TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

# Diplomarbeit

## Development of a maturity model for assessing the capabilities to utilise data in industrial enterprises

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines

## Diplom-Ingenieurs

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# Danksagung

An dieser Stelle möchte ich mich zuerst bei meinem Betreuer Andreas Schumacher für die Hilfestellung bei der Konzeption, die aufschlussreichen Hinweise während der Ausarbeitung und die allgemein sehr gute Betreuung dieser Diplomarbeit bedanken. Die aufschlussreichen Gespräche über Reifegradmodelle und Datennutzung in Unternehmen haben mir während der Entwicklung des Modells gute Anhaltspunkte zur Anwendungsmethode des MMACUDIEs gegeben und zum Erfolg des Pilot Tests beigetragen.

Außerdem möchte ich auch den Teilnehmern meines Pilot Tests herzlich danken, die dazu bereit waren sich im Rahmen der MMACUDIE Bewertung Zeit für dieses komplexe Thema und die von mir entwickelte Methode zu nehmen. Erst in der Anwendung und dem daraus resultierendem kritischen Feedback konnte die Brücke von der Theorie zur Praxis tatsächlich überwunden werden. Ihre Anmerkungen und Hinweise haben mir dabei geholfen die Thematik noch einmal mit frischen Augen zu sehen, Schwachstellen zu erkennen und diese zu verbessern.

Da mit dieser Arbeit meine Zeit als Student an der TU Wien endet, möchte ich hier auch noch einmal kurz auf die letzten Jahre und die Menschen, die mich dabei begleitet haben, zurückblicken. Schon Marcus Tullius Cicero sagte: „Freundschaft verdoppelt unsere Freude und halbiert unseren Schmerz.“ Ich bin mir sicher, dass ich ohne meine Freunde und Familie nicht an diesen Punkt gekommen wäre. Danke für euren Beistand in meinen schlechten Zeiten; danke für das Vertrauen in den eurigen; aber vor allem danke für all das Lachen und das Gefühl der Geborgenheit in den gemeinsamen Momenten. Ihr habt mich ertragen, mir Mut gemacht, mir den Kopf gewaschen und mich motiviert, wenn ich es selbst nicht mehr konnte. Diese Arbeit widme ich vor allem auch euch.

# Kurzfassung

„Gute“ Entscheidungen treffen zu können ist in der heutigen globalen Wirtschaft zu einer essentiellen Fähigkeit geworden und ist ein Herausstellungsmerkmal effektiv agierender Unternehmen. Hierbei hat sich die datenbasierte Entscheidungsfindung als die geeignetste Methode erwiesen um zukünftige Entwicklungen und die Auswirkungen des eigenen Handelns zuverlässig vorhersagen zu können. Für den datenbasierten Entscheidungsprozess, also die Datennutzung, ist dabei die Fähigkeit Daten in der nötigen Qualität zu generieren und in weiterer Folge auch effektiv nutzen zu können, maßgeblich.

Das wachsende Bewusstsein für das Potential von Datennutzung in Bezug auf Optimierungs- und Innovationsprozesse in Unternehmen, hat sowohl in der Datengenerierung (z.B. Cyber Physical Systems in der Industrie 4.0) wie auch der Datenanalyse (Big Data, AI Analysewerkzeuge, etc.) zur Entstehung mächtiger neuer Technologien geführt. Während einige Unternehmen es schaffen die Vorteile dieser Technologien erfolgreich in ihre bestehende Datennutzung zu integrieren, scheitern andere noch daran das ihnen bereits zur Verfügung stehende Potential voll auszuschöpfen. Dies kann unter anderem auf den akuten Mangel von zuverlässigem, strukturiertem und verständlich aufbereitetem Wissen zurückgeführt werden.

Obwohl ein breites Spektrum an Literatur zu Datennutzungsrelevanten Konzepten existiert (Business Intelligence Management, Knowledge Management, etc.), ist derzeit keine Publikation bekannt die sowohl eine theoretisch fundierte Übersicht über die Voraussetzungen zur effektiven Datennutzung, wie auch eine Methode zur Bewertung der Fähigkeit zur Datennutzung darlegt. Mit dem Ziel diese theoretische Grundlage und eine auf ihr basierende Bewertungsmethode zu schaffen, wurde in dieser Diplomarbeit das „**M**aturity **M**odel for **A**ssessing the **C**apability to **U**tilise **D**ata in **I**ndustrial **E**nterprises” (MMACUDIE) entwickelt.

