6 and 7 of the MM development process as described by Becker, Knackstedt and Pöppelbuß (2009) should be executed to complete the full MM development process. These steps would be (5). the conception of the transfer and evaluation, (6). the implementation of the transfer media, and finally (7). the evaluation of the MM.

Further future work undertakings, that have been suggested by participants from the evaluation phase, are to operationalize all dimensions in the MM with practical questions. These questions should be created to further improve the understanding of the dimensions and to steer the discussion towards an accurate evaluation. Or instead of adding practical questions, the MM would benefit from conversion into a prescriptive MM. This would help with creating a roadmap towards improvement when using the MM and would improve the understandability, usability and repeatability of the MM. As all dimensions and their respective maturity levels would be described in full by describing what a similar EAM approach would look like in practice.

One participant also suggested it would be interesting to explore how the sequence of presenting the focus areas and dimensions would affect the MM scores. Starting the MM evaluation, for example, by assessing financial dimensions, may cause the interviewed organisation's representative to be more cautious in their assessments going forward as compared to starting off with a focus area such as human capital.

The MM could most definitely also benefit from extensive testing through case studies, so through applying the MM in practice in collaboration with an organisation and evaluating the usefulness of the generated insights and outcomes. To add to this future work, it would be especially interesting to test various organisations in multiple industries. This way, one could potentially map patterns occurring in the EAM approach for the various industries. It also would give more insight into how competitors or comparable organisations score and what differentiates a firm from others in the same industry.

Lastly, to improve the accuracy of the assessment of the proposed MM, the model would benefit from making the MM assessment more quantitatively measurable. This can be done by determining computable KPIs for the various MM dimensions.

7. Conclusion

This final chapter summarises the thesis goal and the research questions answered to achieve this goal. The goal of this thesis was to create a comprehensive and explorative MM for evaluating an organisation's EAM performance. To achieve this goal the following research question was formulated:

> *What are the key dimensions and* sub-dimensions *that make up a maturity model for comprehensively evaluating an asset-intensive organisation's approach to enterprise asset management?*

To answer this research question, 5 sub-questions were formulated and answered. These sub-questions and their respective answers are presented here first. After this, the answer to the main research question will be presented.

> **RQ1.** *What is a maturity model?*

To explore what a MM is, first, the definition of maturity was explored. The working definition of maturity in the context of this thesis is defined as follows: *Maturity is the dynamic state which indicates how explicitly defined, managed, controlled and effective a process is. This state is dynamic and can progress in various ways to reach an improved state. The final state/level of maturity is considered to be complete and perfect.*

With this definition in mind, the definition of the term MM is explored. The working definition of the MM in the context of this thesis is defined as follows: *A MM is a model which assesses the maturity of a specific domain based on a multitude of maturity levels, doing this can assist in decision-making and be used to guide, as well as monitor, the transformation process towards reaching an improved or fully mature state over time.*

This answers RQ1, yet to be thorough and complete in the exploration of what a MM is, the various maturity modelling approaches, benefits and shortcomings of MM from the SLR have also been documented in the theoretical framework of this thesis.

The various MM types and approaches explored are *(1) Descriptive, prescriptive, and comparative MMs, (2) Progression models, capability models and hybrid models, (3) Fixed-level MMs and focus area MMs, (4) The continuous representation approach and the staged representation approach, (5) Top-down maturity modelling approach and bottom-up maturity modelling approach, and (6) Qualitative measures, quantitative measures and a combination of both*.

The identified benefits from the SLR associated with MMs from the SLR were grouped and described as *(1) Improvement Roadmap, (2) Gain insight into capacity and capabilities, (3)Aid in decision-making, (4) Comparisons, (5) Monitoring progress, and (6) Common language.*

The identified shortcomings from the SLR of (existing EAM) MMs are *(1) Lacking a clear structure, documentation, or methodology on the creation process, (2) MMs on EAM oftentimes fail to take into account the broader organisation as a whole and only focus on the evaluation of operational and technical levels of mainly physical asset management, (3) MMs are oftentimes capable of describing the gap between actual and intended organisational design, yet unable to depict how to fill or solve this gap, (4) A lack of empirical*

assessment and evaluation. A high number of conceptually developed MMs lack evaluation/validation due to authors often opting for creating new MM instead of using, improving, extending or validating already existing MMs, (5) Challenging nature of translating the goals of certain domains into varying maturity levels, (6) Oftentimes MM insufficiently address interoperability by exclusively accounting for a single facet of interoperability, (7) MMs often are not flexible enough to keep up with managing changes whilst adhering to certain quality improvement principles.

RQ2. *What maturity model characteristics are suitable for the proposed (new) maturity model on EAM?*

Whilst taking the thesis goal, time constraints and resource limitations into account, it was decided to shape the MM according to the following design choices: the MM will be *(1) descriptive, (2) fixed-level, (3) display a staged representation, (4) created with a bottom-up approach, and (5) using qualitative measures to assess maturity.*

RQ3. *What is enterprise asset management?*

To explore what an EAM is, first, the definition of an asset was explored. The working definition of an asset in the context of this thesis is defined as follows: *"Item, thing or entity that has potential or actual value to an organisation. Note 1 to entry: Value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities. It can be positive or negative at different stages of the asset life."* - International Organization for Standardization (2014).

With this definition in mind, the definition of the term EAM is explored. The working definition of EAM in the context of this thesis is defined as follows: *Enterprise Asset Management is the coordinated process of an organisation to cost-effectively monitor, manage and optimise asset performance throughout the whole life-cycle of the assets.*

This answers RQ3, yet to be thorough and complete in the exploration of what EAM is, the various benefits and shortcomings of EAM from the SLR have also been documented in the theoretical framework of this thesis.

The identified benefits from the SLR associated with EAM were grouped and described as *(1) Improved decision-making for asset utilisation / planning in line with overarching business goals, (2) Improved transparency and visibility of an organisation's assets, (3) Improved asset value creation / asset performance throughout its entire lifecycle, and (4) Enable accurate monitoring and control of assets.*

The identified shortcomings of EAM approaches from the SLR are *(1). Lacking effective information quality management for the data supporting the implemented EAM approach, (2) Lacking alignment of an organisation's asset strategy with strategic objectives / goals, (3) Lacking the ability to effectively manage the increasing complexity of a larger organisation's EAM. Which can cause interoperability issues, and (4) A lack of accounting for emerging trends, changing external environments and societal expectations.*

RQ4. *What dimensions and sub-dimensions from existing maturity models are transferable to the new model?*

Based on a combination of the MM development steps, as set out by Becker, Knackstedt and Pöppelbuß (2009) and Lautenschutz et al. (2018). It was determined that the following dimensions are to be transferred from existing MMs to the first iteration of the new MM for improved EAM.

Strategic Direction
- Capital Expenditure Planning
- Organisational Operational Plan
- Organisational Business Process Map
- Organisational Contingency Planning
- Process Transformation
- Stakeholder Management
- Contract Management
- Internal Co-ordination
- External Co-ordination
- Performance Review

Asset Life Cycle Management
- Asset Policy
- Asset Acquisition
- Asset Registering
- Asset Planning
- Asset Operation Management
- Asset Maintenance
- Asset Disposal

Asset Cost Optimization
- Financial Planning
- Life-cycle Costs
- Operational Costs
- Maintenance Costs

Information Collection and Dissemination
- Information Management
- Asset Data Monitoring and Recording
- Information Storage
- Communication
- Knowledge Management and Sharing

Information Quality
- Information Quality Governance
- Information Quality Assessment
- Information Openness

Risk Management
- Safety
- Risk Identification
- Risk Analysis
- Risk Evaluation
- Risk Treatment

Security
- Information Security Management
- Information Access Control
- Secure Transmission of Sensitive Information

Human Capital
- Skill Management and Development
- Roles and Responsibility
- Leadership and Business Culture
- Qualified external support

Tool Management and Standardisation
- Formal Standards and Protocols as the Basis
- Consistency and Standardisation of Tools
- Conceptual Modelling
- Decision Support System
- Application Management
- Digital Twin

RQ5. *To what extent is the proposed maturity model usable and useful in practice?*

To summarise, taking into consideration the feedback from the open discussion, the questionnaire and specifically the feedback gained from the UTAUT model scores, it is to be concluded that the first iteration of the MM is well-received and considered to be useful according to the eight interviewed EAM experts. There is, however, definitely room for improvement. Therefore a second iteration of the MM was performed and an improved MM was created.

RQ. *What are the key dimensions and* sub-dimensions *that make up a maturity model for comprehensively evaluating an asset-intensive organisation's approach to enterprise asset management?*

After carefully considering the feedback gathered from the semi-structured interviews with eight experts in the field of EAM, the following key dimensions (also referred to as focus areas in this thesis, see the bold dimensions below) and sub-dimensions were determined to be necessary for comprehensively evaluating an asset-intensive organisation’s approach to

EAM. It should be noted, however, that this second iteration of the MM setup ideally would benefit from another evaluation round.

Strategic Direction
- Capital Expenditure Planning
- Organisational Operational Plan
- Organisational Business Process Map
- Organisational Contingency Planning
- Process Transformation
- Stakeholder Management
- Contract Management
- Internal Co-ordination
- External Co-ordination
- Performance Review
- Business Culture

Asset Life Cycle Management
- Asset Policy
- Asset Acquisition
- Asset Registering
- Asset Planning
- Asset Operation Management
- Asset Maintenance
- Asset Disposal

Asset Cost Optimization
- Financial Planning
- Life-cycle Costs
- Operational Costs
- Maintenance Costs

Information Collection and Dissemination
- Information Management
- Asset Data Monitoring and Recording
- Information Storage
- Communication
- Knowledge Management and Sharing

Corporate Social Responsibility
- Environmental Sustainability
- Social Impact
- Employee Well-being
- Inclusive Recruitment
- (Personal) Data Protection and Privacy

Information Quality
- Information Quality Governance
- Information Quality Assessment
- Information Availability and Accessibility

Risk Management
- Safety
- Risk Identification
- Risk Analysis
- Risk Evaluation
- Risk Treatment

Security
- Information Security Management
- Information Access Control
- Secure Transmission of Sensitive Information
- Physical Asset Vulnerability

Human Capital
- Skill Management and Development
- Roles and Responsibility
- Leadership and Business Culture
- Qualified External Support

Tool Management and Standardization
- Formal Standards and Protocols as the Basis
- Consistency and Standardisation of Tools
- Conceptual Modelling
- Decision Support System
- Application Management

Compliance
- Law and Regulations
- Insurance Compliance
- Corporate Policy Compliance
- Contractual Obligations

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Appendix A

Systematic Literature Review Statistics

Table A.1 - SLR Search Part I:
SCOPUS (Search filters: Article title, Abstract, Keywords + Cited by (highest))
Search conducted during 12-2022

Systematic Literature Review Search Part I - Focus: Maturity Models

	I	II	III	IV	V	VI	VII	VIII	IX
Query 1	5,581	3,646	3,467	100	63	21	21	21	17
Query 2	534	445	428	100	33	18	18	14	12
Total	**6,115**	**4,091**	**3,895**	**200**	**96**	**39**	**39**	**35**	**29**

Table A.2 - SLR Search Part II:
SCOPUS (Search filters: Article title, Abstract, Keywords + Cited by (highest))
Search conducted during 12-2022

Systematic Literature Review Search Part II - Focus: Enterprise Asset Management

	I	II	III	IV	V	VI	VII	VIII	IX
Query 3	20,199	11,543	11,184	100	28	14	12	12	12
Query 4	164	52	50	50	26	14	14	12	7
Total	**20,363**	**11,595**	**11,234**	**150**	**54**	**28**	**28**	**26**	**19**

Table A.3 - SLR Search Part III:
SCOPUS (Search filters: Article title, Abstract, Keywords + Cited by (highest))
Search conducted during 12-2022

Systematic Literature Review Search Part III - Focus: Maturity Models and Enterprise Asset Management

	I	II	III	IV	V	VI	VII	VIII	IX
Query 5	184	122	117	100	37	18	18	17	14
Query 6	82	48	46	46	22	8	8	7	7
Total	**296**	**170**	**163**	**146**	**59**	**26**	**26**	**24**	**21**

Table A.4 - SLR Search Results - Total Overview:
SCOPUS (Search filters: Article title, Abstract, Keywords + Cited by (highest))
Search conducted during 12-2022

Systematic Literature Review Search Results - Total Overview									
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
Total	**26,744**	**15,856**	**15,292**	**496**	**209**	**93**	**87**	**85**	**69**

Appendix B

Table B.1 - Complete overview SJR-Scores and H-Index

Title	Year	ISSN / ISBN	SJR-Score	H-Index
Integrated strategic asset management: Frameworks and dimensions	2014	15660443 (ISSN)	0.102	7
Maturity models in supply chain sustainability: A systematic literature review	2017	20711050 (ISSN)	0.537	109
Application of openBIM for the Management of Existing Railway Infrastructure: Case Study of the Cancello–Benevento Railway Line	2022	20711050 (ISSN)	**Unavailable**	109
Gemini principles-based digital twin maturity model for asset management	2021	20711050 (ISSN)	0.664	109
Service development in product-service systems: A maturity model	2013	02642069 (ISSN)	0.343	70
Maturity models: identifying the state-of-the-art and the scientific gaps from a bibliometric study	2017	01389130 (ISSN)	1.125	123
BIM: Enabling sustainability and asset management through knowledge management	2013	1537744X (ISSN)	0.509	103
Maintenance optimization and inspection planning of wind energy assets: Models, methods and strategies	2019	09518320 (ISSN)	1.925	157
Development of maturity model for assessing the implementation of Industry 4.0: learning from theory and practice	2021	09537287 (ISSN)	1.661	85
Maintenance, replacement, and reliability: Theory and applications, second edition	2013	9781466554863 (ISBN); 9781138072107 (ISBN)	**Unavailable**	**Unavailable**
Development and implementation of a maturity model for professionalising maintenance management	2016	21954356 (ISSN)	0.113	21
Asset management decisions—based on system thinking and data analysis	2015	21954356 (ISSN)	0.124	21
Asset data quality—A case study on mobile mining assets	2015	21954356 (ISSN)	0.124	21
An evaluation template for expert review of maturity models	2014	03029743 (ISSN)	0.354	415
A review of methods for evaluation of maturity models for process improvement	2012	20477481 (ISSN)	**Unavailable**	32
Integration of big-data ERP and business analytics (BA)	2018	10478310 (ISSN)	0.273	49
Maintenance strategy selection using AHP and COPRAS under fuzzy environment	2012	1648715X (ISSN)	0.612	33
Value of maturity models in performance measurement	2015	00207543 (ISSN)	1.306	153
Measuring the benefits of erp on supply management maturity model: A “big data” method	2015	01443577 (ISSN)	2.062	146
The dual effects of the Internet of Things (IoT): A systematic review of the benefits and risks of IoT adoption by organisations	2020	02684012 (ISSN)	2.77	132
Automating the process of an oil and gas company property management: Regulatory and economic aspects	2018	2227524X (ISSN)	0.113	30
A novel model for business process maturity assessment through combining maturity models with EFQM and ISO 9004:2009	2013	17418763 (ISSN)	0.277	19
Development of an integrated BIM-ERP-IoT module for construction projects in Ahmedabad	2022	23644176 (ISSN)	**Unavailable**	16
Toward Better Understanding and Use of Business	2016	10580530 (ISSN)	0.444	61

Intelligence in Organizations				
The maturity of maturity model research: A systematic mapping study	2012	09505849 (ISSN)	0.925	107
Business process maturity models: A systematic literature review	2016	09505849 (ISSN)	0.801	107
Exploring barriers to knowledge flow at different knowledge management maturity stages	2012	03787206 (ISSN)	1.523	170
Analytics maturity models: An overview	2020	20782489 (ISSN)	0.349	36
Development of maturity levels for agile industrial service companies	2018	18684238 (ISSN); 9783319997063 (ISBN)	0.188	56
A maturity model for assessing the digital readiness of manufacturing companies	2017	18684238 (ISSN); 9783319669229 (ISBN)	0.1788	56
Exploring the role of Digital Twin for Asset Lifecycle Management	2018	24058963 (ISSN)	0.298	76
Organisation-wide maintenance & inspection improvement plan: A dutch electricity & gas distribution network operators approach	2012	9781849196932 (ISBN)	**Unavailable**	**Unavailable**
Critical component identification in reliability centered asset management of power distribution systems via fuzzy AHP	2012	19328184 (ISSN)	0.424	88
Towards a best practice asset management framework for electrical power distribution organisations	2016	21574839 (ISSN); 9781467381321 (ISBN)	0.171	28
Integrating Resource-Based View and Performance Improvement Theory in Developing Maintenance Management Continuous Improvement Model: A Conceptual Framework	2021	11333197 (ISSN)	**Unavailable**	8
Enterprise maturity models: a systematic literature review	2019	17517575 (ISSN)	0.511	50
A conceptual framework and classification of capability areas for business process maturity	2014	17517575 (ISSN)	2.341	50
Maturity model for enterprise interoperability	2015	17517575 (ISSN)	1.059	50
Approaches to information quality management: State of the practice of UK asset-intensive organisations	2013	21907846 (ISSN); 9781447129233 (ISBN)	0.121	5
Business intelligence systems	2018	14311941 (ISSN)	**Unavailable**	15
Maturity Models for Information Systems - A State of the Art	2016	18770509 (ISSN)	0.259	92
MD3M: The master data management maturity model	2015	07475632 (ISSN)	1.583	203
Service oriented architecture maturity models: A systematic literature review	2019	09205489 (ISSN)	0.662	67
Maturity models in business process management	2012	14637154 (ISSN)	0.502	87
Framework for implementing track deterioration analytics into railway asset management	2022	2044124X (ISSN)	**Unavailable**	24
BIM in facilities management applications: A case study of a large university complex	2015	2044124X (ISSN)	0.263	24
The building information modelling trajectory in facilities management: A review	2017	09265805 (ISSN)	1.613	138
Developing owner information requirements for BIM-enabled project delivery and asset management	2017	09265805 (ISSN)	1.613	138
A Maturity Model Proposal for Industrial Maintenance and Its Application to the Railway Sector	2022	20763417 (ISSN)	**Unavailable**	75
Digital transformation maturity: A systematic review of literature	2019	12118516 (ISSN)	0.167	20
Digital Technology and Quality Management	2018	9781538667576 (ISBN)	**Unavailable**	**Unavailable**
The impact of SAP on the utilisation of business process management (BPM) maturity models in ERP projects	2018	16130073 (ISSN)	0.166	57
Critical literature review on maturity models for business	2014	21573611 (ISSN);	0.138	21

process excellence		9781479964109 (ISBN)		
The role of big data in improving power system operation and protection	2013	9781479901999 (ISBN)	**Unavailable**	**Unavailable**
A maturity model for the deployment of Systems Engineering processes	2012	9781467307499 (ISBN)	**Unavailable**	**Unavailable**
M2DDM - A Maturity Model for Data-Driven Manufacturing	2017	22128271 (ISSN)	0.668	78
Toward the development of a maturity model for digitalization within the manufacturing industry's supply chain	2017	15301605 (ISSN); 9780998133102 (ISBN)	0.237	92
Do mature business processes lead to improved performance?-A review of literature for empirical evidence	2015	Unknown	**Unavailable**	14
Towards a business analytics capability maturity model	2012	9781741561722 (ISBN)	**Unavailable**	**Unavailable**
Research on ERP customer capability maturity model based on PEMM	2013	9783642384417 (ISBN)	**Unavailable**	**Unavailable**
Development of an assessment model for industry 4.0: Industry 4.0-MM	2017	18650929 (ISSN); 9783319673820 (ISBN)	0.17	55
A project driven approach for enhanced maturity model development for EAM capability evaluation	2013	15417719 (ISSN)	0.418	34
Development of maturity models: A systematic literature review	2012	9781849195416 (ISBN)	**Unavailable**	**Unavailable**
AMICO: The asset management for industrial complex enterprise	2013	9789898565594 (ISBN)	**Unavailable**	**Unavailable**
A Common Risk Framework for Road and Rail Infrastructures	2021	21954356 (ISSN); 9783030642273 (ISBN)	0.19	21
Intelligent Maintenance Maturity of Offshore Oil and Gas Platform: A Customized Assessment Model Complies with Industry 4.0 Vision	2020	21954356 (ISSN); 9783030480202 (ISBN)	0.15	21
Analysis of Selected ERP 4.0 Features and Proposal of an ERP 4.0 Maturity Model	2019	18651348 (ISSN); 9783030376314 (ISBN)	0.26	52
Towards an Integrated Maturity Model of Asset Management Capabilities	2015	21954356 (ISSN); 9783319024615 (ISBN)	0.124	21
Towards a decision tool for choosing a business process maturity model	2012	03029743 (ISSN); 9783642298622 (ISBN)	0.346	415

Appendix C

- **MM 1 - [Ref. 7]:** The MM as presented by Basl and Novakova (2019) addresses the topic of Industry 4.0 trends in ERP systems. The MM assesses the penetration of industry 4.0 trends into the available ERP systems and the expectations amongst users. The proposed model does not name/define their maturity levels themselves explicitly but does describe from a practical standpoint what they entail for each of the four considered dimensions. The MM was created through means of literature review but also verified through a survey of ERP suppliers within the Czech Republic. However, it should be noted, that the amount of respondents is not revealed.
- **MM 2 - [Ref. 17]:** The MM created by Chen et al. (2021) concerns itself with testing the maturity of digital twin implementations and guiding organisations towards improved digital twin implementations to support their asset management endeavours. The model consists of three dimensions, which are divided into nine groupings and twenty-seven sub-dimensions, named “rubrics”. These dimensions were examined by a team of 40 experts and the model was evaluated by a twofold of case studies.
- **MM 3 - [Ref. 19]:** The MM as described by Cornu et al. (2012) focuses on the implementation of system engineering (SE) to improve business process efficiency. The created MM is to be used before the SE deployment processes. The MM differentiates between five maturity levels and considers three dimensions (with six sub-groupings) described by twenty-two sub-dimensions. The proposed MM is submitted to a group of design office experts of an aviation manufacturer for validation and has been applied to an organisation to validate and improve its content. However, it should be noted that no clear approach or outcomes of these endeavours have been documented in the article itself.
- **MM 4 - [Ref. 29]:** Errandonea et al. (2022) created a MM specific to industrial maintenance in the context of the railway sector. This model defines guidelines to evolve within various maintenance strategies towards prescriptive maintenance from a blanket perspective. This MM differentiates into four maturity levels and three dimensions divided into eighteen sub-dimensions. The model is built from an in-depth literature review. Before presenting the main conclusions, the article presents a case for the applicability of the proposed Maintenace Maturity Model (M3) in the railway domain. However, the paper only tackles the applicability theoretically and no empirical research is conducted.
- **MM 5 - [Ref. 36]:** The MM created by Gersonius et al. (2017) concentrates on asset management in the context of flood protection (specifically across the North Sea Region). This is of importance as where, when and how much to invest in assets is critical in ensuring flood protection. The MM differentiates between five maturity levels and seven dimensions. The proposed MM is tested by assessing the maturity of 5 flood protection asset management organisations (in Belgium, Sweden, Denmark, Germany and The Netherlands). Subsequently, the results from these assessments are analysed and compared.
- **MM 6 - [Ref. 37]:** Gökalp et al. (2017) present a MM which concerns itself with the topic of Industry 4.0 and provides a MM to guide the transition of organisations towards Industry 4.0 in a systematic and repeatable manner. The presented MM is based on seven previously existing MMs and is built with 6 maturity levels in mind. The model differentiates between five dimensions. The paper does not document any empirical evidence to evaluate or validate the usability and performance of the proposed MM.

- **MM 7 - [Ref. 45]:** The MM created by Huang and Handfield (2015) assesses the effects of ERP system implementations (comparing a selection of ERP vendors and non-ERP system users) regarding supply chain management. The assessment is split into 4 dimensions which are evaluated against 5 maturity levels.
- **MM 8 - [Ref. 48]:** The MM as described by Kampker et al. (2018) enables industrial service organisations to introduce Industry 4.0 and transform into learning, agile organisations. This process of change is described in four development stages and approached from three different perspectives: technological, organisational and cultural. The technological dimensions are then again split into two sub-dimensions, considering machine data and order data separately. The model is created based on expert workshops as well as a literature study.
- **MM 9 - [Ref. 49]:** Khaliq et al. (2016) present a MM which focuses on asset management in the context of electrical power distribution organisations. The MM is built with the intended goal of benchmarking and improving asset management. The model evaluates aspects based on a set of thirteen grouped activities which are referred to as key process areas and seven key attributes as adopted from the British Standard Asset Management System (2014). These key attributes are evaluated for each of the key process areas. Maturity levels are split into five: from initial or ad hoc to optimised. The proposed MM is evaluated by conducting case studies at 2 different organisations specializing in electrical power distribution. However, it should be noted that the documented findings are referred to as preliminary findings, yet no paper describing the decisive findings could be discovered.
- **MM 10 - [Ref. 60]:** The MM created by Khaliq et al. (2016) concerns itself with evaluating asset management practices relating to power distribution organisations. The goal of Khaliq et al. (2016) is to help organisations to implement effective EAM and thus ensure reliability and the most advantageous service delivery. In this pursuit, they identify five levels of maturity, thirteen dimensions or “key process areas” and seven sub-dimensions or “attributes”.
- **MM 11 - [Ref. 63]:** This MM by Liu and Wen (2013) focuses on the evaluation of process management, organisational maturity and the ERP system customer characteristics to explore the maturity level of ERP customers. The model differentiates by defining four maturity levels, six dimensions and eighteen sub-dimensions.
- **MM 12 - [Ref. 64]:** Mehairjan et al. built a MM in 2016 to evaluate the maturity of organisations regarding their maintenance and inspection. They deem this critical to achieve asset performance requirements. The model concerns itself with electricity and gas distribution networks in specific and differentiates four individual maturity levels, five separate dimensions and sixteen sub-dimensions.
- **MM 13 - [Ref. 68]:** The Property Asset Management Capability Assessment Model (PAMCAM) designed by the Office of Government Commerce and the National Audit Office (in 2014) concerns itself with the topic of property asset management. This model addresses a total of seven dimensions but split these up into various sub-groupings so the total separate dimensions considered, including the sub-groupings, adds up to twenty-nine. The sub-dimensions described in the model under “Sub text” differentiate in thirty-two different ways. Maturity levels are not clearly expressed in a staged and defined manner, but depending on implementation the score given to sub-dimensions is scored either “PARTIAL” or “YES”.
- **MM 14 - [Ref. 75]:** Patrício and Almeia (2021) present a MM intending to create a common risk framework for assessing risk management processes in the context of road and rail infrastructures. This model differentiates six maturity levels, from innocent to excellent and assesses an organisation's maturity based on eight dimensions. The proposed MM has been empirically evaluated by conducting a case study of a public infrastructure organisation which manages both the Portuguese national road and railway networks.

- **MM 15 - [Ref. 83]:** Proença et al. (2017) created a MM concerning risk management based on the ISO 31000 standard. They differentiate between five maturity levels and consider only the dimension of risk management impact on business value. To evaluate the maturity level they have presented thirty-nine examples of risk management processes which are categorised as belonging to a certain maturity level.
- **MM 16 - [Ref. 90]:** The MM as described by Sauni et al. (2022) has a clear focus on railway (track) asset management. This model takes five levels of maturity, from ensuring safety to vision. These are applied to six dimensions. The MM has been evaluated by conducting semi-structured expert interviews with 22 interviewees from 8 organisations and has been successfully applied to railway asset management in Finland.
- **MM 17 - [Ref. 68]:** The Office of Government Commerce MM on property asset management defines five individual maturity levels, from unawareness to excellence and has split its assessment into eight different dimensions. The proposed MM is developed based on 50 conducted questionnaires at various departments, executive agencies and non-department public bodies. Followed by 32 interviews and a developmental workshop.
- **MM 18 - [Ref. 111]:** The MM presented by Woodall et al. (2013) focuses on understanding an organisation's approach to IQM in the context of asset management and providing guidance towards improved IQM practices. Maturity is evaluated in a five-staged maturity level assessment from chaotic to optimising. The MM creation process does include the evaluation of seven previously existing MMs on the topic of IQM and is split into thirteen process areas and forty-five critical success factors (CSF). The occurrence of these process areas and CSF are linked to the various maturity levels. The MM is tested in a case study by evaluating 10 U.K.-based organisations.

Appendix D

Table D.1 - Reference List - SLR Extracted Maturity Models

Maturity Model Number and Reference	Reference
MM1 - [7]	Basl, J., & Novakova, M. (2019) Analysis of Selected ERP 4.0 Features and Proposal of an ERP 4.0 Maturity Model. In: Vol. 375 LNBIP. 13th IFIP WG 8.9 Working Conference on Research and Practical Issues of Enterprise Information Systems, CONFENIS 2019 (pp. 3-11): Springer.
MM2 - [17]	Chen, L., Xie, X., Lu, Q., Parlikad, A. K., Pitt, M., & Yang, J. (2021). Gemini principles-based digital twin maturity model for asset management. Sustainability (Switzerland), 13(15). doi:10.3390/su13158224
MM3 - [19]	Cornu, C., Chapurlat, V., Quiot, J. M., & Irigoin, F. (2012). A maturity model for the deployment of Systems Engineering processes. Paper presented at the 2012 6th IEEE International Systems Conference, SysCon 2012, Vancouver, BC.
MM4 - [29]	Errandonea, I., Alvarado, U., Beltrán, S., & Arrizabalaga, S. (2022). A Maturity Model Proposal for Industrial Maintenance and Its Application to the Railway Sector. Applied Sciences (Switzerland), 12(16). doi:10.3390/app12168229
MM5 - [36]	Gersonius, B., Vonk, B., Ashley, R. M., Den Heijer, F., Klerk, W. J., Manojlovic, N., Pathirana, A. (2020). Maturity improvements in flood protection asset management across the North Sea Region. Infrastructures, 5(12), 112. doi:10.3390/infrastructures5120112
MM6 - [37]	Gökalp, E., Şener, U., & Eren, P. E. (2017) Development of an assessment model for industry 4.0: Industry 4.0-MM. In: Vol. 770. 17th International Conference on Software Process Improvement and Capability Determination, SPICE 2017 (pp. 128-142): Springer Verlag.
MM7 - [45]	Huang, Y. Y., & Handfield, R. B. (2015). Measuring the benefits of erp on supply management maturity model: A “big data” method. International Journal of Operations and Production Management, 35(1), 2-25. doi:10.1108/IJOPM-07-2013-0341
MM8 - [48]	Kampker, A., Frank, J., Emonts-Holley, R., & Jussen, P. (2018) Development of maturity levels for agile industrial service companies. In: Vol. 536. IFIP WG 5.7 International Conference on Advances in Production Management Systems, APMS 2018 (pp. 11-19): Springer New York LLC.
MM9 - [49]	Khaliq, S. A., Mahmood, M. N., & Das, N. (2016). Towards a best practice asset management framework for electrical power distribution organisations. Paper presented at the IEEE PES Asia-Pacific Power and Energy Engineering Conference, APPEEC 2015.
MM10 - [60]	Liu, Z. Z., & Wen, H. Y. (2013). Research on ERP customer capability maturity model based on PEMM. Paper presented at the 19th International Conference on Industrial Engineering and Engineering Management: Engineering Economics Management, Changsha.
MM11 - [63]	Mehairjan, R. P. Y., Krijgsman, M. A., Van Hattem, M., Manuel, R., Boutahri, F., & Weerts, J. (2012). Organisation-wide maintenance & inspection improvement plan: A dutch electricity & gas distribution network operators approach. Paper presented at the IET and IAM Asset Management Conference 2012, London.
MM12 - [64]	Mehairjan, R. P. Y., van Hattem, M., Djairam, D., & Smit, J. J. (2016) Development and implementation of a maturity model for professionalising maintenance management. In: Vol. PartF4. Lecture Notes in Mechanical Engineering (pp. 415-427): Pleiades journals.

MM13 - [68]	National Audit Office (NAO), Office of Government Commerce (OGC), & PricewaterhouseCoopers (PWC). (2014). Property Asset Management Capability Assessment Model (PAMCAM). Retrieved March 10, 2023.
MM14 - [75]	Patrício, H., & Almeia, N. (2021) A Common Risk Framework for Road and Rail Infrastructures. In. 14th World Congress on Engineering Asset Management, WCEAM 2019 (pp. 113-125): Springer Science and Business Media Deutschland GmbH.
MM15 - [83]	Proenca, D., Estevens, J., Vieira, R., & Borbinha, J. (2017). Risk management: A maturity model based on ISO 31000. 2017 IEEE 19th Conference on Business Informatics (CBI). https://doi.org/10.1109/cbi.2017.40
MM16 - [90]	Sauni, M., Luomala, H., Kolisoja, P., & Vaismaa, K. (2022). Framework for implementing track deterioration analytics into railway asset management. Built Environment Project and Asset Management, 12(6), 871-886. doi:10.1108/BEPAM-04-2022-0058
MM17 - [100]	The Office of Government Commerce (OGC). (2007). Improving property asset management in the central civil government estate - UK Office Of Government Commerce Research Study. Retrieved March 10, 2023, from http://www.consilian.co.uk/images/rcj%20event%20assets/Steven%20Male%20Presentation.pdf
MM18 - [111]	Woodall, P., Parlikad, A. K., & Lebrun, L. (2013) Approaches to information quality management: State of the practice of UK asset-intensive organisations. In. Engineering Asset Management Review (pp. 1-18).

Appendix E

Table E.1 - SLR Extracted Maturity Model List Analysis

Maturity Model Number and Reference	Research Context	Total Number of Maturity Levels	Maturity Levels	Total Number of Dimensions	Dimensions	Total Number of Sub-Dimensions	Sub-Dimensions
MM1 [7]	ERP 4.0	6	Expressed as a numerical value: 0, 1, 2, 3, 4, and 5.	4	(1). Business Model - On promise/cloud (2). Technology - 4.0 Trends (3). Data - Planning and decision support (4). Processes - Digitalization and automation	N / A	N / A

MM2 [17]	Digital Twin Asset Management	6	(1). Unaware (2). Identifiable (3). Aware (4). Communicative (5). Interactive (6). Instructive and Intelligent	3	(1). Purpose: (1.1). Asset Management Project (1.2). Insights (1.3). Public Good (2) Trust: (2.1). Federation (2.2). Curation (2.3). Evolution (3). Function: (3.1). Openness (3.2). Security (3.3). Quality	27	(1). Project target/objective, (2). Organisational business process map, (3). Organisational operational plan, (4). Improved management performances with digital twin involved, (5). Qualified consulting company/expert supported, (6). Digital twin relevant experience and aptitude of professionals and value creation, (7). Role and responsibility definitions within the organisation, (8). Well-organised training programs within the organisation, (9). Communication strategies among different stakeholders and within the organisation, (10). Data/model updating/collecting techniques based on as-is conditions for effective information collection (e.g., camera, sensor systems), (11). Data/model storage, exchange and sharing method (e.g., cloud-based storage technology), (12). Information visualisation technology, (13). Data integration (e.g., centre database, data warehouse), (14). Asset integration, (15). Asset register techniques implementation (e.g., RFID, QR code), (16). Digital model/data generating and updating process/technology, (17). Information/model sharing process/technology, (18). Asset data updating and capturing process/technology, (19). Integrity and accuracy of as-is digital model (e.g., BIM), (20). Information security assurance, (21). Formal standards and protocols as the basis, (22). Removal and replacement reminders and records, (23). Interoperability/IFC or COBie support (e.g., openBIM), (24). Integrity, accuracy and openness of collected information/data resources (e.g., space information, asset information, building management information), (25). Digital twin for asset management implementation guide, (26). Continuous quality assurance mechanism/rules, and (27). Formal services and data delivery provision (e.g., data exchange standard).
MM3 [19]	System Engineering Processes	5	(1). Initial (2). Low (3). Neutral (4). Good (5). Excellent	3	(1). Processes: (1.1). Technical Processes (1.2). Technical Management Processes (2). People: (2.1). Skills (2.2). SE Mindset (3). Method & Tools: (3.1). Knowledge Management and Sharing (3.2) Tools	22	(1). Engineering Processes (Consisting of: (1.1). Consistency & standardisation of engineering activities and (1.2). Type of design). (2). Technical Management Processes (Consisting of: (2.1). Consistency & standardisation of technical management activities, (2.2). Definition of interfaces, R&R, & constraints of stakeholders all along design technical & management activities, (2.3). Existence of a team responsible for the design office practices standardization & overall improvement, (2.4). Design Processes modelling). (3) Required Skills (consisting of (3.1). Engineering, (3.2). Project management, (3.3). Systems Engineering, (3.4). Modelling). (4) Management and Development of Skills (Consisting of (4.1). Training, (4.2). Validation of skills, (4.3). Establishment of a "sense of urgency", (4.4). Establishment of a "powerful guiding coalition", (4.5). Visions of top management, (4.6). Arbitration between project short-term vision and SE deployment long-term vision, (4.7). Involvement of managers in the SE deployment project). (5.1). Capacity to exchange & share

							information within the entity, (5.2). Capitalization, formalization and sharing of knowledge about design engineering activities, (5.3). Capitalization, formalization and sharing of knowledge about design technical management. (5.4). Sharing of artefact templates, and (5.5). Design tools standardization.
MM4 [29]	Maintenance	4	(1). Preventive (2). Condition-based (3). Predictive (4). Prescriptive	3	(1). Asset (2) Status (3). Maintenance	18	(1). Asset Management, (2). Reliability, (3). Safety, (4). Risk Management, (5). Availability, (6). Failure Mode Criteria, (7). Status Monitoring, (8) Diagnosis, (9) Prognosis, (10). Life-cycle Cost, (11). Operation Cost, (12). Maintenance Cost, (13) Resources Management, (14). Operation management, (15). Maintainability, (16). Decision Support System, (17). Decision Models, and (18) Optimization.
MM5 [36]	Flood Protection	5	(1). Ad hoc (2). Repeatable (3). Standardised (4). Well managed (5). Optimised	7	(1). Asset management decisions (2). Information management (3). Internal coordination (4). External coordination (5). Outsourcing activities (6). Processes and roles (7). Culture and leadership	N / A	N / A
MM6 [37]	Industry 4.0	6	Level 0: Incomplete Level 1: Performed Level 2: Managed Level 3: Established Level 4: Predictable Level 5: Optimizing	5	(1). Asset Management (2). Data Governance (3). Application Management (4). Organisational Alignment (5). Process Transformation	N / A	N / A
MM7 [45]	Supply Management	5	(1). Ad hoc (2). Defined (3). Managed (4). Leveraged (5). Optimised	4	(1). Spend management (2). Strategic sourcing (3). Category management (4). Supplier relationship management.	N / A	N / A
MM8 [48]	Industrial Service	4	(1). Visibility (2). Transparency (3). Predictability (4). Adaptability	3	(1). Technology (2). Organisation (3) Culture	2	The dimension Technology is split into two criteria, consisting of (1). Machine Data, and (2). Order Data.

MM9 [49]	Electrical Power Distribution	5	(1). Ad hoc / Initial (2). Repeatable Organisation (3). Defined Organisation (4). Controlled Organisation (5). Optimised Organisation	13	(1). Asset Policy (2). Asset Planning (3). Asset Creation and Acquisition (4). Asset Disposal (5). Environmental Analysis (6). Asset Operations (7). Asset Maintenance (8). Asset Management Information System (9). Risk Management (10). Contingency Planning (11). Financial Planning (12). Capital Expenditure Planning (13). Review of Asset Management System	7	(1). Scope, (2). Leadership, (3). Planning, (4). Support, (5). Operation, (6). Performance evaluation, and (7). Improvement.
MM10 [60]	ERP Customer	4	(1). Initial (Low Process Maturity and Low Enterprise Maturity) (2). Standardize (High Process Maturity and Low Enterprise Maturity) (3). Managing (Low Process Maturity and High Enterprise Maturity) (4). Optimizing (High Process Maturity and High Enterprise Maturity)	6	(1). Process maturity: (1.1). Design (1.2). Performers (1.3). Infrastructure (2). Enterprise maturity: (2.1). Leadership (2.2). Culture (2.3). Governance	18	Design consisting of (1). Purpose, (2). Context, and (3). Documentation. Performers consisting of (4). Knowledge, (5). Skill, and (6). Attitude. Infrastructure consisting of (7). Information System, (8). Human Resources, and (9). Master Data. Leadership consisting of (10). Awareness, (11). Behaviour, and (12). Style. Culture, consisting of (13). Teamwork, (14). Responsibility, and (15). Attitude toward Change. Governance, consisting of (16). Process Model, (17). Accountability, and (18). Integration.

MM11 [63]	Maintenance and Inspection Improvement for Electricity and Gas Network Operators	3	(1). Practically managed (2). House in Order (3). Best in Class	7	(1). Transition (2). Vision and Pilot for RCM (3). Organisation and Process (4). Policy and Criteria (5). Information & Systems (6). Data Quality (7) Portfolio and Performance	N / A	N / A
MM12 [64]	Maintenance	4	(1). Not much in place (2). Practically Managed (3). House in Order (4). Best in Class	5	(1). Organisation and Processes (2). Policy and Criteria (3). Information and Systems (4). Data Quality (5). Performance and Portfolio	16	(1). Maintenance Total, consisting of (2). Gas (consisting of (3). Connections, (4). Pipelines, and (5). Stations) and (6). Electricity (consisting of (7). Primary, (consisting of (8). Low Voltage, (9). Public Lighting, (10). Medium Voltage Substations, (11). Medium Voltage Grid, (12). Sub-transmission Grid, (13). Substations, and (14). Transformers), (15). Secondary, and (16). Tertiary.
MM13 [68]	Property Asset Management	N / A	Maturity level scores are appointed based on specific implementations which are considered in two groupings: a partial score and a YES score. Examples of evidence for both these scores per dimension/criteria are given.	29	(1). Strategy: (1.1). Cross Government Strategy (1.2). Cross-Organisation/Family (1.3). Business Strategy (1.4). Cross-Organisation Strategy (1.5). Workplace Strategy) (2). Planning to deliver: (2.1) Planning to deliver (2.2). Planning to deliver - Procurement (3). Deliver Change: (3.1). Programme/Project delivery (4). Operate: (4.1). Stakeholder relationship management (4.2). Operate (4.3). Cross Organisation/Family (4.4). Service delivery management (5). Corporate Governance: (5.1). Cross Organisation/Family (5.2). Corporate Governance (6). Capacity and Capability: (6.1). Intelligent Client Function (6.2). Cross Organisation/Family (7). Policies and standards:	32	(1). Property Asset Management, (2). Portfolio review, (3). Smart working, (4). Programmes and projects, (5). Business cases, (6). Prioritised implementation plans, (7). Risk planning, (8). Risk management, (9). Procurement strategy, (10). Specifications, (11). Governance, (12). Project change control, (13). Benefits analysis, (14). Communications, (15). Contact management, (16). Service delivery management, (17). Change control management, (18). Advisory and decision-making structure, (19). Roles and responsibilities, (20). Governance, (21). Resources, (22). Developing capacity and skills, (23). Occupation, (24). Management of data, (25). Content, (26). Performance reporting, (27). Post-implementation review, (28). Audit/Peer review, (29). Service level agreements, (30). Service review, (31). Benchmarking, and (32). Sustainability

					(7.1). Cross Organisation/Family (7.2). Cross government (8). Data / MIS (9). Performance Review and Audit: (9.1) Performance Review and Audit (9.2) Cross Organisation/Family		
MM14 [75]	Risk Framework for Road and Rail Infrastructures	6	(1). Innocent (2). Aware (3). Developing (4). Competent (5). Optimizing (6). Excellent	8	(1). Communication and Consultation (2). Context (3). Risk Identification (4). Risk Analysis (5). Risk Evaluation (6). Risk Treatment (7). Monitoring and review (8). Recording and reporting	N / A	N / A
MM15 [83]	Risk Management	5	(1). Initial (2). Managed (3). Defined (4). Quantitatively Managed (5). Optimizing	1	(1). Risk Management Impact on Business Value	N / A	N / A
MM16 [90]	Railway (Track) Asset Management	5	(1). Ensuring safety (2). Monitoring track quality (3). Track geometry management (4). Optimising track geometry (5). Vision	6	(1). Measurement result analysis (2). Data systems (3). Maintenance (4). Asset Renewal (5). Knowledge (6). Contracts	N / A	N / A

MM17 [100]	Property Asset Management	5	(1). Unawareness (2). Awareness (3). Knowledge (4). Competence (5). Excellence	8	(1). Strategic PAM Policy (2). Roles and Responsibilities (3). Communication (4). PAM Planning (5). Acquisition and Disposal (6). Operation & Maintenance (7). Performance Review & Accounting (8). Audit and Review	N / A	N / A
MM18 [111]	Information Quality Management	5	(1). Reactive (2). Aware (3). Quantified (4). Managed (5). Optimizing	13	(1). Information Needs Analysis (2). Information Storage Management (3). Access Control Management (4). Information Security Management (5). Information Product Management (6). IQ Needs Analysis (7). IQ Assessment (8). IQ Management Roles and Responsibilities (9). IQM Governance (10). Enterprise Information Architecture Management (11). Continuous IQ Improvement (12). IQ Management Performance "Monitoring" (13). IQ Firewall	45	(1). Physical Modelling, (2). Logical Modelling, (3). Conceptual Modelling, (4). Stakeholder Management, (5). Information Destruction, (6). Archival and Retrieval, (7). Backup and Recovery, (8). Physical Storage, (9). Audit Trail, (10). Authorisation, (11). Authentication, (12). Sensitive Information Disposal Management, (13). Secure Transmission of Sensitive Information, (14). Security Classification of Information Products, (15). Meta-Information Management, (16). Derived Information Products Management, (17). Information Product Visualisation, (18). Information Product Taxonomy, (19). Information Product Configuration Management, (20). Information Supply Chain Management, (21). Requirements Management, (22). Requirements Analysis, (23). Requirements Elicitation, (24). Information Quality Evaluation, (25). Information Quality Metrics, (26). Scripted information Cleansing, (27). Information Quality Problem Reporting and Handling, (28). Information Quality Management, Education, Training, (29). Information Quality Management Team and Project Management, (30). Information Quality Audit Trail, (31). Strategic Information Quality, (32). Information Quality Benchmarking, (33). IQM Accountability, Rewards & Incentives, (34). Master Data Management/Redundant Storage, (35). Physical Tier Management, (36). Application Tier Management, (37). Information Tier Management, (38). Enterprise Tier Management, (39). Business Process Reengineering for Information Quality, (40). Information Quality Management Cost-Benefit Analysis, (41). Information Quality Risk Management and Impact Assessment, (42). Information Quality Problem Root-Cause-Analysis, (43). Information Quality Management Benchmarking, (44). Analysis and reporting, (45). Information Quality Management Metrics, and (46). Information Quality Firewall.