Um einen strikten, zuverlässigen und verständlichen Entwicklungsprozess zu gewährleisten, wurde dieser durch den Design Science Ansatz und seine Reifegradmodellspezifischen Adaptionen durch Hevner und De Bruin abgehandelt. Reifegradmodell und Beurteilungsmethode wurden dabei durch eine **S**ystematische **L**iteratur **R**echerche (SLR) bis zur Anwendungstauglichkeit entwickelt und dann auf Basis des Feedbacks aus einem persönlich durchgeführten Pilot Test in einem Wiener Industrieunternehmen in drei Iterationszyklen weiterentwickelt.

Trotz der frühen evolutionären Phase wurde die Beurteilung durch das MMACUDIE von den Interview Partnern als aufschlussreich, akkurat und verständlich beurteilt und die Plausibilität (Face Validity) bestätigt. Somit ist das MMACUDIE bereit für die großflächige Anwendung und Prüfung der Inhaltsvalidität durch Experten.

# Abstract

In today's global economy, making "good" decisions has become one of the last areas of operations still enabling organisations to gain a competitive advantage. The ability to predict future developments and anticipate which outcomes actions will have based on facts rather than intuition, enables organisations to consistently operate in a more effective manner. Establishing facts requires knowledge, at the core of which lies the creation and utilisation of objective measurements; data.

The demand for optimisation and innovation, paired with the growing awareness for the role data utilisation (DU) can play in it, has led to innovations in both data creation (e.g. Cyber Physical Systems in the dawn of the Industry 4.0 revolution) and analysis (Big Data, AI based analytic services, etc.). Some organisations are managing to harness this increasing potential through effective integration into existing DU systems, while others are struggling to even make use of the DU capabilities already available to them. This may partly be due to the fact that organisations are looking to improve their DU capabilities are faced with a lack of comprehensive, reliable and structured resources providing practical guidance in this field of expertise.

Although a range of literature dealing with DU related concepts (e.g. Business Intelligence Management, Knowledge Management, etc.) exists, there are no publications providing both an exhaustive overview of the theoretical foundation of what constitutes DU capability, as well as a method by which DU capability could be assessed in organisations. To provide both, a sound theoretical basis for DU requirements, as well as a practical approach to assessing an organisation's capabilities the "**M**aturity **M**odel for **A**ssessing the **C**apability to **U**tilise **D**ata in **I**ndustrial **E**nterprises" (MMACUDIE) was developed over the course of this Master Thesis.

To make the MMACUDIE development a rigorous, reliable and comprehensible process, development was based on the Design Science guidelines of Hevner and the maturity model specific adaptions by Becker and De Bruin. The model and an accompanying assessment method were developed to the point of being deployable, based on the insights of highly relevant and qualitative pieces of literature that resulted out of a SLR. They were then further developed under the considerations of the feedback that was received in a pilot test, conducted in the context of personal interviews in a Vienna based industrial enterprise.

Despite its early evolutionary development stage, the assessment experience through the MMACUDIE was rated as being insightful, accurate and comprehensible by the assessment partners, establishing face validation for both the model and method. The MMACUDIE is ready for deployment and a confirmation of its content validity through experts in the field.

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# 1 Introduction

## 1.1 Data utilisation

In today's globalised economy, regional advantages no longer protect organisations from competitive pressure, leading to a need for constant adaptation and innovation. The increasing amount of international competition and convergence of available products make processes one of the last remaining areas enabling organisations to gain a competitive advantage through good decision making.[1] Organisations that are unable to learn how to increase their efficiency and adjust to the volatile demands and challenges of the market, are being punished and pushed out. Making the "right" decisions has become imperative, driving the demand for capabilities to enable organisations to do so.

At the core of making the "right" decision stands being informed. The more complete the available information is, the more accurately it can represent reality and predict the consequences of decisions that are made. This need for information has sparked the widespread demand for qualitative data (defined through quantity, topicality, continuity, compatibility and context)[2], and the analytic systems and services inevitably required to utilise it (see Figure 1).