Appendix H

Table H.1 - Overview of the dimension selection process

Rating	Chen et al. (2021)	Cornu et al. (2012)	Errandonea et al. (2022)	Gersonius et al. (2020)	Gökalp et al. (2017)	Khaliq et al. (2016)	Patrício and Almeia (2021)	Sauni et al. (2022)	OGC (2007)	Woodall et al. (2013)
Fits the scope	22	12	17	6	4	14	7	3	8	20
Too General	13	15	4	1	1	5	1	3	0	3
Too specific	4	8	0	0	0	1	0	0	0	36
1	(1). Purpose	(1). Processes	(1). Asset	(1). Asset management decisions	(1). Asset Management	(1). Asset Policy	(1). Communication and Consultation	(1). Measurement result analysis	(1). Strategic PAM Policy	(1). Information Needs Analysis
2	(1.1). Insight	(1.1). Technical Processes	(2) Status	(2). Information management	(2). Data Governance	(2). Asset Planning	(2). Context	(2). Data systems	(2). Roles and Responsibilities	(2). Information Storage Management
3	(1.2). Value Creation	(1.2). Technical Management Processes	(3). Maintenance	(3). Internal co-ordination	(3). Application Management	(3). Asset Creation and Acquisition	(3). Risk Identification	(3). Maintenance	(3). Communication	(3). Access Control Management
4	(1.3). Public Good	(2). People	(1). Asset Management	(4). External co-ordination	(4). Organizational Alignment	(4). Asset Disposal	(4). Risk Analysis	(4). Asset Renewal	(4). PAM Planning	(4). Information Security Management
5	(2) Function	(2.1). Skills	(2). Reliability	(5). Outsourcing activities	(5). Process Transformation	(5). Environmental Analysis	(5). Risk Evaluation	(5). Knowledge	(5). Acquisition and Disposal	(5). Information Product Management
6	(2.1). Federation	(2.2). SE Mindset	(3). Safety	(6). Processes and roles		(6). Asset Operations	(6). Risk Treatment	(6). Contracts	(6). Operation & Maintenance	(6). IQ Needs Analysis
7	(2.2). Curation	(3). Method & Tools	(4). Risk Management	(7). Culture and leadership		(7). Asset Maintenance	(7). Monitoring and review		(7). Performance Review & Accounting	(7). IQ Assessment
8	(2.3). Evolution	(3.1). Knowledge Management and Sharing	(5). Availability			(8). Asset Management Information System	(8). Recording and reporting		(8). Audit and Review	(8). IQ Management Roles and Responsibilities
9	(3). Trust	(3.2) Tools	(6). Failure Mode Criteria			(9). Risk Management				(9). IQM Governance
10	(3.1). Opennes	(1). Engineering Processes (Consisting of:	(7). Status Monitoring			(10). Contingency Planning				(10). Enterprise Information Architecture Management
11	(3.2). Security	(1.1). Consistency & standardisation of engineering activities and	(8) Diagnosis			(11). Financial Planning				(11). Continuous IQ Improvement
12	(3.3). Quality	(1.2). Type of design).	(9) Prognosis			(12). Capital Expenditure Planning				(12). IQ Management Performance "Monitoring"

Rating	Chen et al. (2021)	Cornu et al. (2012)	Errandonea et al. (2022)	Gersonius et al. (2020)	Gökalp et al. (2017)	Khaliq et al. (2016)	Patrício and Almeia (2021)	Sauni et al. (2022)	OGC (2007)	Woodall et al. (2013)
13	(1). Project target/objective	(2). Technical Management Processes (Consisting of:	(10). Life-cycle Cost			(13). Review of Asset Management System				(13). IQ Firewall
14	(2). Organisational business process map	(2.1). Consistency & standardisation of technical management activities	(11). Operation Cost			(1). Scope				(1). Physical Modelling
15	(3). Organisational operational plan	(2.2). Definition of interfaces, roles and responsibilities, and constraints of stakeholders all along design technical and management activities	(12). Maintenance Cost			(2). Leadership				(2). Logical Modelling
16	(4). Improved management performances with digital twin involved	(2.3). Existence of a team responsible for the design office practices standardization & overall improvement	(13) Resources Management			(3). Planning				(3). Conceptual Modelling
17	(5). Qualified consulting company/expert supported	(2.4). Design Processes modelling)	(14). Operation management			(4). Support				(4). Stakeholder Management
18	(6). Digital twin relevant experience and aptitude of professionals and value creation	(3) Required Skills (consisting of:	(15). Maintainability			(5). Operation				(5). Information Destruction
19	(7). Role and responsibility definitions within the organisation	(3.1). Engineering	(16). Decision Support System			(6). Performance evaluation				(6). Archival and Retrieval
20	(8). Well-organised training programs within the organisation	(3.2). Project management	(17). Decision Models			(7). Improvement				(7). Backup and Recovery
21	(9). Communication strategies among different stakeholders and within the organisation	(3.3). Systems Engineering	(18) Optimization							(8). Physical Storage
22	(10). Data/model updating/collecting techniques based on as-is conditions for effective information collection (e.g., camera, sensor systems)	(3.4). Modelling)								(9). Audit Trail
23	(11). Data/model storage, exchange and sharing method (e.g., cloud-based storage technology)	(4) Management and Development of Skills (Consisting of:								(10). Authorisation
24	(12). Information visualisation technology	(4.1). Training								(11). Authentication

Rating	Chen et al. (2021)	Cornu et al. (2012)	Errandonea et al. (2022)	Gersonius et al. (2020)	Gökalp et al. (2017)	Khaliq et al. (2016)	Patricio and Almeia (2021)	Sauni et al. (2022)	OGC (2007)	Woodall et al. (2013)
25	(13). Data integration (e.g., centre database, data warehouse)	(4.2). Validation of skills								(12). Sensitive Information Disposal Management
26	(14). Asset integration	(4.3). Establishment of a "sense of urgency"								(13). Secure Transmission of Sensitive Information
27	(15). Asset register techniques implementation (e.g., RFID, QR code)	(4.4). Establishment of a "powerful guiding coalition"								(14). Security Classification of Information Products
28	(16). Digital model/data generating and updating process/technology	(4.5). Visions of top management								(15). Meta-Information Management
29	(17). Information/model sharing process/technology	(4.6). Arbitration between project short-term vision and SE deployment long term vision								(16). Derived Information Products Management
30	(18). Asset data updating and capturing process/technology	(4.7). Involvement of managers in the SE deployment project								(17). Information Product Visualisation
31	(19). Integrity and accuracy of as-is digital model (e.g., BIM)	(5.1). Capacity to exchange & share information within the entity								(18). Information Product Taxonomy
32	(20). Information security assurance	(5.2). Capitalization, fomalization and sharing of knowledge about desing engineering activities								(19). Information Product Configuration Management
33	(21). Formal standards and protocols as the basis	(5.3). Capitalization, formalization and sharing of knowledge about design technical management								(20). Information Supply Chain Management
34	(22). Removal and replacement reminders and records	(5.4). Sharing of artefacts templates								(21). Requirements Management
35	(23). Interoperability/IFC or COBie support (e.g., openBIM)	(5.5). Design tools standardization								(22). Requirements Analysis
36	(24). Integrity, accuracy and openness of collected information/data resources (e.g., space information, asset information, building management information)									(23). Requirements Elicitation

Rating	Chen et al. (2021)	Cornu et al. (2012)	Errandonea et al. (2022)	Gersonius et al. (2020)	Gökalp et al. (2017)	Khaliq et al. (2016)	Patrício and Almeia (2021)	Sauni et al. (2022)	OGC (2007)	Woodall et al. (2013)
37	(25). Digital twin for asset management implementation guide									(24). Information Quality Evaluation
38	(26). Continuous quality assurance mechanism/rules									(25). Information Quality Metrics
39	(27). Formal services and data delivery provision (e.g., data exchange standard)									(26). Scripted information Cleansing
40										(27). Information Quality Problem Reporting and Handling
41										(28). Information Quality Management, Education, Training
42										(29). Information Quality Management Team and Project Management
43										(30). Information Quality Audit Trail
44										(31). Strategic Information Quality
45										(32). Information Quality Benchmarking
46										(33). IQM Accountability, Rewards & Incentives
47										(34). Master Data Management/Redundant Storage
48										(35). Physical Tier Management

Rating	Chen et al. (2021)	Cornu et al. (2012)	Errandonea et al. (2022)	Gersonius et al. (2020)	Gökalp et al. (2017)	Khaliq et al. (2016)	Patrício and Almeia (2021)	Sauni et al. (2022)	OGC (2007)	Woodall et al. (2013)
49										(36). Application Tier Management
50										(37). Information Tier Management
51										(38). Enterprise Tier Management
52										(39). Business Process Reengineering for Information Quality
53										(40). Information Quality Management Cost-Benefit Analysis
54										(41). Information Quality Risk Management and Impact Assessment
55										(42). Information Quality Problem Root-Cause-Analysis
56										(43). Information Quality Management Benchmarking
57										(44). Analysis and reporting
58										(45). Information Quality Management Metrics
59										(46). Information Quality Firewall

Appendix F

Table F.1 - Full dimension grouping overview

	Focus Area	Total
(1).	Human Resources	8
(2).	Risk management	8
(3).	Information quality	9
(4).	Cost management / Financial Planning	4
(5).	Security	7
(6).	Asset life-cycle	21
(7).	Information Collection and Dissemination	19
(8).	Strategic Direction	19
(9).	Tool Management and Standardization	16

Dimension	(01). Chen et al. (2021)	(02). Comu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1	(01). Security	(02). People	(03). Maintenance	(04). Information management	(05). Data Governance	(06). Asset Policy	(07). Communication and Consultation	(08). Maintenance	(09). Strategic PAM Policy	(10). Information Storage Management
2	(01). Quality	(02). Design tools standardization	(03). Reliability	(04). Internal co-ordination	(05). Application Management	(06). Asset Planning	(07). Risk Identification	(08). Asset Renewal	(09). Roles and Responsibilities	(10). Access Control Management
3	(01). Organisational business process map	(02). Knowledge Management and Sharing	(03). Safety	(04). External co-ordination	(05). Organizational Alignment	(06). Asset Creation and Acquisition	(07). Risk Analysis	(08). Contracts	(09). Communication	(10). Information Security Management
4	(01). Organisational operational plan	(02). Tools	(03). Risk Management	(04). Outsourcing activities	(05). Process Transformation	(06). Asset Disposal	(07). Risk Evaluation		(09). PAM Planning	(10). IQ Assessment
5	(01). Improved management performances with digital twin involved	(02). Consistency & standardisation of engineering activities	(03). Availability	(04). Processes and roles		(06). Asset Operations	(07). Risk Treatment		(09). Acquisition and Disposal	(10). IQ Management Roles and Responsibilities
6	(01). Qualified consulting company/expert supported	(02). Consistency & standardisation of technical management activities	(03). Failure Mode Criteria	(04). Culture and leadership		(06). Asset Maintenance	(07). Monitoring and review		(09). Operation & Maintenance	(10). IQM Governance
7	(01). Role and responsibility definitions within the organisation	(02). Definition of interfaces, roles and responsibilities, and constraints of stakeholders all along design technical and management activities	(03). Status Monitoring			(06). Asset Management Information System	(07). Recording and reporting		(09). Performance Review & Accounting	(10). Logical Modelling
8	(01). Well-organised training programs within the organisation	(02). Existence of a team responsible for the design office practices standardization & overall improvement	(03). Diagnosis			(06). Risk Management			(09). Audit and Review	(10). Conceptual Modelling
9	(01). Communication strategies among different stakeholders and within the organisation	(02). Design Processes modelling	(03). Prognosis			(06). Contingency Planning				(10). Stakeholder Management
10	(01). Data/model updating/collecting techniques based on as-is conditions for effective information collection (e.g., camera, sensor systems)	(02). Management and Development of Skills	(03). Life-cycle Cost			(06). Capital Expenditure Planning				(10). Authorisation

Dimension	(01). Chen et al. (2021)	(02). Comu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
11	(01). Data/model storage, exchange and sharing method (e.g., cloud-based storage technology)	(02). Capacity to exchange & share information within the entity	(03). Operation Cost			(06). Review of Asset Management System				(10). Secure Transmission of Sensitive Information
12	(01). Data integration (e.g., centre database, data warehouse)	(02). Sharing of artefacts templates	(03). Maintenance Cost			(06). Leadership				(10). Security Classification of Information Products
13	(01). Asset register techniques implementation (e.g., RFID, QR code)		(03). Resources Management			(06). Performance evaluation				(10). Information Quality Evaluation
14	(01). Digital model/data generating and updating process/technology		(03). Operation management			Financial Planning				(10). Physical Tier Management
15	(01). Information/model sharing process/technology		(03). Maintainability							(10). Application Tier Management
16	(01). Asset data updating and capturing process/technology		(03). Decision Support System							(10). Information Tier Management
17	(01). Integrity and accuracy of as-is digital model (e.g., BIM)		(03). Decision Models							(10). Enterprise Tier Management
18	(01). Information security assurance									(10). Information Quality Risk Management and Impact Assessment
19	(01). Formal standards and protocols as the basis									(10). Analysis and reporting
20	(01). Integrity, accuracy and openness of collected information/data resources (e.g., space information, asset									
21	(01). Continuous quality assurance mechanism/rules									
22	(01). Formal services and data delivery provision (e.g., data exchange standard)									

Appendix G

Table G.1 - Full dimension pivot model comparisons

Group (1).	Human Resources									
Dimension	(01). Chen et al. (2021)	(02). Cornu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1	(01). Qualified consulting company/expert supported									
2	(01). Role and responsibility definitions within the organisation								(09). Roles and Responsibilities	
3	(01). Well-organised training programs within the organisation	(02). Management and Development of Skills								
4		(02). People								
5				(04). Culture and leadership		(06). Leadership				

Group (2).	Risk management									
Dimension	(01). Chen et al. (2021)	(02). Cornu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1			(03). Risk Management			(06). Risk Management				
2			(03). Safety							
3							(07). Risk Identification			
4							(07). Risk Analysis			
5							(07). Risk Evaluation			
6							(07). Risk Treatment			
7										(10). Information Quality Risk Management and Impact Assessment

Group (3).	Information quality									
Dimension	(01). Chen et al. (2021)	(02). Cornu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1	(01). Quality									(10). IQ Assessment
2	(01). Integrity and accuracy of as-is digital model (e.g., BIM)									
3	(01). Integrity, accuracy and openness of collected information/data resources (e.g., space information, asset information, building management information)									
4	(01). Continuous quality assurance mechanism/rules				(05). Data Governance					(10). IQM Governance
5										(10). IQ Management Roles and Responsibilities
6										(10). Information Quality Evaluation

Group (4).	Cost management / Financial Planning									
Dimension	(01). Chen et al. (2021)	(02). Cornu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1			(03). Life-cycle Cost							
2			(03). Operation Cost							
3			(03). Maintenance Cost							
4						Financial Planning				

Group (5).	Security									
Dimension	(01). Chen et al. (2021)	(02). Cornu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1	(01). Security									(10). Information Security Management
2	(01). Information security assurance									(10). Access Control Management
3										(10). Authorisation
4										(10). Authentication
5										(10). Secure Transmission of Sensitive Information
6										(10). Security Classification of Information Products

Group (6).	Asset life-cycle									
Dimension	(01). Chen et al. (2021)	(02). Cornu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1	(01). Asset register techniques implementation (e.g., RFID, QR code)									
2			(03). Maintenance			(06). Asset Maintenance		(08). Maintenance	(09). Operation & Maintenance	
3			(03). Reliability							
4			(03). Availability			(06). Asset Planning			(09). PAM Planning	
5			(03). Failure Mode Criteria							
6			(03). Resources Management							
7			(03). Operation management			(06). Asset Operations				(10). Physical Tier Management
8			(03). Maintainability							
9						(06). Asset Policy			(09). Strategic PAM Policy	
10						(06). Asset Creation and Acquisition		(08). Asset Renewal	(09). Acquisition and Disposal	
11						(06). Asset Disposal				

Group (7).	Information collecting / sharing									
Dimension	(01). Chen et al. (2021)	(02). Cornu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1	(01). Communication strategies among different stakeholders and within the organisation	(02). Capacity to exchange & share information within the entity					(07). Communication and Consultation		(09). Communication	
2	(01). Data/model updating/collecting techniques based on as-is conditions for effective information collection (e.g., camera, sensor systems)									
3	(01). Data/model storage, exchange and sharing method (e.g., cloud-based storage technology)					(06). Asset Management Information System				(10). Information Storage Management
4	(01). Data integration (e.g., centre database, data warehouse)									
5	(01). Information/model sharing process/technology	(02). Knowledge Management and Sharing								
6	(01). Asset data updating and capturing process/technology		(03). Status Monitoring				(07). Recording and reporting			
7	(01). Formal services and data delivery provision (e.g., data exchange standard)									
8		(02). Sharing of artefacts templates								
9			(03). Diagnosis							
10			(03). Prognosis							
11				(04). Information management						(10). Information Tier Management

Group (8).	Strategic Direction									
Dimension	(01). Chen et al. (2021)	(02). Cornu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1	(01). Organisational business process map									
2	(01). Organisational operational plan									
3				(04). Internal co-ordination						
4				(04). External co-ordination						
5				(04). Outsourcing activities						
6				(04). Processes and roles	(05). Process Transformation					
7					(05). Organizational Alignment					
8						(06). Capital Expenditure Planning				(10). Enterprise Tier Management
9						(06). Contingency Planning				
10						(06). Review of Asset Management System				
11						(06). Performance evaluation	(07). Monitoring and review		(09). Performance Review & Accounting	(10). Analysis and reporting
12								(08). Contracts		
13									(09). Audit and Review	
14										(10). Stakeholder Management

Group (9).	Tool Management and Standardization									
Dimension	(01). Chen et al. (2021)	(02). Cornu et al. (2012)	(03). Errandonea et al. (2022)	(04). Gersonius et al. (2020)	(05). Gökalp et al. (2017)	(06). Khaliq et al. (2016)	(07). Patrício and Almeia (2021)	(08). Sauni et al. (2022)	(09). OGC (2007)	(10). Woodall et al. (2013)
1	(01). Formal standards and protocols as the basis									
2	(01). Improved management performances with digital twin involved									
3	(01). Digital model/data generating and updating process/technology									(10). Conceptual Modelling
4		(02). Design tools standardization								
5		(02). Tools								
6		(02). Consistency & standardisation of engineering activities								
7		(02). Existence of a team responsible for the design office practices standardization & overall improvement								
8		(02). Consistency & standardisation of technical management activities								
9		(02). Definition of interfaces, roles and responsibilities, and constraints of stakeholders all along design technical and management activities								
10		(02). Design Processes modelling								
11			(03). Decision Models							
12			(03). Decision Support System							
13					(05). Application Management					(10). Application Tier Management
14										(10). Logical Modelling

Appendix I


Workshop:
Enterprise Asset Management Maturity Modelling
Bernard Verheijen
UNIVERSITY OF TWENTE.
In collaboration with
PERNINO CONSULTING
Digitale Innovatie

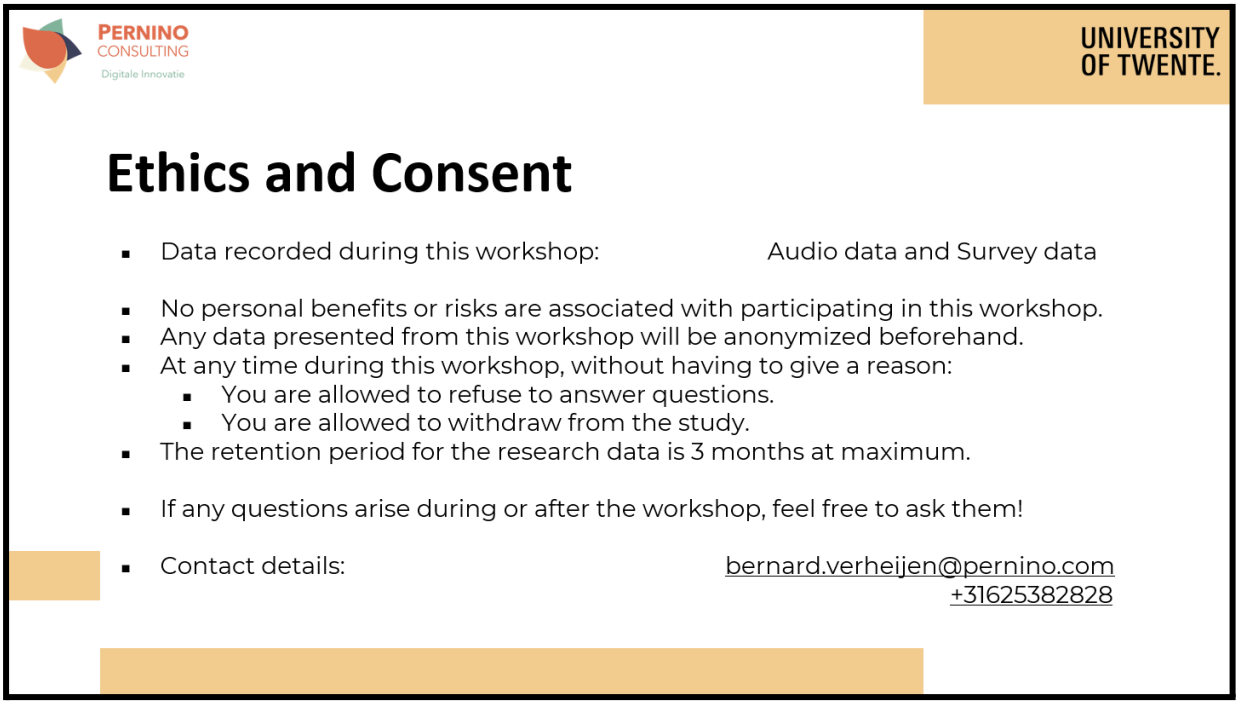
PERNINO CONSULTING
Digitale Innovatie
UNIVERSITY OF TWENTE.
Ethics and Consent
Data recorded during this workshop: Audio data and Survey data
No personal benefits or risks are associated with participating in this workshop.
Any data presented from this workshop will be anonymized beforehand.
At any time during this workshop, without having to give a reason:
You are allowed to refuse to answer questions.
You are allowed to withdraw from the study.
The retention period for the research data is 3 months at maximum.
If any questions arise during or after the workshop, feel free to ask them!
Contact details: bernard.verheijen@pernino.com
+31625382828

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Table of Contents

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01

Introduction

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Introduction

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Working Definition – Part I

01

Maturity

Maturity is the dynamic state which indicates how explicitly defined, managed, controlled and effective a process is. This state is dynamic and thus can improve/progress in various ways to reach the final mature state. The final mature state is considered to be complete and perfect.

02

Maturity Model

A Maturity Model is a model which assesses the maturity of a specific domain based on a multitude of maturity levels, doing this can assist in decision-making and be used to guide, as well as monitor, the transformation process towards reaching an improved or fully mature state over time.

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Introduction

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Working Definition – Part II

03

Asset

"Item, thing or entity that has potential or actual value to an organization."
Note to entry: "*Value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities. It can be positive or negative at different stages of the asset life."*

- International Organization for Standardization (2014)

04

Enterprise Asset Management

Enterprise Asset Management is the coordinated process of an organization to cost-effectively monitor, manage and optimise asset performance throughout the whole life-cycle of the assets.

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Introduction

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Thesis Goal

The goal of this thesis is to create a broad, inclusive and explorative Maturity Model (MM) that enables large-scale, asset-intensive organizations to take a holistic view of their EAM processes and their respective maturity. This is done to help with decision-making towards improved Enterprise Asset Management (EAM) practices.

The envisioned MM should be theory-backed and by practitioners evaluated.

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Introduction

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Workshop Goal

The goal of this workshop is to evaluate and, where possible, validate the newly created maturity model with the help of experienced practitioners.

This is done in order to gain valuable new insights and refine the model further.

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02

Maturity Model

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Maturity Model

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Maturity Model Creation Process

01 18 MMs were selected and analyzed

02 The 18 MMs were ranked on their suitability

03 10 MMs were selected for the development of the new MM

04 An overview is created of all respective dimensions and criteria

05 Suitable dimensions / criteria from the model were selected

06 The selected dimensions are compared against one other and groupings are made.

07 Dimension descriptions were created.

08 Finally, corresponding maturity levels were created.

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Maturity Model

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Maturity Focus Areas

01 Strategic Direction
02 Asset Life-cycle Management
03 Asset Cost Optimization
04 Information Collection and Dissemination
05 Information Quality
06 Risk Management
07 Security
08 Human Capital
09 Tool Management and Standardization

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Maturity Model

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Maturity Levels

0 **Ad hoc / Initial Organization**

Business processes are unorganized, undefined, unstandardized, unaligned with business goals and created / adopted on an ad hoc basis.

1 **Repeatable Organization**

Business processes are organized and consistently repeated, yet undefined, unstandardized and unaligned with business goals.

2 **Defined Organization**

Business processes are organized, repeated, and defined yet unaligned with business goals.

Maturity Levels

Controlled Organization

Business processes are fully controlled, defined, documented, monitored and aligned with business goals.

Optimized Organization

Business processes are fully controlled, defined, documented, monitored, optimized for performance, flexible and adjustable if necessary, and aligned with business goals. Best practices are utilized for maximal value creation.

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Questions?

Before moving on to the questionnaire,
are there any remaining questions concerning the maturity model?

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03

Questionnaire

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Questionnaire

Please take this time to fill out the questionnaire

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04

Open Discussion

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Open Discussion – Part I

- What is your opinion on using a maturity model assessment to identify strengths and weaknesses in EAM implementations?
- Do you think the focus area(s) are logically divided? If not, which one(s) and why?
- Do you think any focus area(s) are missing? If so, which one(s) and why?
- Do you think any focus area(s) mentioned are not necessary? If so, which one(s) and why?
- Do you think the dimensions in the maturity model are representing the most important aspects of EAM in a comprehensive manner?

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Open Discussion – Part II

- Do you think any dimension(s) are missing? If so, which one(s) and why?
- Do you think any dimension(s) mentioned are not necessary? If so, which one(s) and why?
- Do you think the granularity of the maturity levels is adequate for the purpose of the maturity model? If not, why?
- Do you think the maturity level descriptions are clear in communicating the maturity stage of the presented dimensions? If not, why and what improvements do you suggest?

THANK YOU!

Do you have any questions?

Feel free to contact me:

bernard.verheijen@pernino.com

Tel.: +31625382828

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Appendix J

Workshop: Maturity Modelling for improved Enterprise Asset Management

Questionnaire:

We will first start off with some general opening questions.

1. What is your current job / function?

……

2. How many years of experience do you have in the field of Enterprise Asset Management?

……

3. Do you have previous experience with using a maturity model as an assessment tool?

……

4. What domain / area within Enterprise Asset Management are you most acquainted with?

……

The following questions are on Focus Area 1: Strategic Direction

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

1. Capital Expenditure Planning

	1	2	3	
Necessary	○	○	○	Not necessary

2. Organisational Operational Plan

	1	2	3	
Necessary	○	○	○	Not necessary

3. Organisational Business Process Map

	1	2	3	
Necessary	○	○	○	Not necessary

4. Organisational Contingency Planning

	1	2	3	
Necessary	○	○	○	Not necessary

5. Process Transformation

	1	2	3	
Necessary	○	○	○	Not necessary

6. Stakeholder Management

	1	2	3	
Necessary	○	○	○	Not necessary

7. Contract Management

	1	2	3	
Necessary	○	○	○	Not necessary

8. Internal Coordination

	1	2	3	
Necessary	○	○	○	Not necessary

9. External Coordination

	1	2	3	
Necessary	○	○	○	Not necessary

10. Performance Review

	1	2	3	
Necessary	○	○	○	Not necessary

11. <u>Focus Area 1: Strategic Direction</u>

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

	1	2	3	
Necessary	○	○	○	Not necessary

<u>The following questions are on Focus area 2: Asset Life Cycle Management</u>

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

12. Asset Policy

	1	2	3	
Necessary	○	○	○	Not necessary

13. Asset Acquisition

	1	2	3	
Necessary	○	○	○	Not necessary

14. Asset Registering

	1	2	3	
Necessary	○	○	○	Not necessary

15. Asset Planning

	1	2	3	
Necessary	○	○	○	Not necessary

16. Asset Operation Management

	1	2	3	
Necessary	○	○	○	Not necessary

17. Asset Maintenance

	1	2	3	
Necessary	○	○	○	Not necessary

18. Asset Disposal

	1	2	3	
Necessary	○	○	○	Not necessary

19. Focus area 2: Asset Life Cycle Management

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

	1	2	3	
Necessary	○	○	○	Not necessary

The following questions are on Focus area 3: Asset Cost Optimization

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

20. Financial Planning

	1	2	3	
Necessary	○	○	○	Not necessary

21. Life-cycle Costs

	1	2	3	
Necessary	○	○	○	Not necessary

22. Operational Costs

	1	2	3	
Necessary	○	○	○	Not necessary

23. Maintenance Costs

	1	2	3	
Necessary	○	○	○	Not necessary

24. <u>Focus area 3: Asset Cost Optimization</u>

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

	1	2	3	
Necessary	○	○	○	Not necessary

<u>The following questions are on Focus area 4: Information Collection and Dissemination</u>

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

25. Information Management

	1	2	3	
Necessary	○	○	○	Not necessary

26. Asset Data Monitoring and Recording

	1	2	3	
Necessary	○	○	○	Not necessary

27. Information Storage

	1	2	3	
Necessary	○	○	○	Not necessary

28. Communication

	1	2	3	
Necessary	○	○	○	Not necessary

29. Knowledge Management and Sharing

	1	2	3	
Necessary	○	○	○	Not necessary

30. Focus area 4: Information Collection and Dissemination

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

	1	2	3	
Necessary	○	○	○	Not necessary

The following questions are on Focus area 5: Information Quality

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

31. Information Quality Governance

	1	2	3	
Necessary	○	○	○	Not necessary

32. Information Quality Assessment

	1	2	3	
Necessary	○	○	○	Not necessary

33. Information Openness

	1	2	3	
Necessary	○	○	○	Not necessary

34. <u>Focus area 5: Information Quality</u>

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

	1	2	3	
Necessary	○	○	○	Not necessary

<u>The following questions are on Focus area 6: Risk Management</u>

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

35. Safety

	1	2	3	
Necessary	○	○	○	Not necessary

36. Risk Identification

	1	2	3	
Necessary	○	○	○	Not necessary

37. Risk Analysis

	1	2	3	
Necessary	○	○	○	Not necessary

38. Risk Evaluation

	1	2	3	
Necessary	○	○	○	Not necessary

39. Risk Treatment

	1	2	3	
Necessary	○	○	○	Not necessary

40. <u>Focus area 6: Risk Management</u>

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

	1	2	3	
Necessary	○	○	○	Not necessary

<u>The following questions are on Focus area 7: Security</u>

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

41. Information Security Management

	1	2	3	
Necessary	○	○	○	Not necessary

42. Information Access Control

	1	2	3	
Necessary	○	○	○	Not necessary

43. Secure Transmission of Sensitive Information

	1	2	3	
Necessary	○	○	○	Not necessary

44. <u>Focus area 7: Security</u>

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

	1	2	3	
Necessary	○	○	○	Not necessary

<u>The following questions are on Focus area 8: Human Capital</u>

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

45. Skill Management and Development

	1	2	3	
Necessary	○	○	○	Not necessary

46. Roles and Responsibility

	1	2	3	
Necessary	○	○	○	Not necessary

47. Leadership and Business Culture

	1	2	3	
Necessary	○	○	○	Not necessary

48. Qualified external support

	1	2	3	
Necessary	○	○	○	Not necessary

49. Focus area 8: Human Capital

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

	1	2	3	
Necessary	○	○	○	Not necessary

The following questions are on Focus area 9: Tool Management and Standardization

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

50. Formal Standards and Protocols as the Basis

	1	2	3	
Necessary	○	○	○	Not necessary

51. Consistency and Standardization of Tools

	1	2	3	
Necessary	○	○	○	Not necessary

52. Conceptual Modeling

	1	2	3	
Necessary	○	○	○	Not necessary

53. Decision Support System

	1	2	3	
Necessary	○	○	○	Not necessary

54. Application Management

	1	2	3	
Necessary	○	○	○	Not necessary

55. Digital Twin

	1	2	3	
Necessary	○	○	○	Not necessary

56. <u>Focus area 9: Tool Management and Standardization</u>

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

	1	2	3	
Necessary	○	○	○	Not necessary

<u>Unified Theory of Acceptance and Use of Technology (UTAUT) questions</u>

The following questions are formulated as statements. Please use the Likert scale to answer how you feel about the statement. The Likert scale is divided as follows:

1. Strongly Disagree
2. Disagree
3. Neither agree nor disagree
4. Agree
5. Strongly Agree

57. Performance expectancy: I would find the maturity model useful for assessing an organisation's EAM Maturity.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

58. Performance expectancy: Using the maturity model enables me to accomplish an EAM maturity assessment more quickly.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

59. Performance expectancy: Using the maturity model will improve my understanding of an organisation's current EAM practices.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

60. Effort expectancy: Without explanation, my interaction with the maturity model would have been clear and understandable.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

61. Effort expectancy: I would find the maturity model easy to use.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

62. Effort expectancy: It would be easy for me to become skilful at using the maturity model.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

63. Effort expectancy: Learning to use the maturity model is easy for me.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

64. Social Influence: People who influence my behaviour would think that I should use the maturity model.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

65. Social Influence: Senior management of my organisation will support the use of the maturity model.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

66. Social Influence: In general, my organisation will support the use of the maturity model.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

67. Facilitating conditions: I have the resources necessary to use the maturity model.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

68. Facilitating conditions: I have the knowledge necessary to use the maturity model.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

69. Facilitating conditions: A specific person (or group) is available for assistance if I encounter difficulties with the maturity model.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Appendix K

Workshop: Maturity Modelling for improved Enterprise Asset Management

Questionnaire Responses:

We will first start off with some general opening questions.

What is your current job / function?

- Director / project manager
- Data Consultant
- Business Process Consultant
- Consultant
- Management Consulting Organisatie
- Implementation Manager
- Hard Service Specialist
- Consultant

How many years of experience do you have in the field of Enterprise Asset Management?

- 25
- 3
- 12
- 7
- 10
- 12
- 20
- 15

Do you have previous experience with using a maturity model as an assessment tool?

- Yes (6/8 Votes; 75%)
- No (2/8 Votes; 25%)

What domain / area within Enterprise Asset Management are you most acquainted with?

- Operationele activiteiten
- Information Collection and Dissemination
- Asset Lifecycle Management
- Maintenance of assets
- Rail
- Dynamic Solution Modeling and Systems Engineering
- Hard Services (fysiek asset management)
- Information

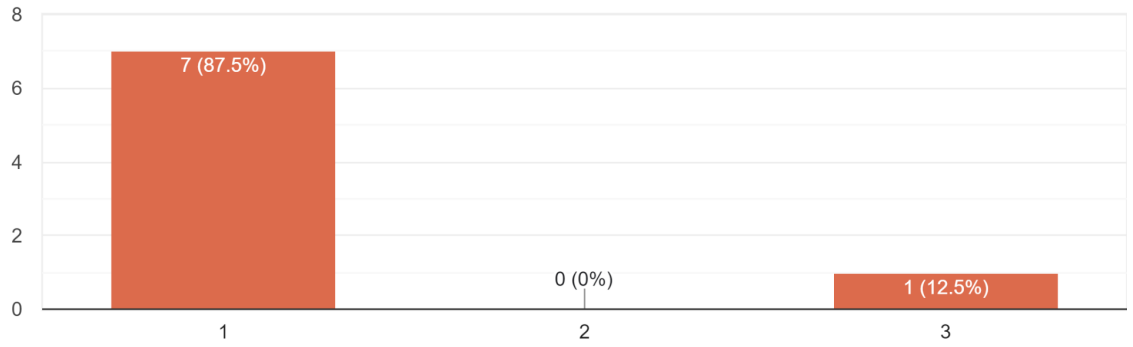
The following questions are on Focus area 1: Strategic Direction

The following sections will ask about the dimensions in the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