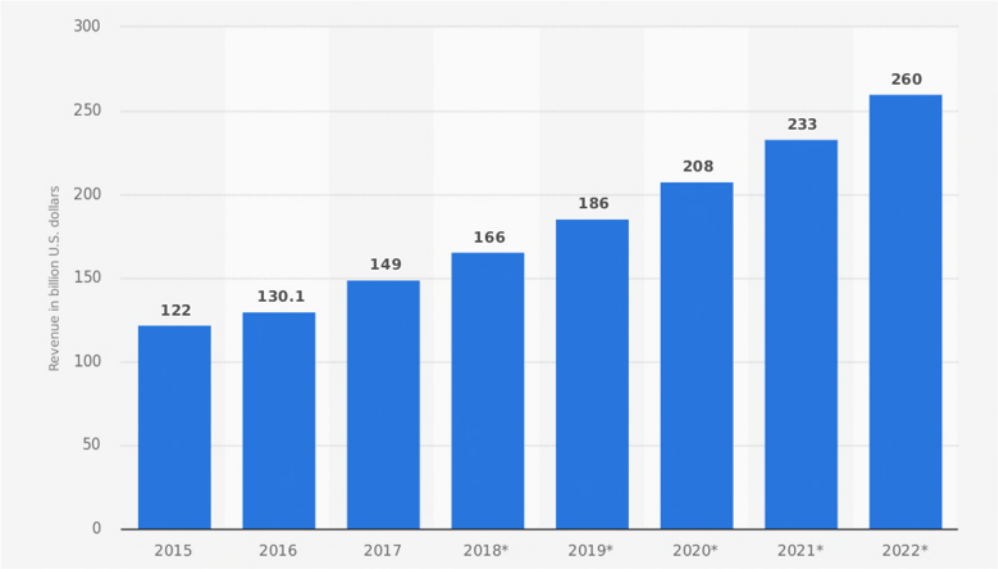


**Figure 1: Revenue from big data and business analytics worldwide from 2015 to 2022 (in billion U.S. dollars)[3]**

Although the wish for effective DU improvement is common, the knowledge of how to implement this change is not. If DU improvement agendas are initiated without a clear

[1] Davenport, Thomas H. (2006).
[2] Köhler, Martin (2014).
[3] Statistika (2018).

understanding of their implications, potentials and requirements they are likely to fail. The lack of clarity, paired with the difficulty of initiating any form of change in established structures, systems and cultures, defies efforts and leaves organisations feeling helpless about how to bring about a change towards better DU.[4] Gauging the potential benefits of DU improvements requires a consistent, reliable and exhaustive theoretical basis for DU in industrial enterprises (DUIE), which is not yet available.

## 1.2 Problem statement and research question

An enterprise's capability in respect to utilizing data is limited by its ability to generate data of high quality, implement a system to handle it and the capability to derive productive actions from the resulting information. Achieving productive utilisation of data is an incredibly complex task that requires a wide range of capabilities, that may not be present in every organisation. Even if these capabilities are identified, enterprises are often unable to objectively self-assess the state of their own data utilisation (DU) capability and tend to display an underwhelming knowledge concerning the necessary prerequisites. In order to close this gap and supply industrial enterprises with an objective tool for the assessment of their data utilisation, the notion for the development of a "**M**aturity **M**odel for **A**ssessing the **C**apability to **U**tilise **D**ata in **I**ndustrial **E**nterprises" (MMACUDIE) was devised.

The global surge in companies striving for higher levels of quality management and process improvement has resulted in an inflation of published standards, procedures, models, guidelines, et cetera, all catering to this demand.[5] Many of these are neither very scientific in their development, nor suitable for assessing the Utilisation of Data in Industrial Enterprises. The need for a reliable assessment method, which has been developed according to a scientific methodology, has led to the initiation of the development of the MMACUDIE in this Master Thesis (MT) through the Fraunhofer Austria Research GmbH. The MMACUDIE will define the key factors for effective data utilisation according to the current state-of-the-art and define what constitutes different levels of maturity regarding the utilisation of data in industrial enterprises.

Therefore, the chosen research question is: **"What are the requirements for an effective utilisation of data in industrial enterprises and how can the fulfilment of these requirements be assessed"**.

[4] Banerjee, Arindam et al. (2013).
[5] Maier, Moultrie, und Clarkson, „Assessing Organisational Capabilities".

## 1.3 Thesis goal

Methods differentiate themselves from models by being systematic, goal-orientated and repeatable approaches to problem solving as opposed to accurate descriptions of states.[6] Although there is an abundance of maturity models describing DU relevant aspects, methods describing how these models may be utilised for actual assessments are scarce. To ensure that the outcome of this MT is not only an accurate and reliable description of requirements but is also relevant to industrial enterprises looking to utilise it in a relevant practical context, special care should be taken during the selection of a research approach.

The goal of this MT is the development of an assessment method that can help industrial enterprises (IE) interested in improving their DU capabilities to:

- Gain insights into aspects that define DU
- Objectively assess their current capabilities
- Identify areas that are most suitable for improvement

To ensure the relevance and necessity for the development of a new assessment method, first extensive research should be conducted via a systematic literature research (SLR). If the need for the development of a new model can be confirmed, this SLR should be further expanded to ensure state of the art development.

Based on the insights gained from the SLR, a development methodology, the actual assessment method, as well as a validation method for the development outcome should be deduced. Once completed, the assessment method should be deployed in a pilot test and validated to an extent that is feasible for a MT.

The desired outcome of this MT is an assessment method that has been reiterated and improved to the point of being deployable functional and useful.

[6] Mettler, Tobias (2009).