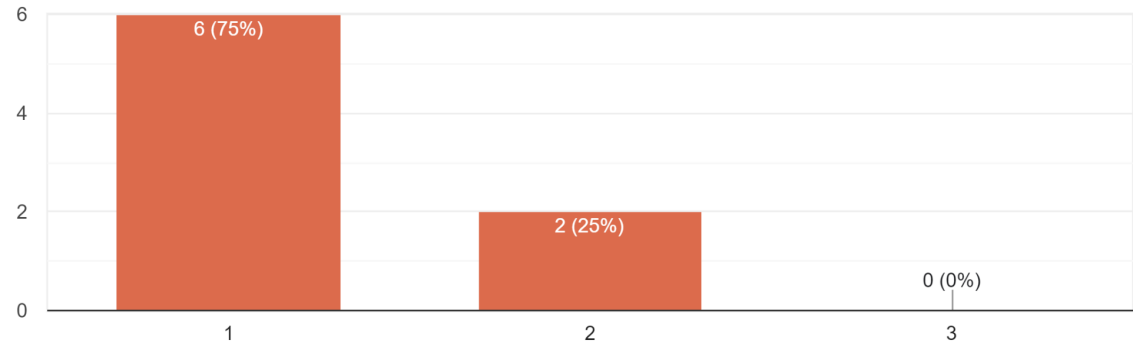
Capital Expenditure Planning

8 responses



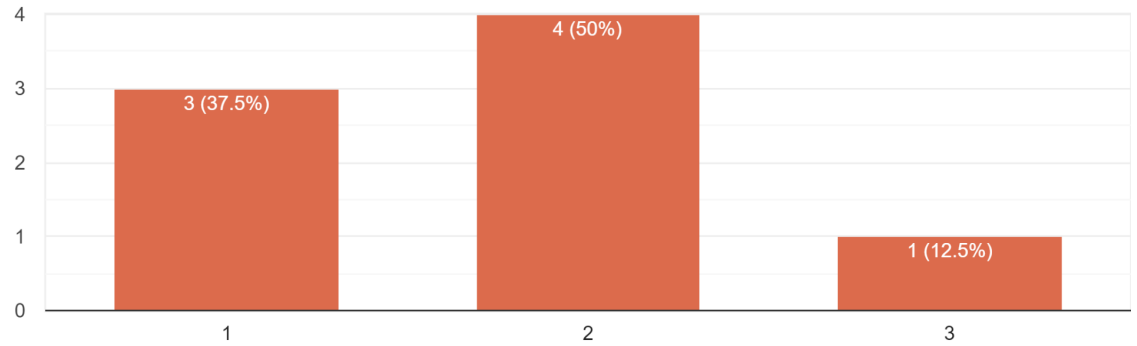
Organizational Operational Plan

8 responses



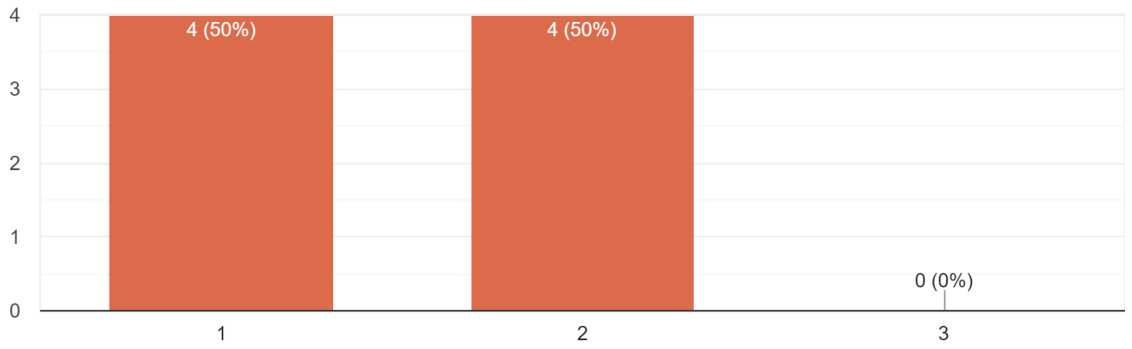
Organizational Business Process Map

8 responses



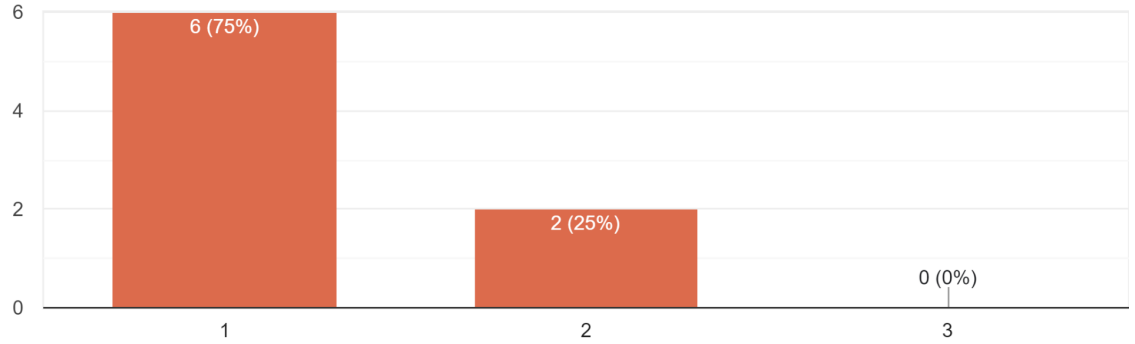
Organizational Contingency Planning

8 responses



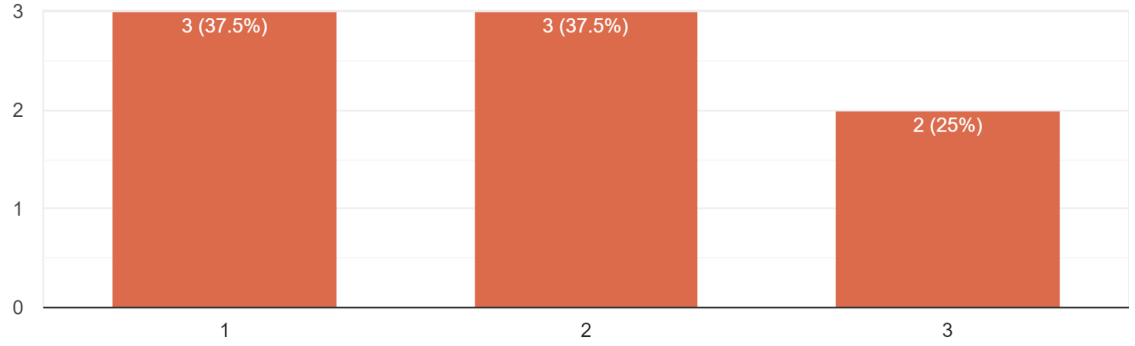
Process Transformation

8 responses



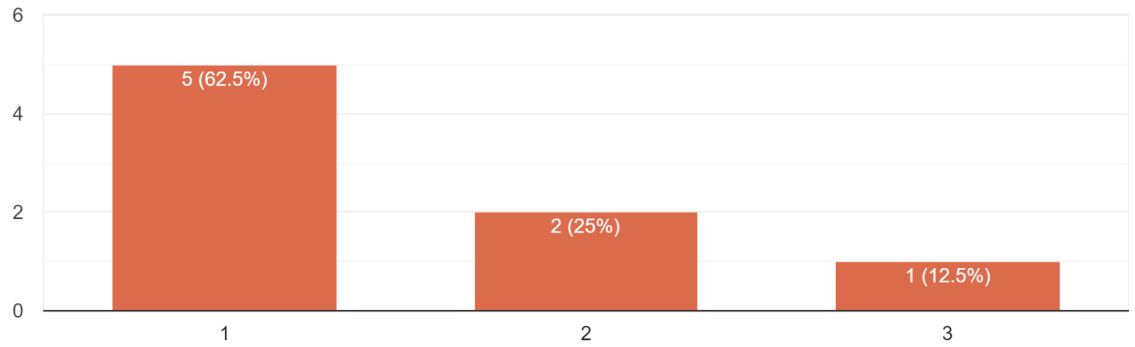
Stakeholder Management

8 responses



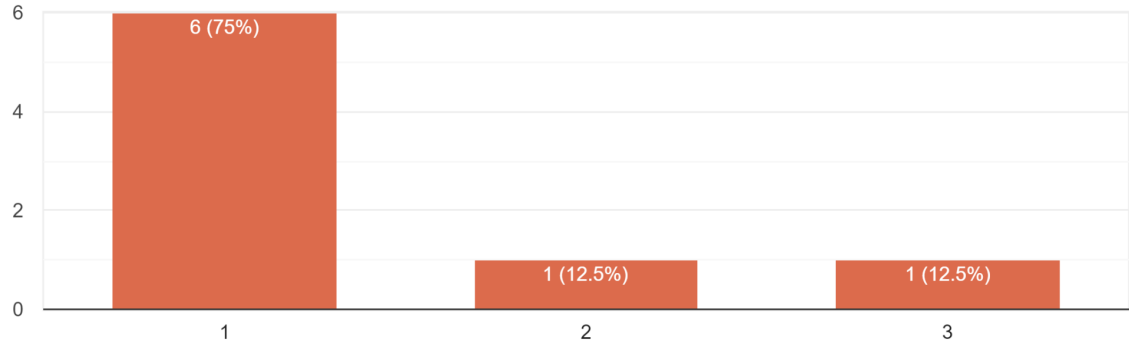
Contract Management

8 responses



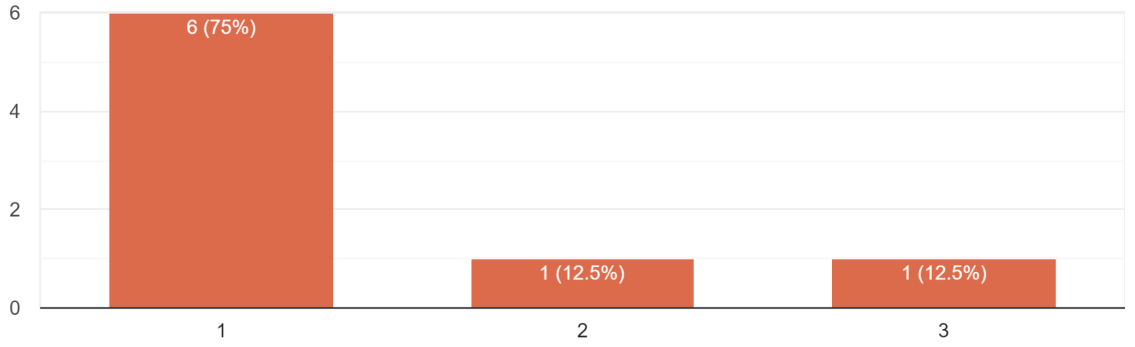
Internal Co-ordination

8 responses



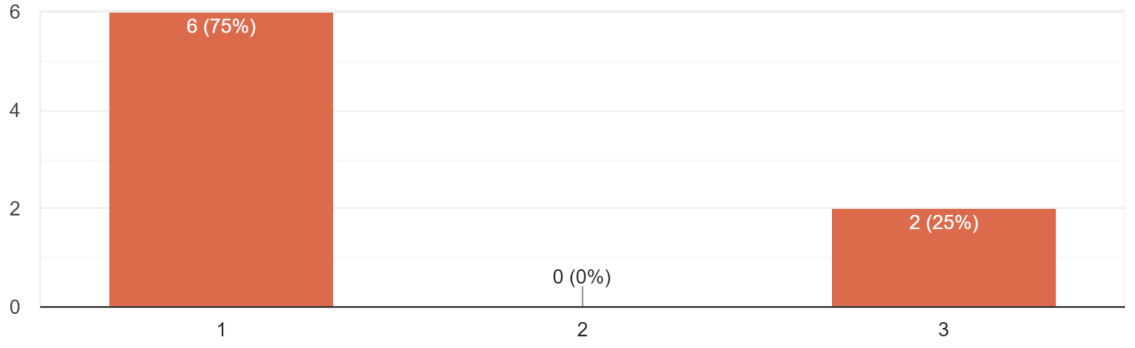
External Co-ordination

8 responses



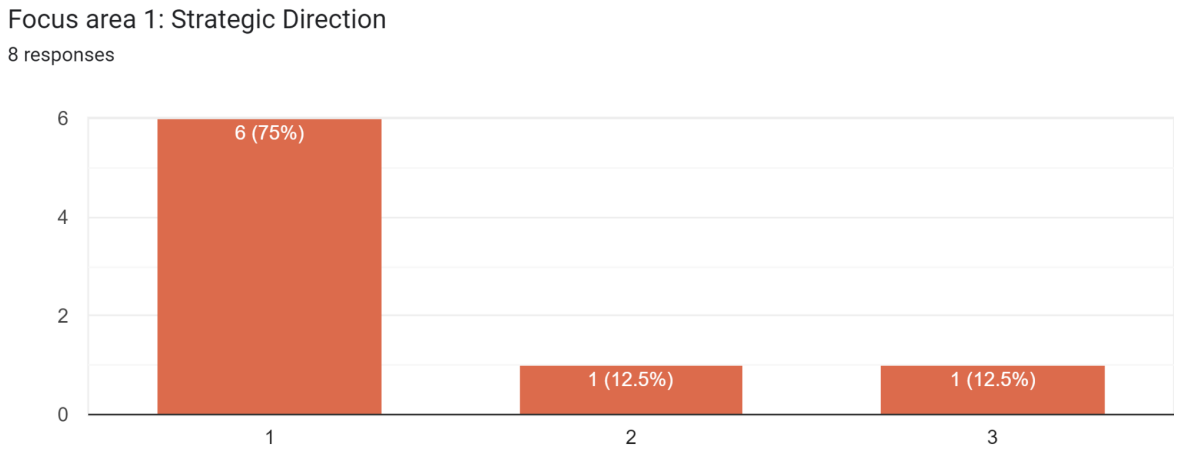
Performance Review

8 responses



Focus area 1: Strategic Direction

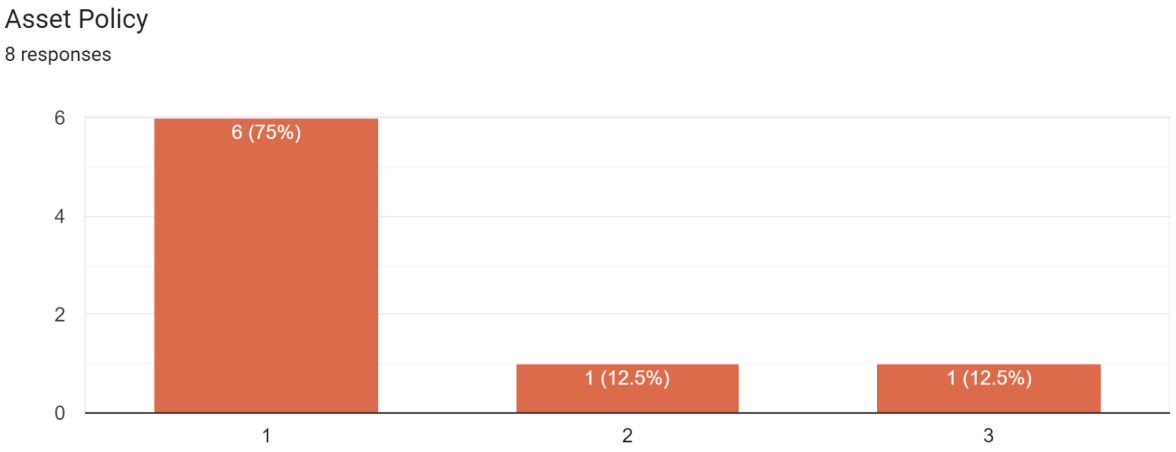
This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:



The following questions are on Focus area 2: Asset Life Cycle Management

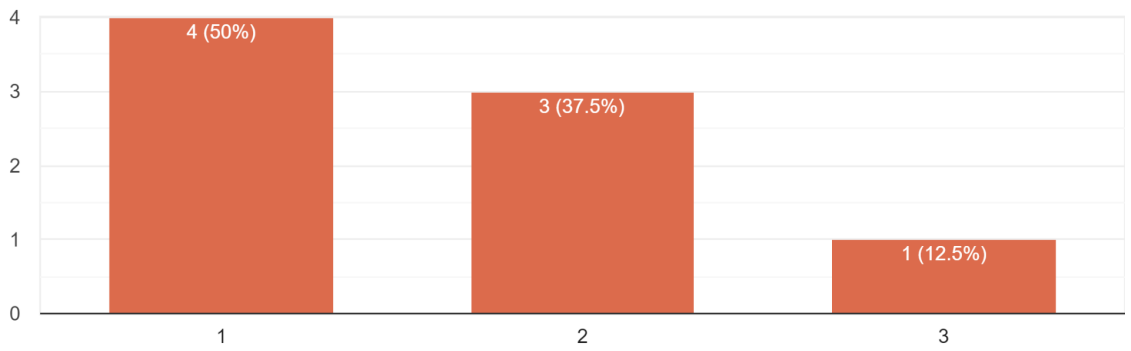
The following sections will ask about the dimensions in the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary



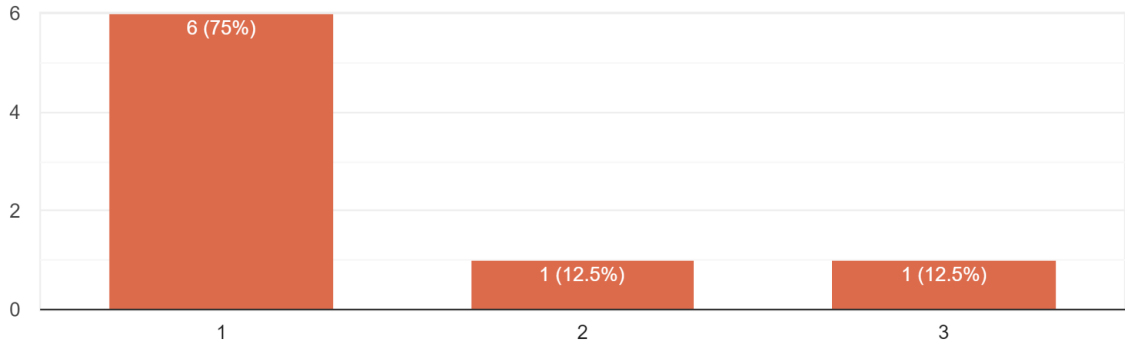
Asset Acquisition

8 responses



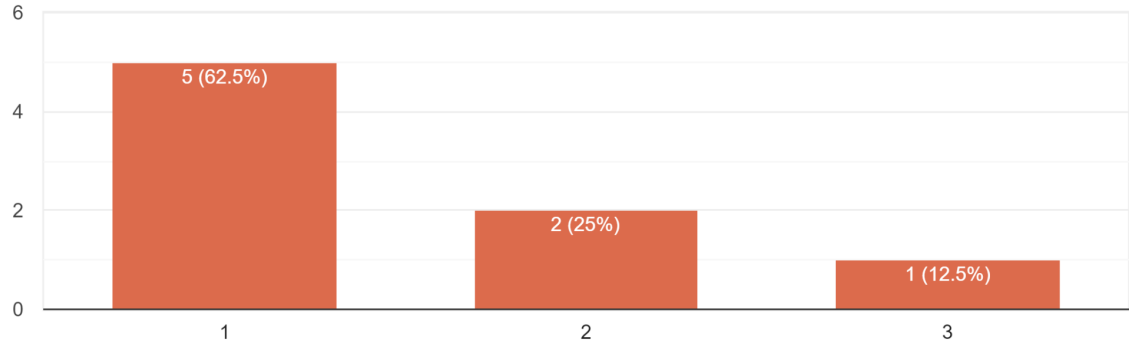
Asset Registering

8 responses



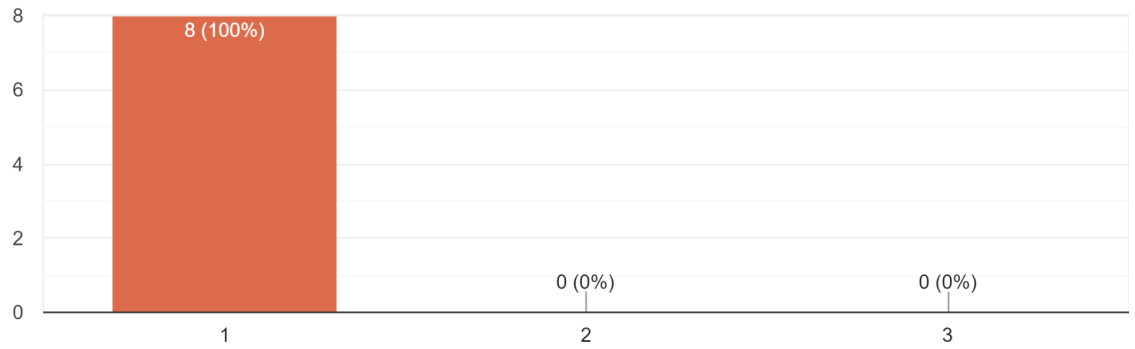
Asset Planning

8 responses



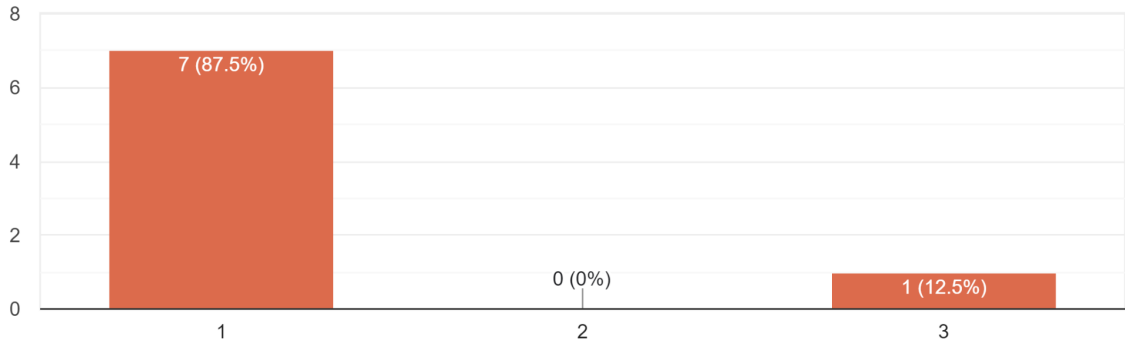
Asset Operation Management

8 responses



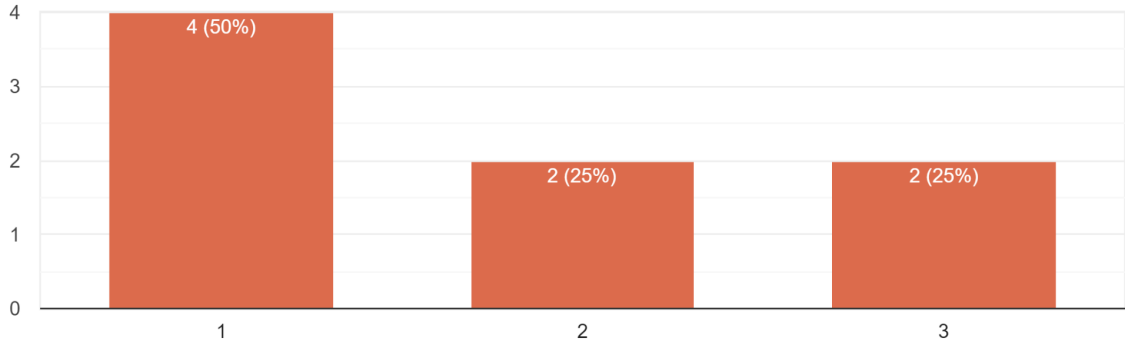
Asset Maintenance

8 responses



Asset Disposal

8 responses

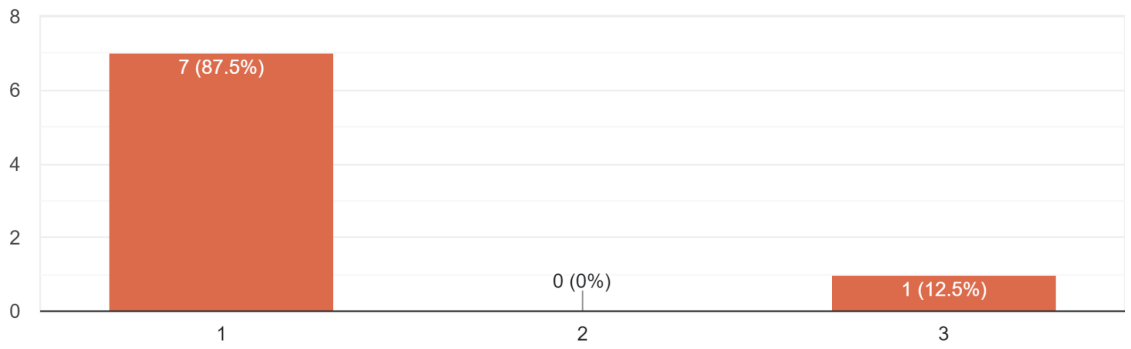


Focus area 2: Asset Life Cycle Management

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

Focus area 2: Asset Life Cycle Management

8 responses



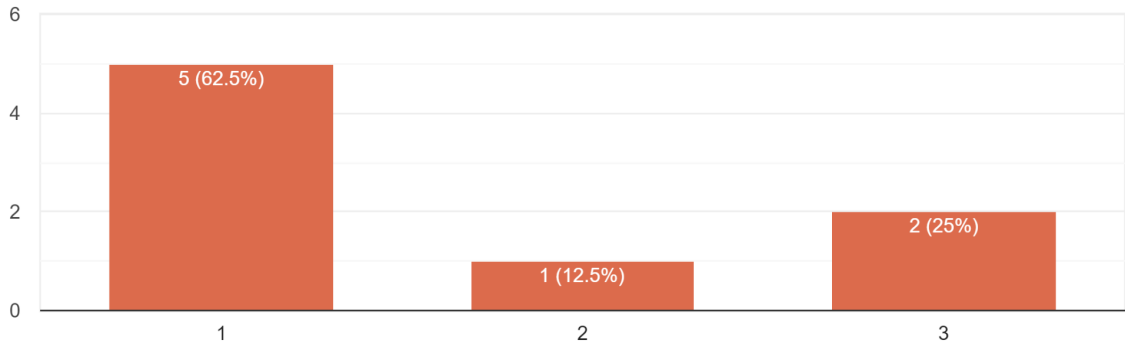
The following questions are on Focus area 3: Asset Cost Optimization

The following sections will ask about the dimensions in the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

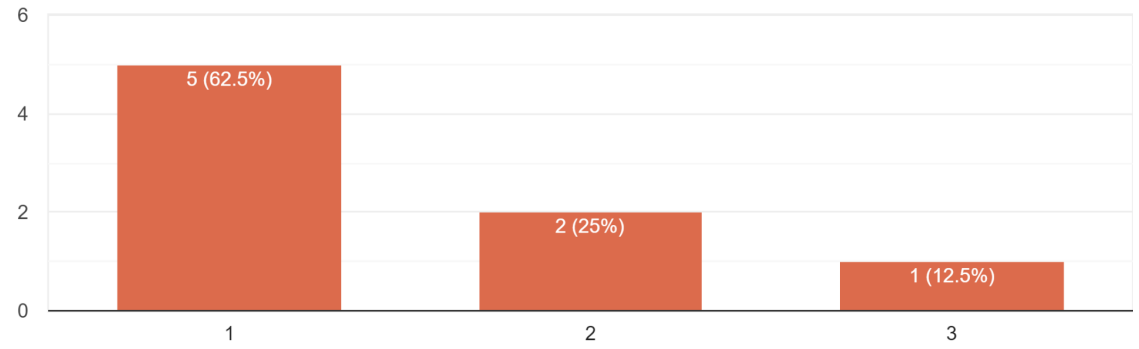
Financial Planning

8 responses



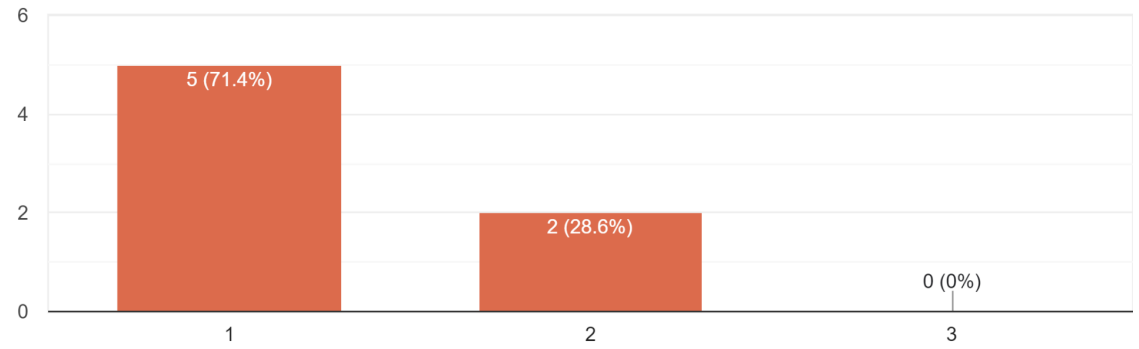
Life-cycle Costs

8 responses



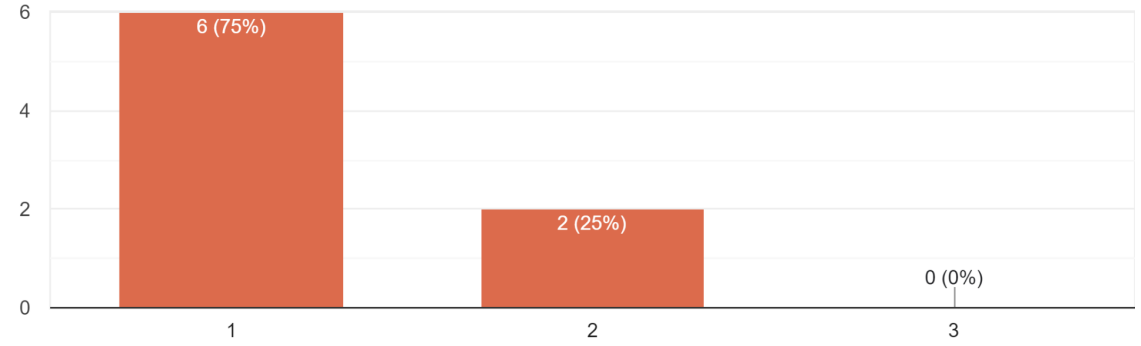
Operational Costs

7 responses



Maintenance Costs

8 responses

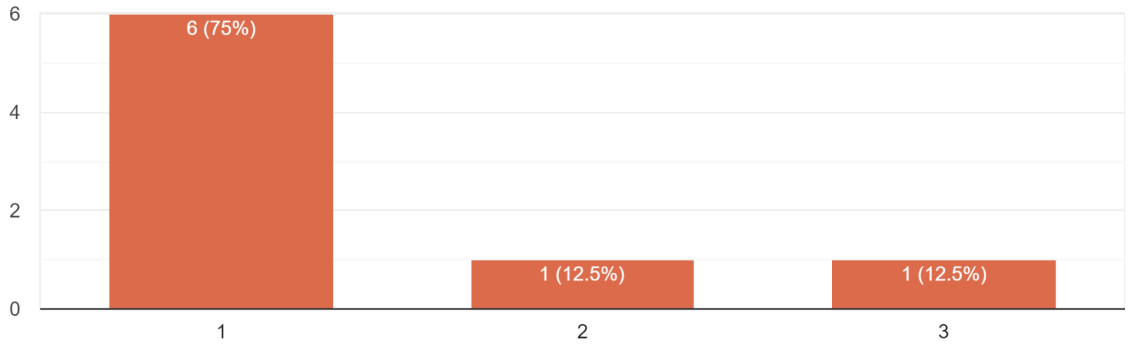


Focus area 3: Asset Cost Optimization

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

Focus area 3: Asset Cost Optimization

8 responses



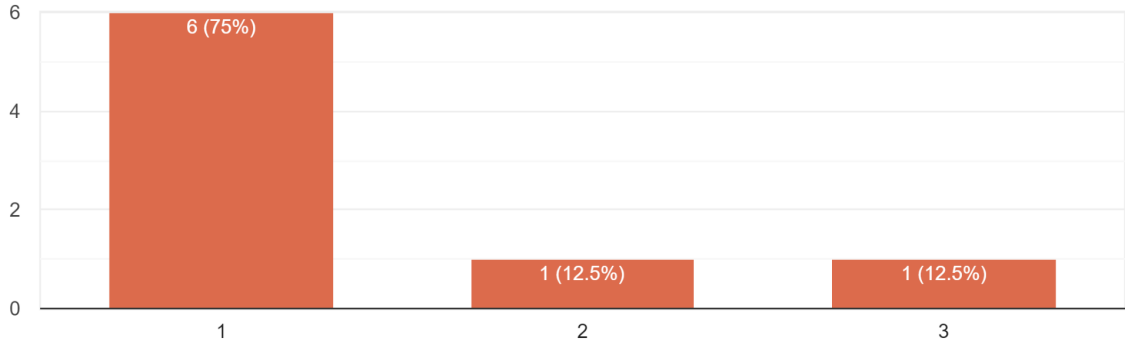
The following questions are on Focus area 4: Information Collection and Dissemination

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

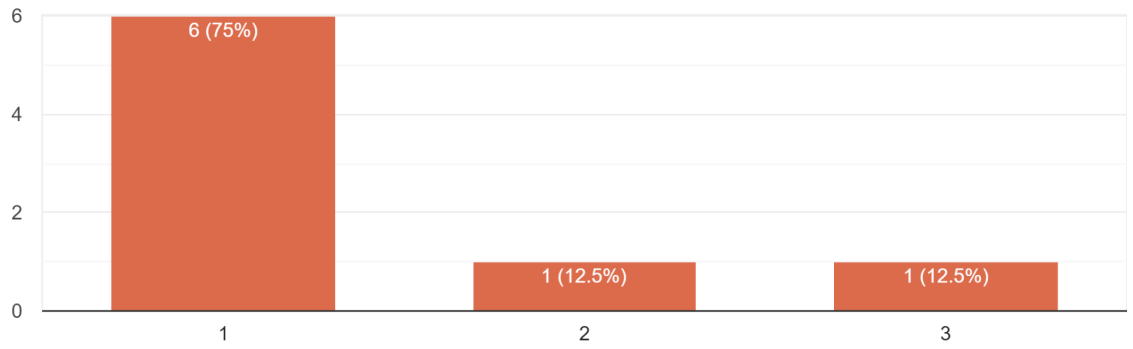
Information Management

8 responses



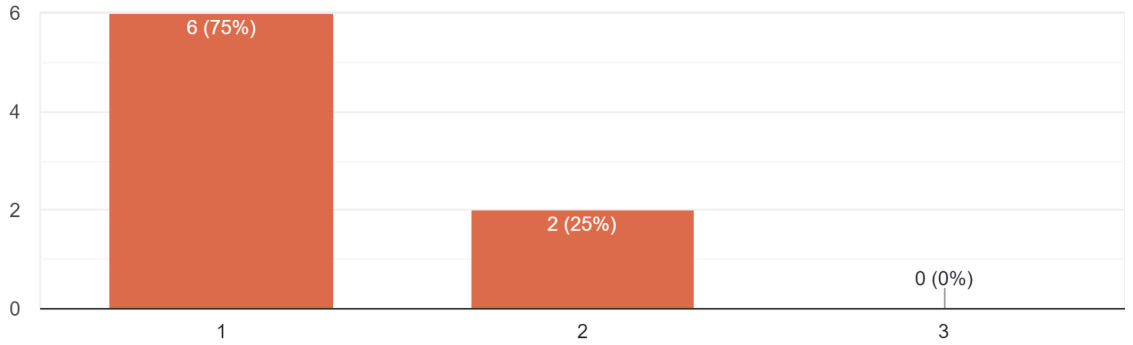
Asset Data Monitoring and Recording

8 responses



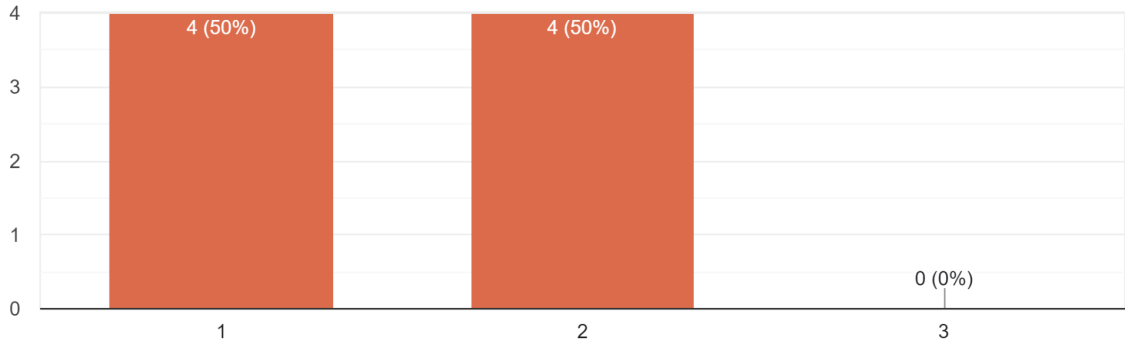
Information Storage

8 responses



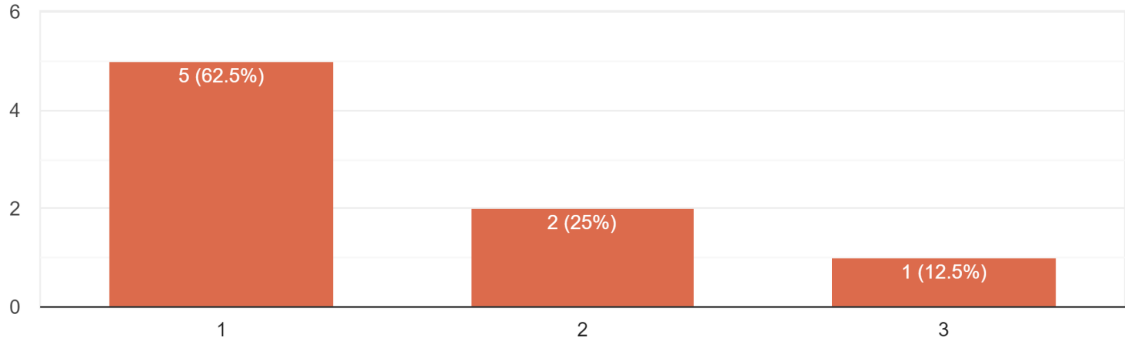
Communication

8 responses

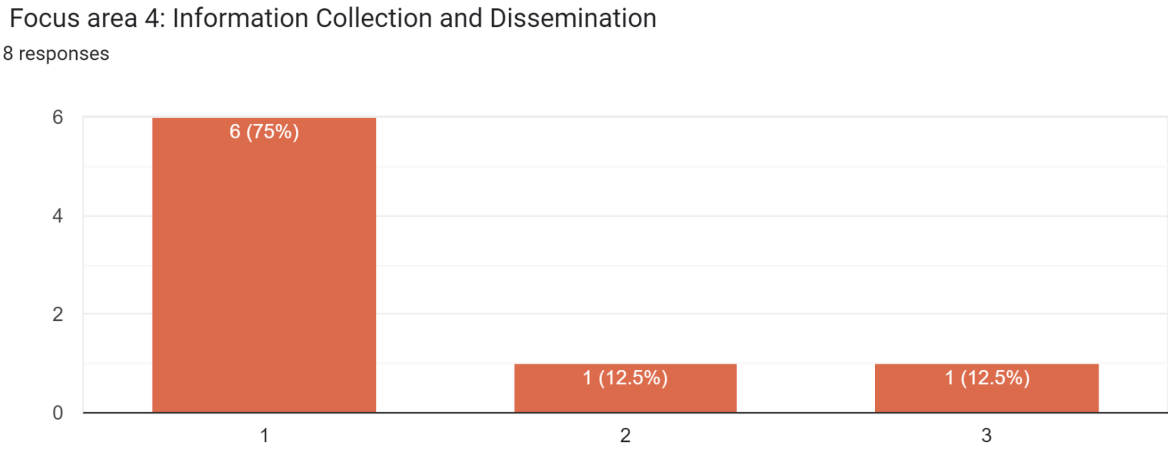


Knowledge Management and Sharing

8 responses

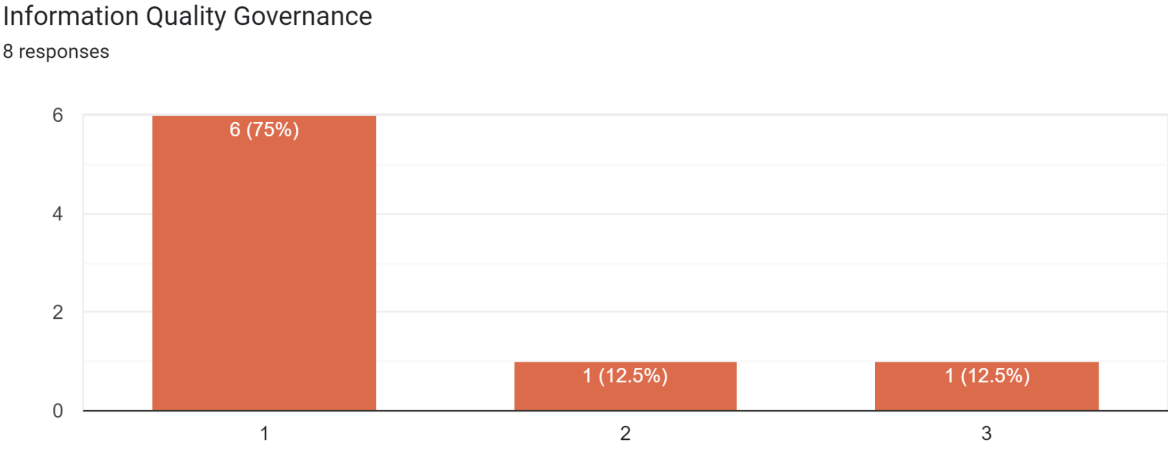


Focus area 4: Information Collection and Dissemination
This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:



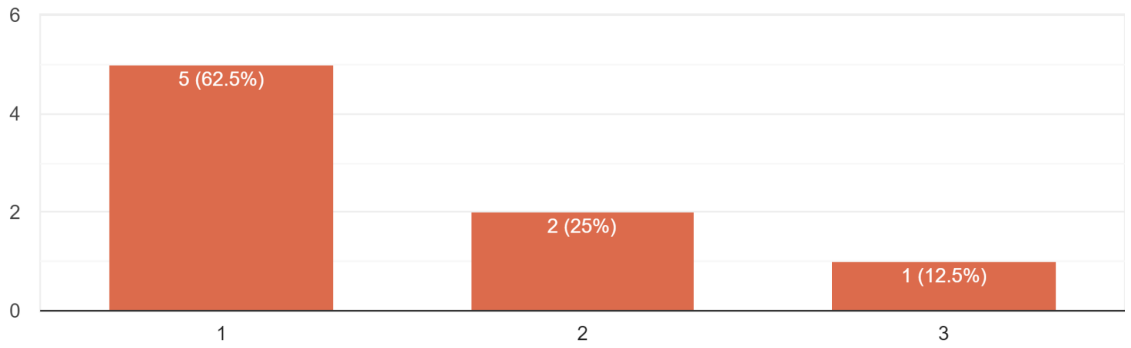
The following questions are on Focus area 5: Information Quality
The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary



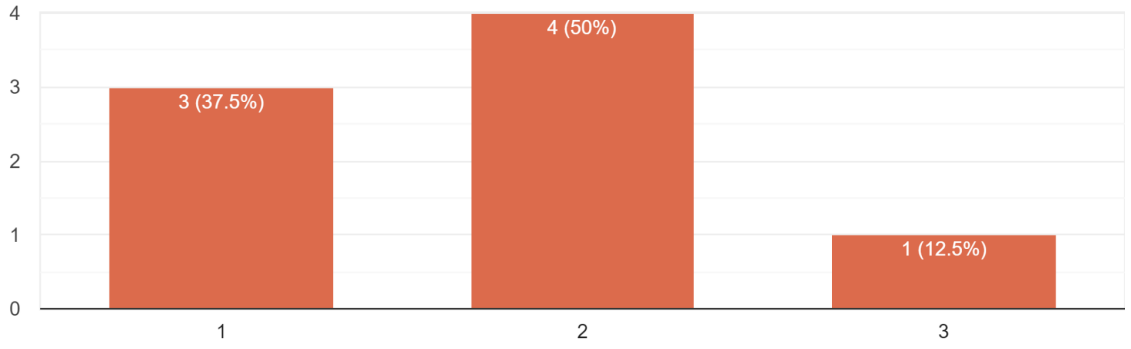
Information Quality Assessment

8 responses



Information Openness

8 responses

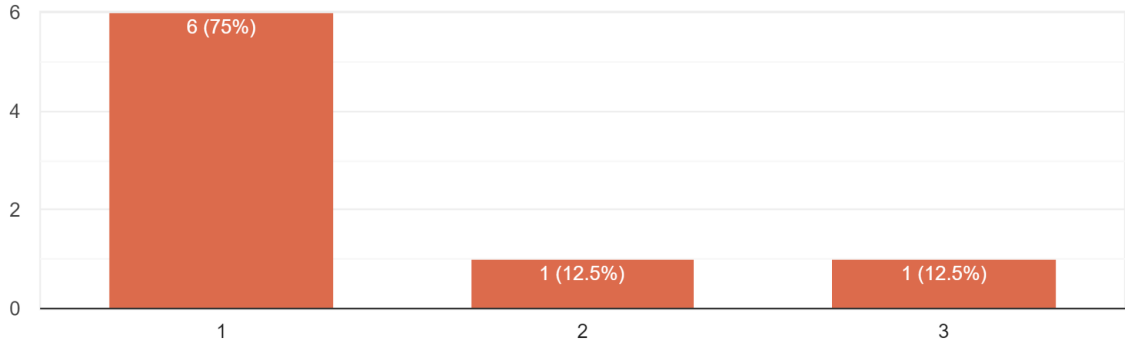


Focus area 5: Information Quality

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

Focus area 5: Information Quality

8 responses



The following questions are on Focus area 6: Risk Management

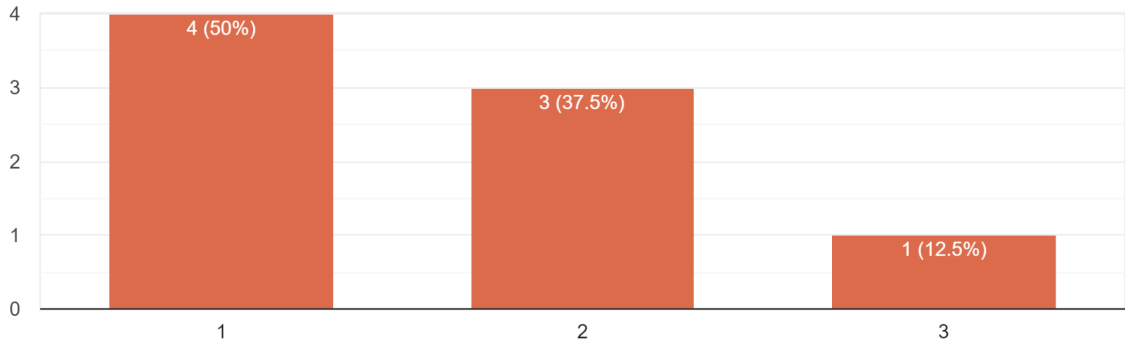
The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary

2 = Neutral
3 = Not necessary

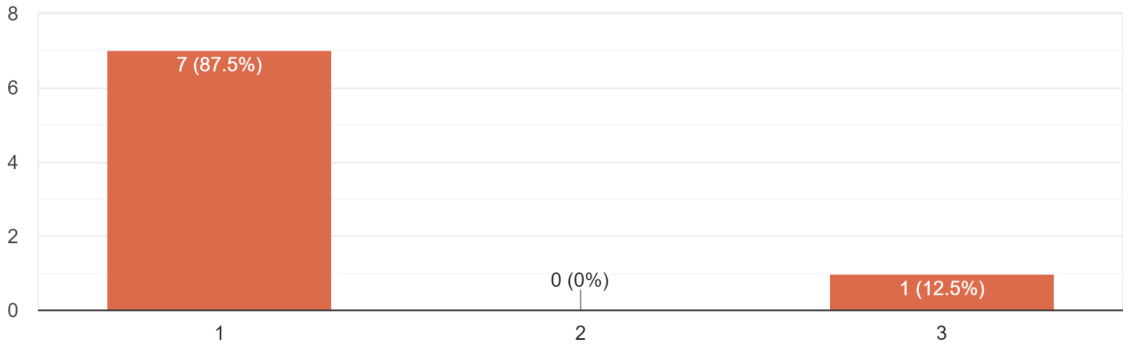
Safety

8 responses



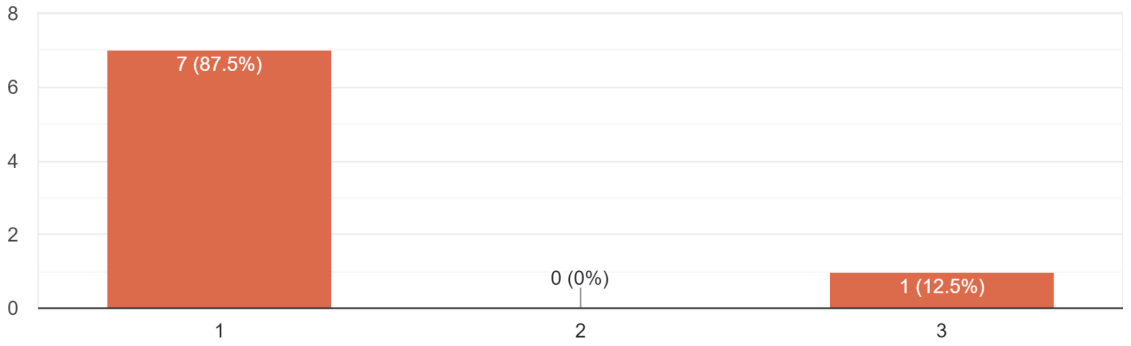
Risk Identification

8 responses



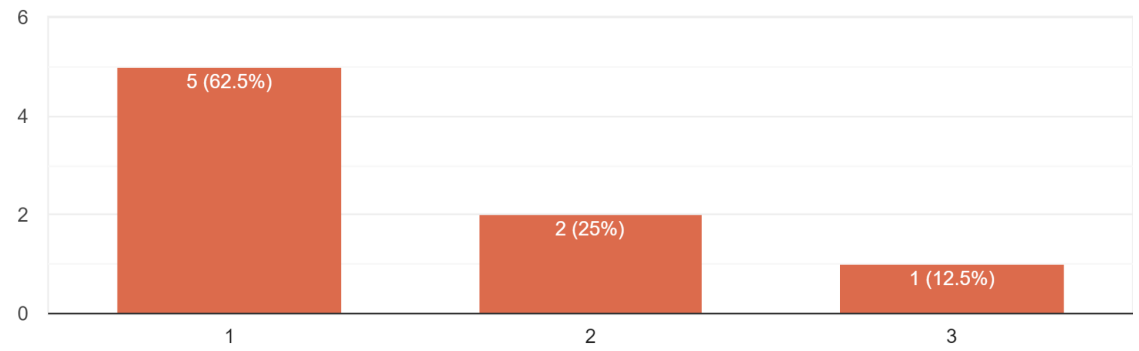
Risk Analysis

8 responses



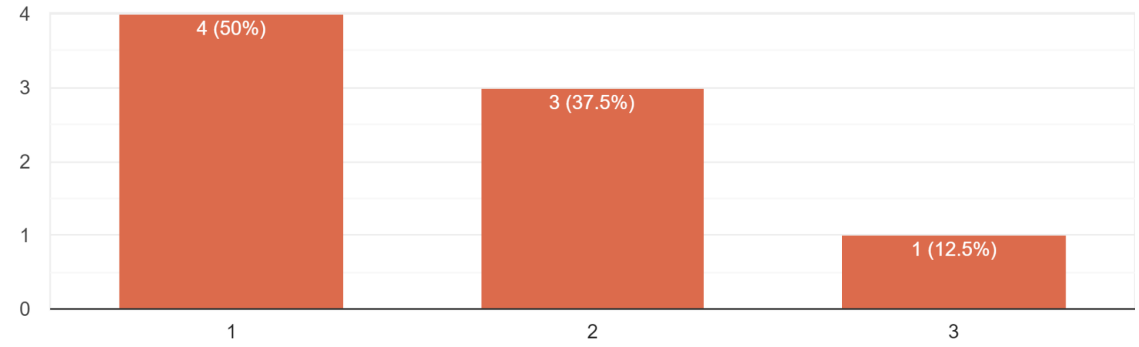
Risk Evaluation

8 responses



Risk Treatment

8 responses

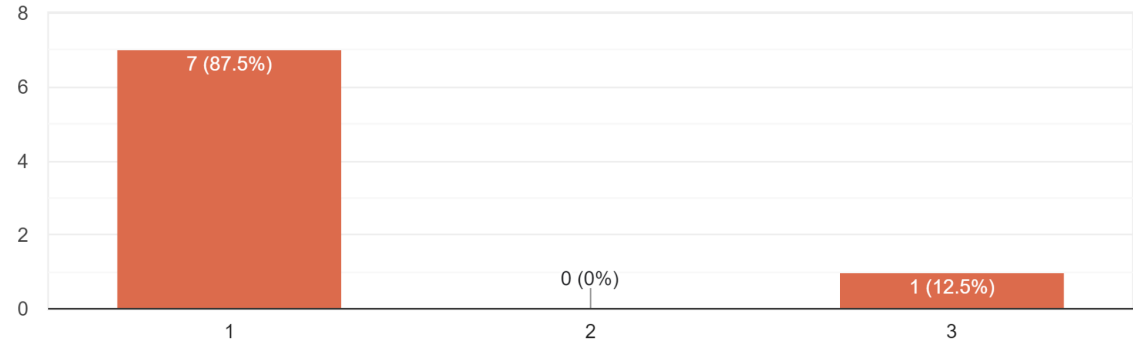


Focus area 6: Risk Management

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

Focus area 6: Risk Management

8 responses



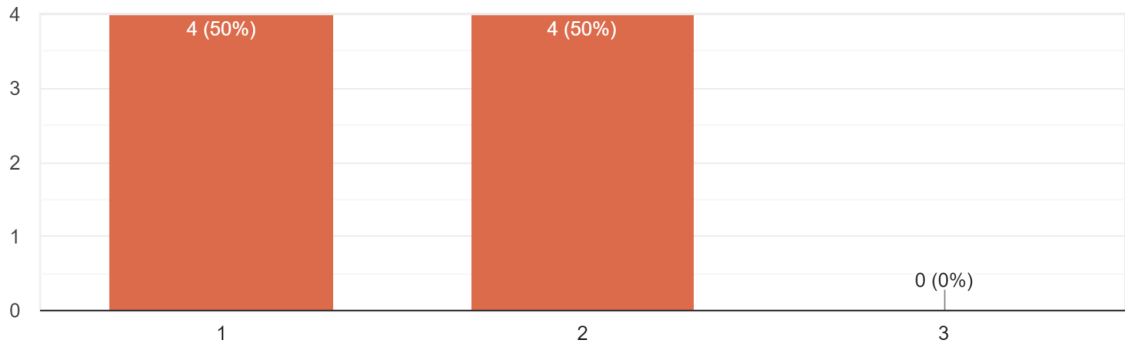
The following questions are on Focus area 7: Security

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

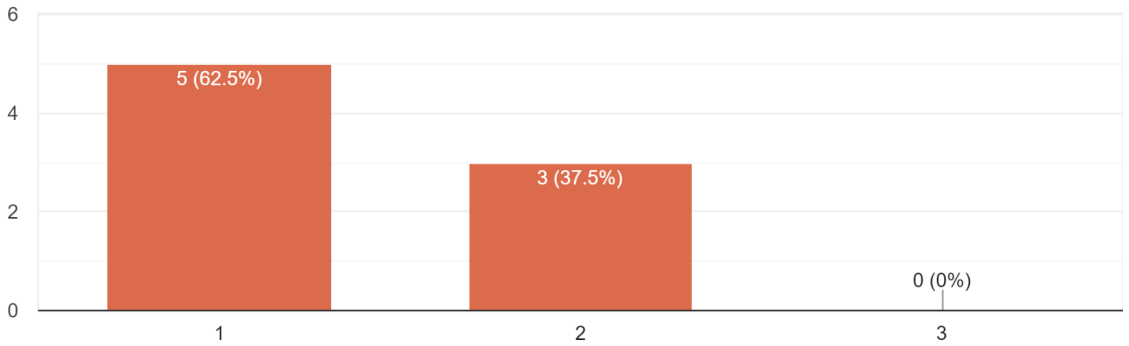
Information Security Management

8 responses



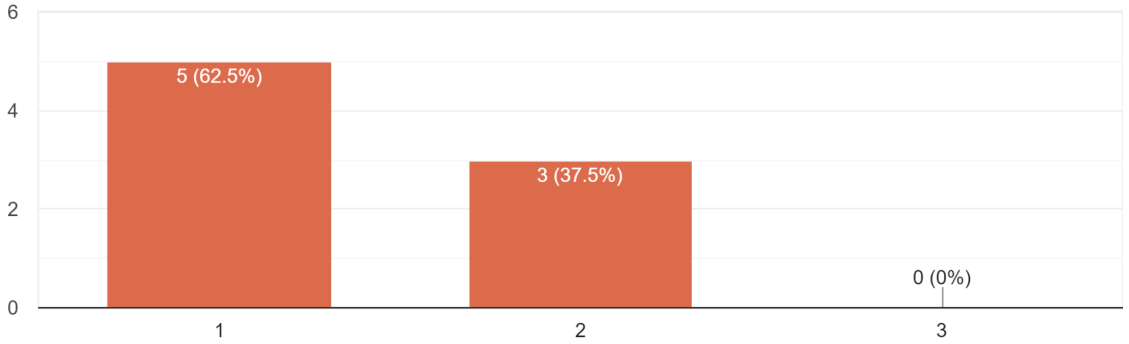
Information Access Control

8 responses



Secure Transmission of Sensitive Information

8 responses

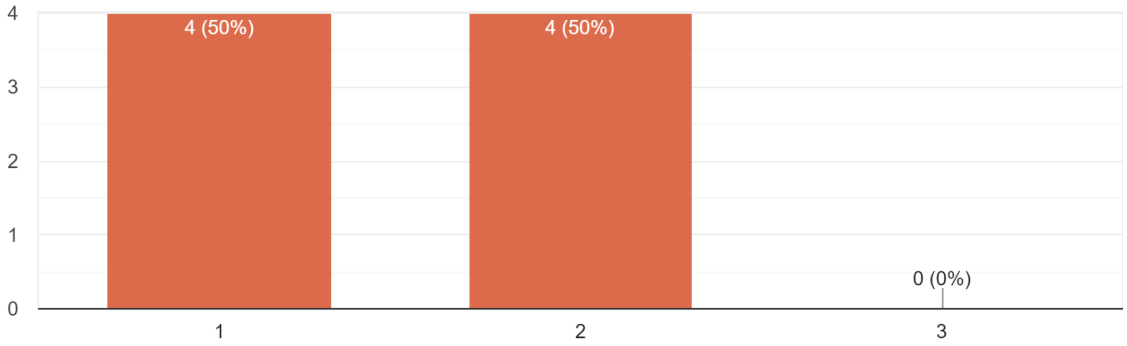


Focus area 7: Security

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

Focus area 7: Security

8 responses



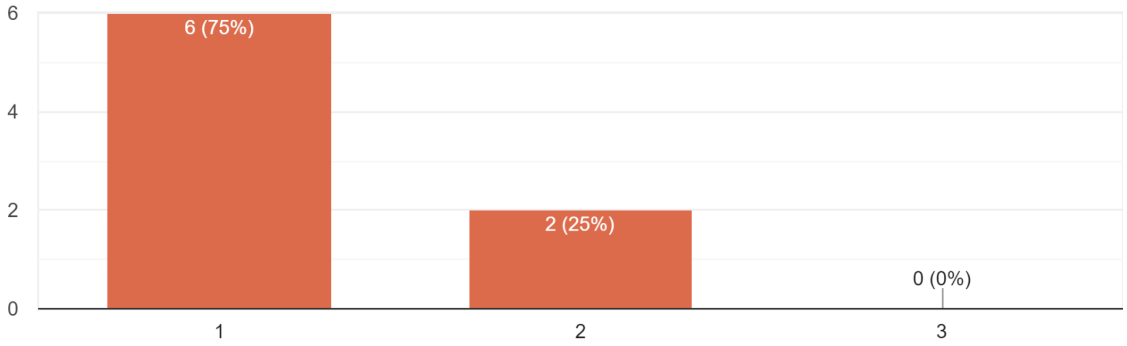
The following questions are on Focus area 8: Human Capital

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

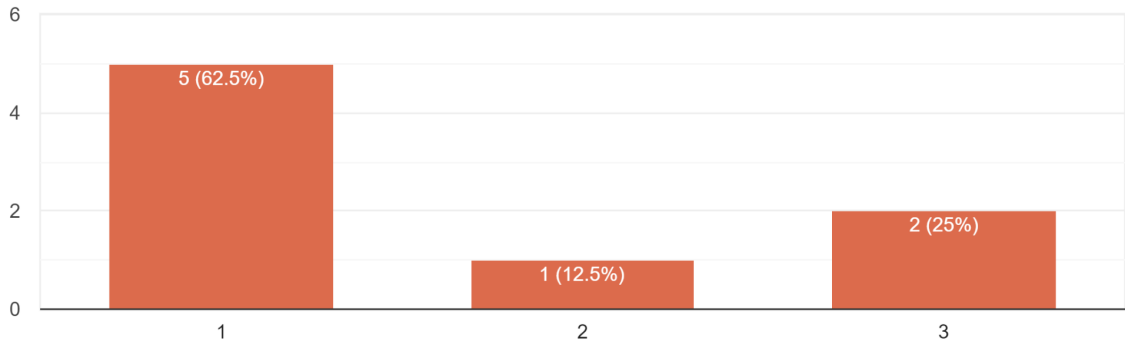
Skill Management and Development

8 responses



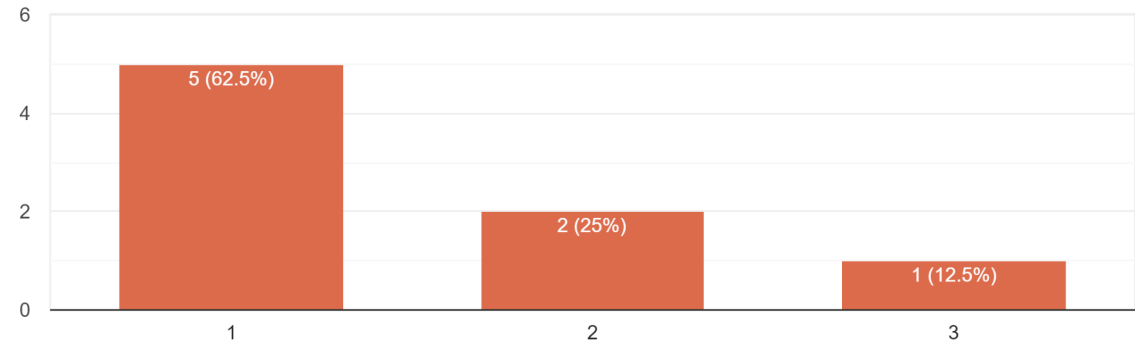
Roles and Responsibility

8 responses



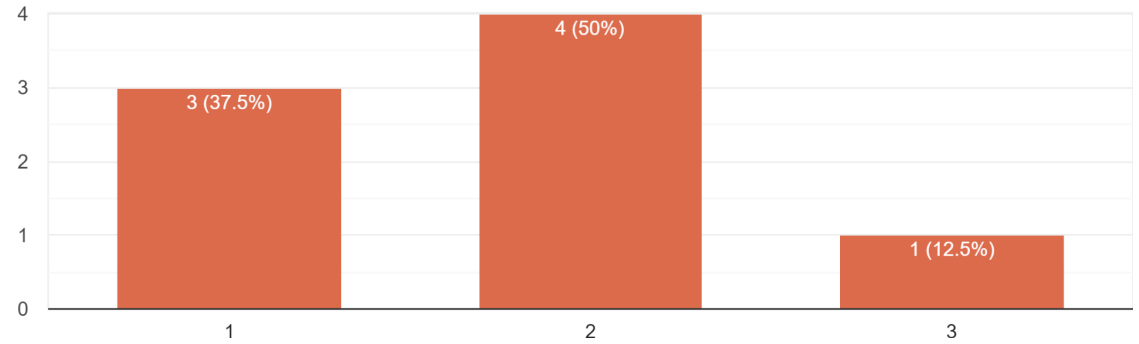
Leadership and Business Culture

8 responses



Qualified external support

8 responses

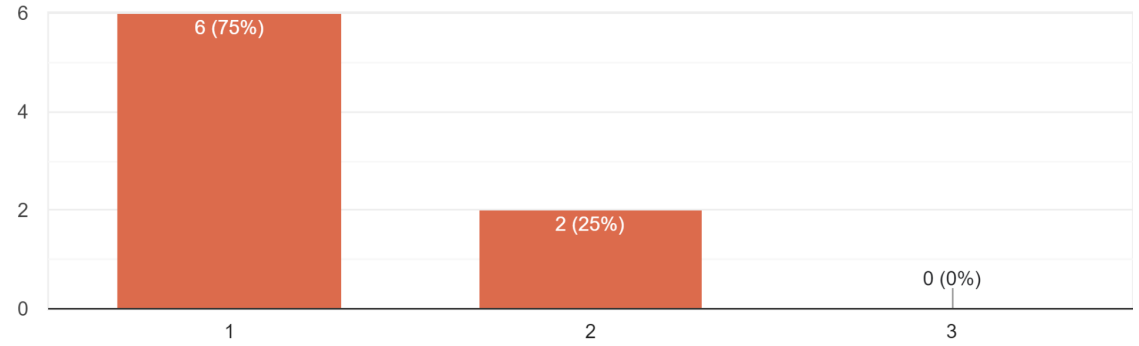


Focus area 8: Human Capital

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

Focus area 8: Human Capital

8 responses



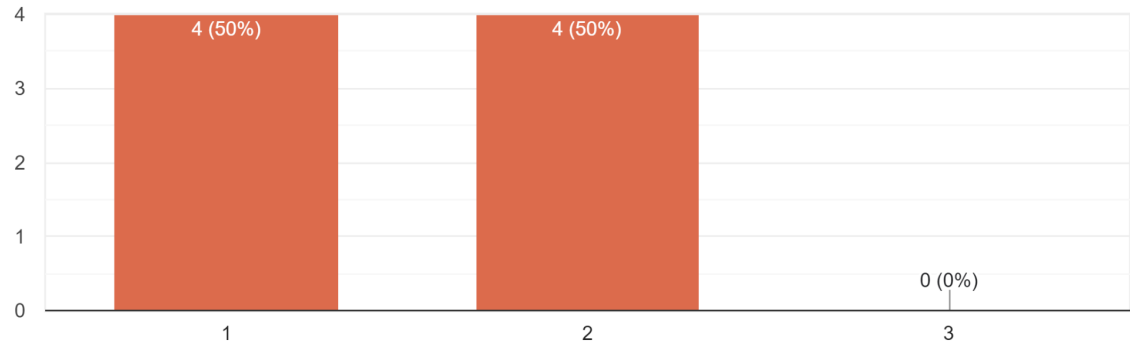
The following questions are on Focus area 9: Tool Management and Standardization

The following sections will ask about the dimensions of the maturity model. Please answer if you think the specific dimension is useful to include based on the previously presented vision / goal of the maturity model. For each of the dimensions (and lastly the focus area as a whole) you are prompted to rate the item:

1 = Necessary
2 = Neutral
3 = Not necessary

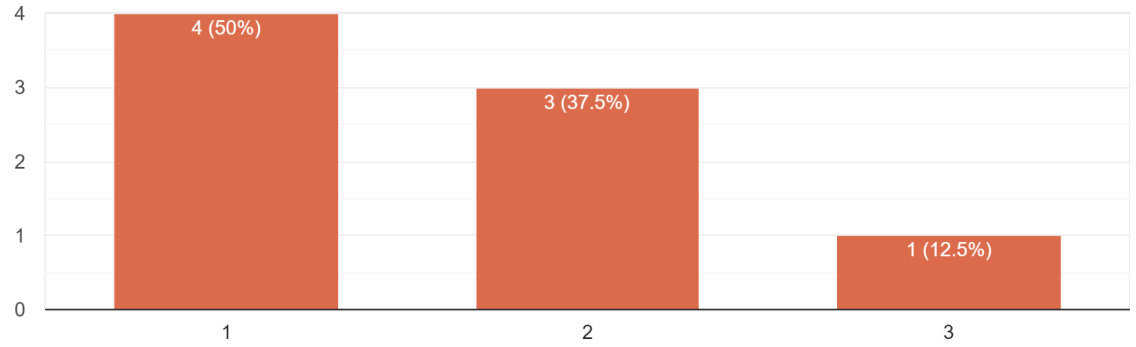
Formal Standards and Protocols as the Basis

8 responses



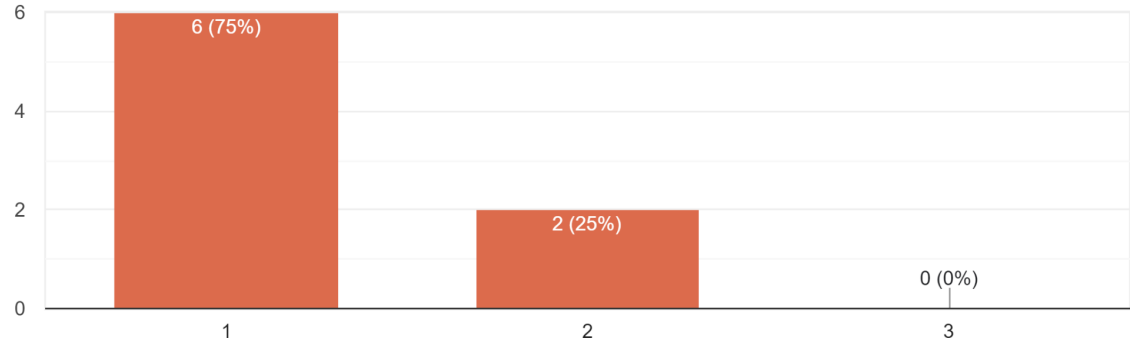
Consistency and Standardisation of Tools

8 responses



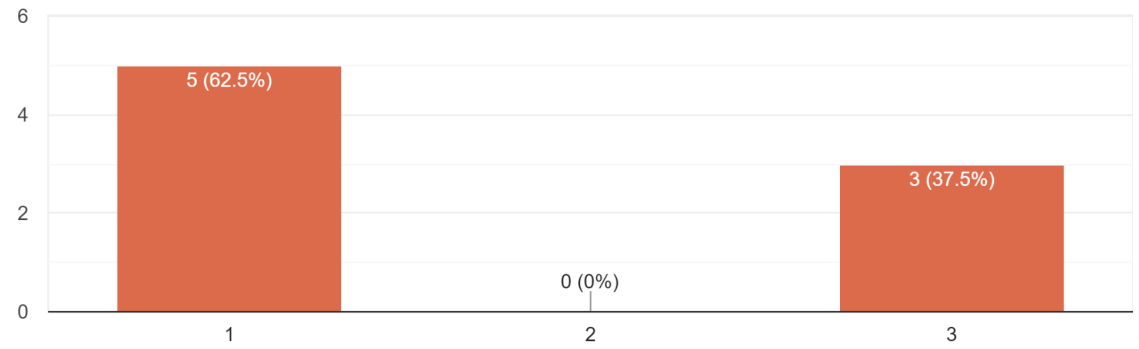
Conceptual Modelling

8 responses



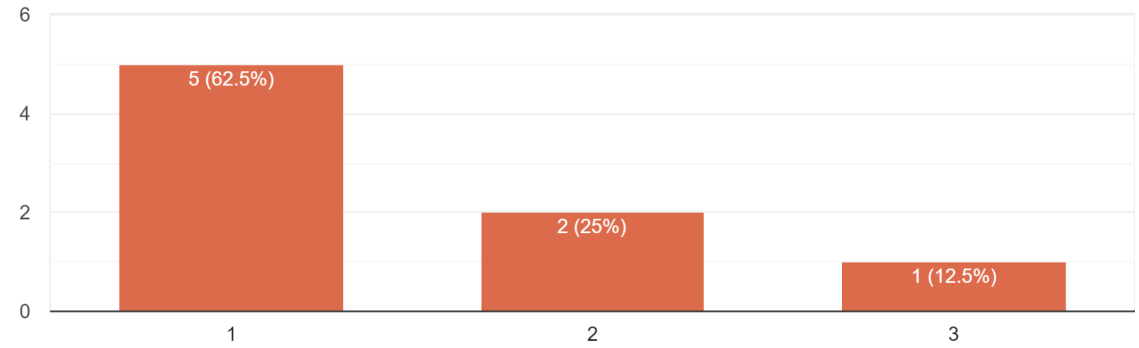
Decision Support System

8 responses



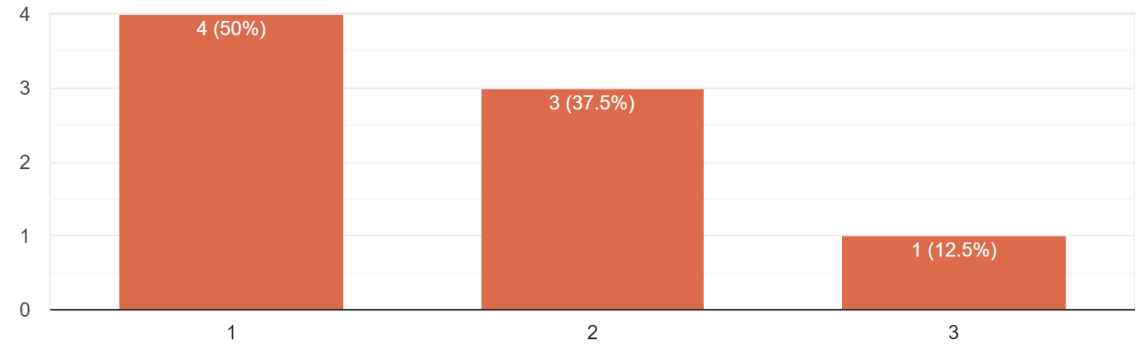
Application Management

8 responses



Digital Twin

8 responses

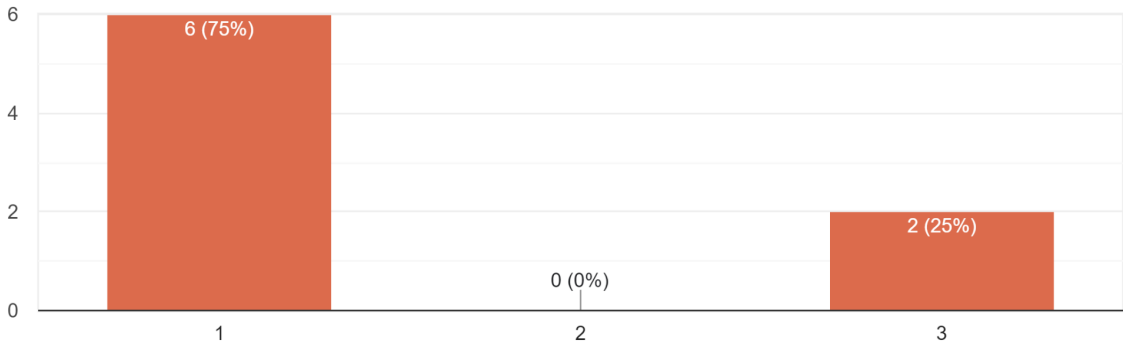


Focus area 9: Tool Management and Standardization

This is the name of the overarching focus area for all previously mentioned dimensions. Please evaluate this focus area as a whole here:

Focus area 9: Tool Management and Standardization

8 responses



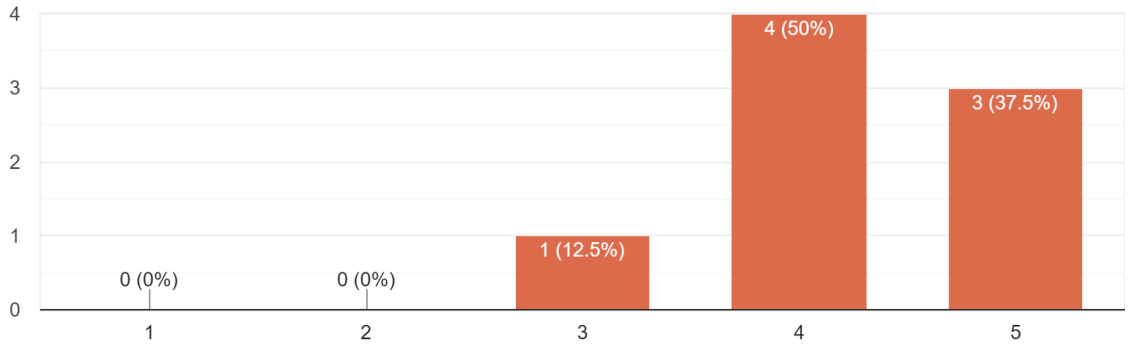
Unified Theory of Acceptance and Use of Technology (UTAUT) questions

The following questions are formulated as statements. Please use the Likert scale to answer how you feel about the statement. The Likert scale is divided as follows:

1. Strongly Disagree
2. Disagree
3. Neither agree nor disagree
4. Agree
5. Strongly Agree

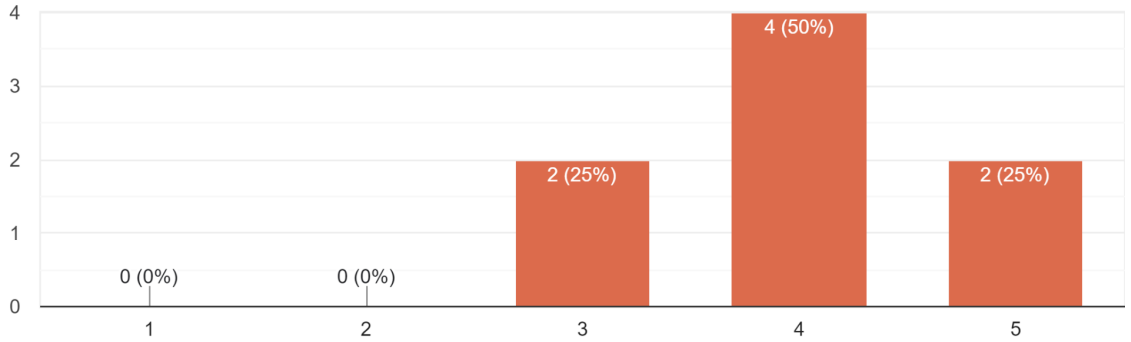
Performance expectancy: I would find the maturity model useful for assessing an organization's EAM Maturity.

8 responses



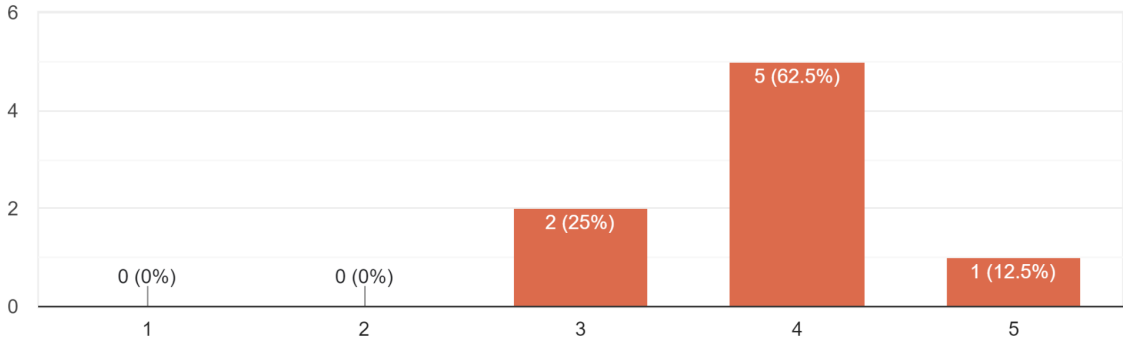
Performance expectancy: Using the maturity model enables me to accomplish an EAM maturity assessment more quickly.

8 responses



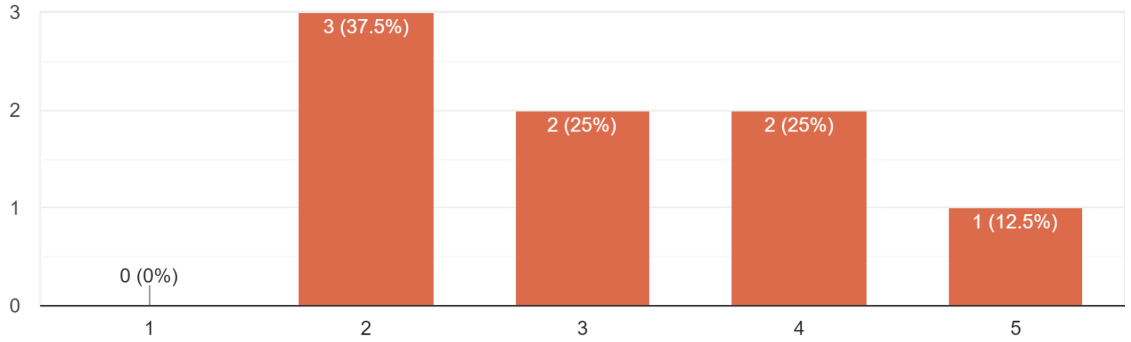
Performance expectancy: Using the maturity model will improve my understanding of an organization's current EAM practices.

8 responses



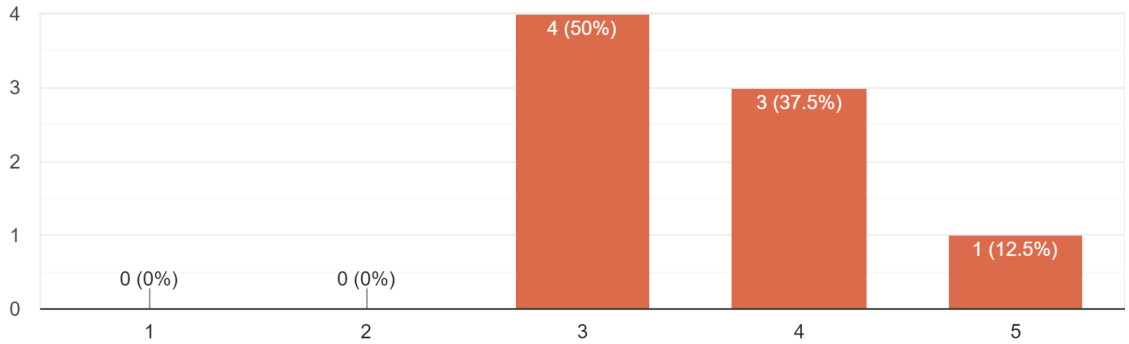
Effort expectancy: Without explanation, my interaction with the maturity model would have been clear and understandable.

8 responses



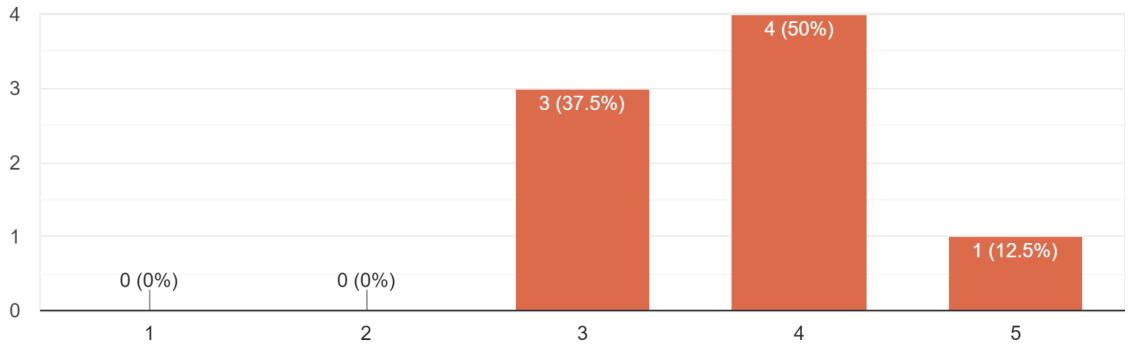
Effort expectancy: I would find the maturity model easy to use.

8 responses



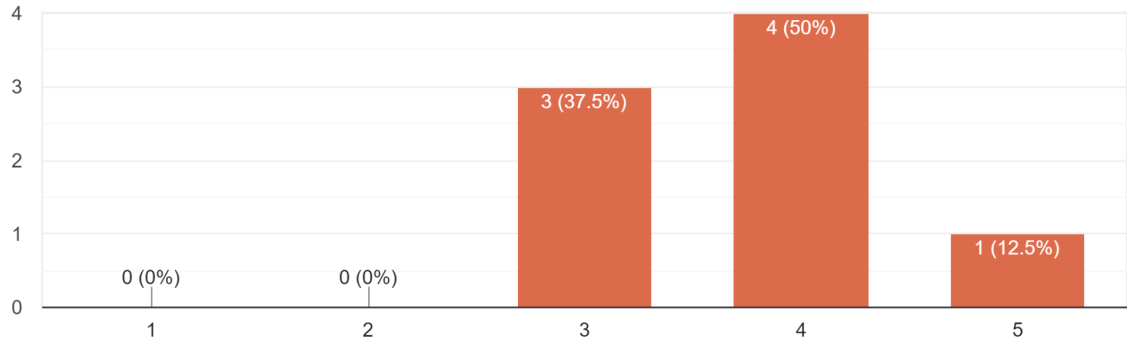
Effort expectancy: It would be easy for me to become skilful at using the maturity model.

8 responses



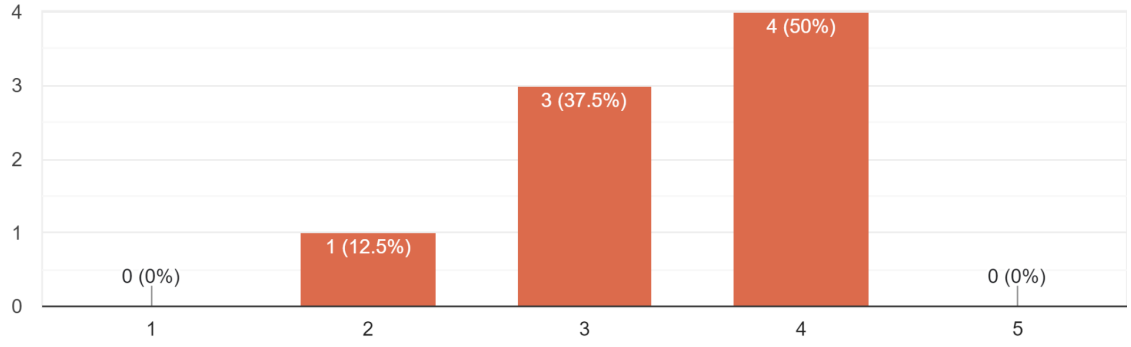
Effort expectancy: Learning to use the maturity model is easy for me.

8 responses



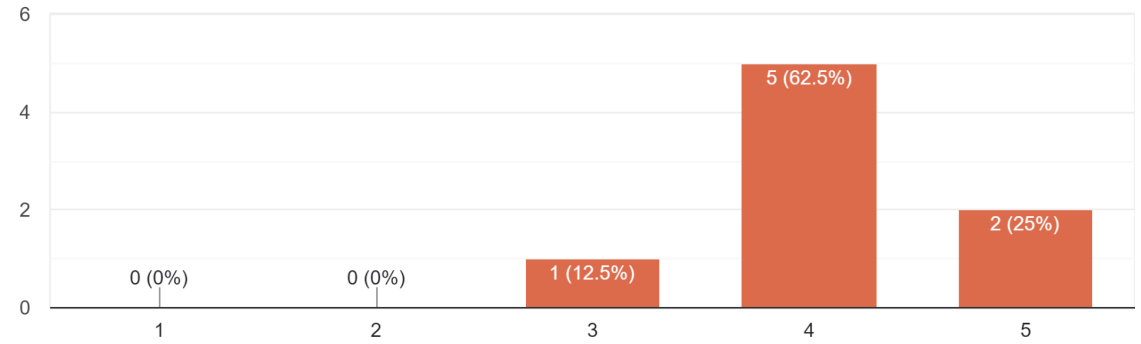
Social Influence: People who influence my behaviour would think that I should use the maturity model.

8 responses



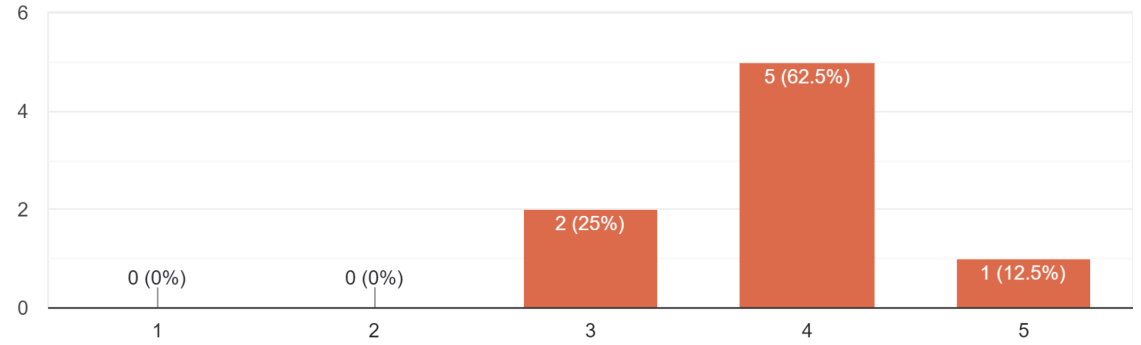
Social Influence: Senior management of my organization will support the use of the maturity model.

8 responses



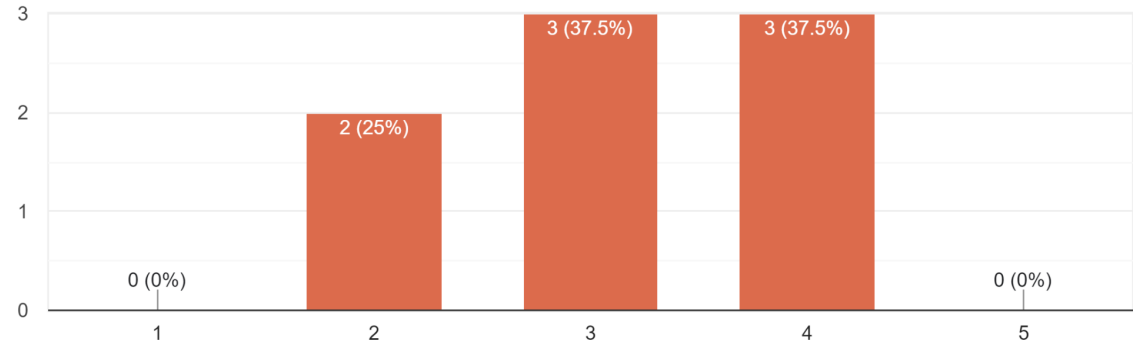
Social Influence: In general, my organization will support the use of the maturity model.

8 responses



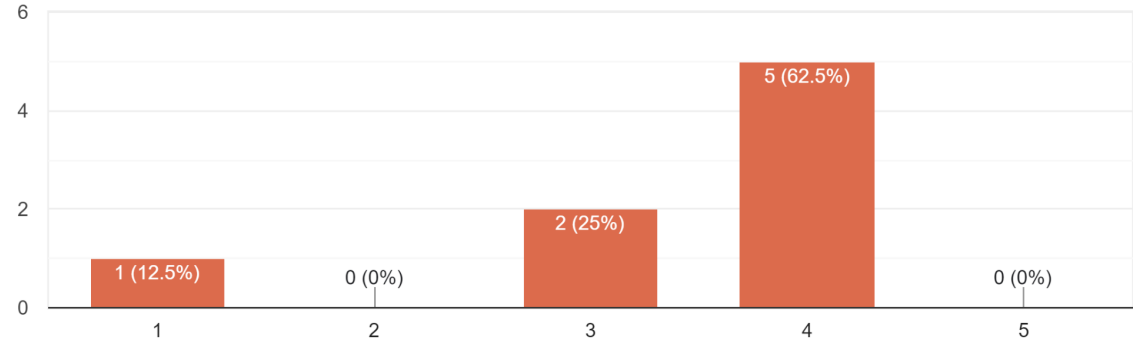
Facilitating conditions: I have the resources necessary to use the maturity model.

8 responses



Facilitating conditions: I have the knowledge necessary to use the maturity model.

8 responses



Facilitating conditions: A specific person (or group) is available for assistance if I encounter difficulties with the maturity model.

8 responses