## 1.4 Structure of thesis

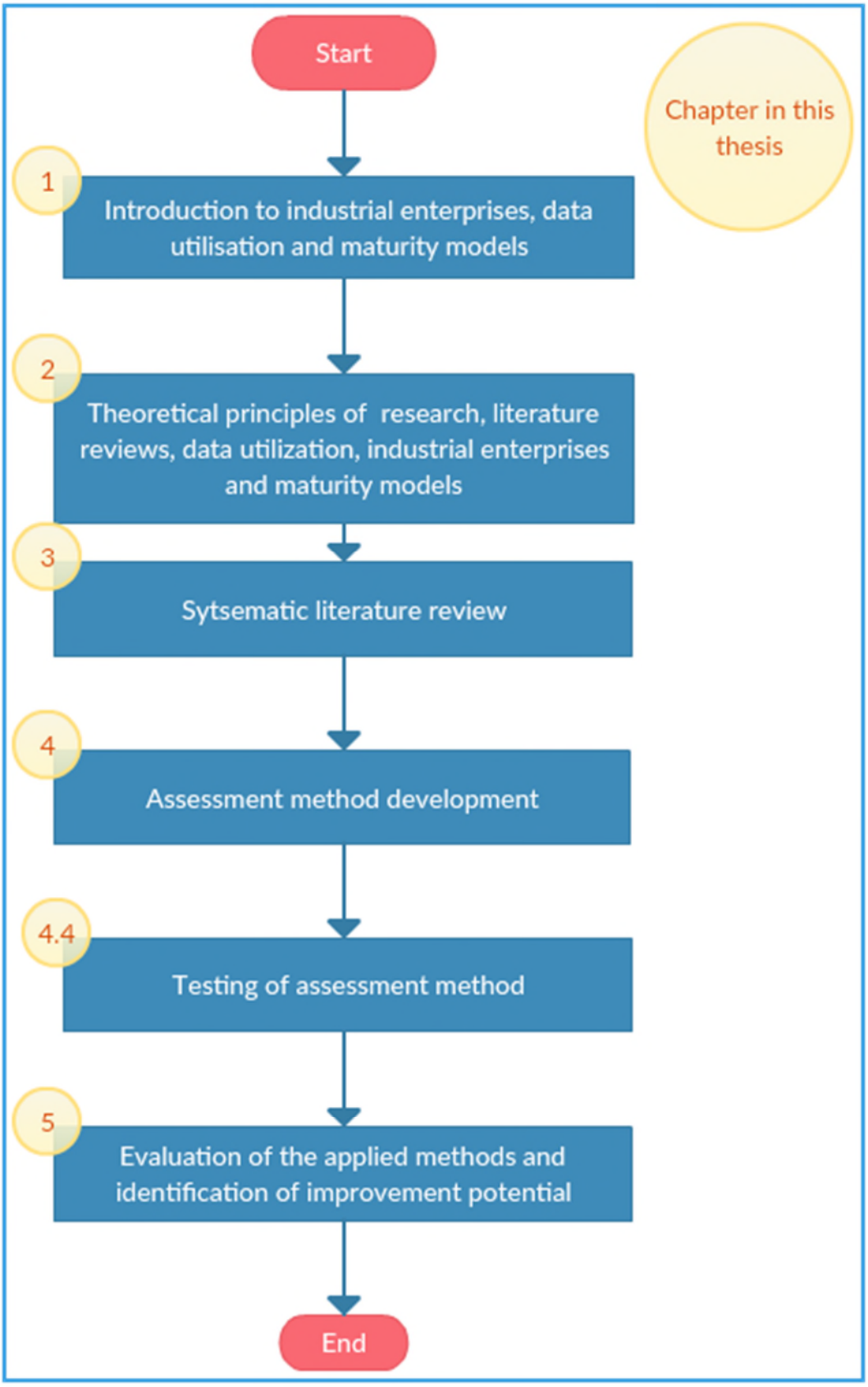


**Figure 2: Structure of this thesis**

# 2 Theoretical principles

## 2.1 Research design

According to Creswell[7], research design can be categorized by three main approaches: Qualitative, Quantitative and Mixed Method approaches. When considering which approach to research design to use, it is important to keep in mind that each method is best suited for different kinds of research questions.

### 2.1.1 Research methods

Qualitative research is focused on understanding social problems which are centred around human interaction and usually delivers information, that requires an informed interpretation by the researcher. Quantitative research delivers information that can be precisely measured, quantified and analysed using tools such as statistical analysis.

Due to the complexity of many of the problems that researchers are faced with today, applying one of these methods exclusively to a research question can often lead to an incomplete understanding of the problem and inconsistent claims. Applying a mixture of both methods to support insights gained from the respective other is called the Mixed Methods approach.

### 2.1.2 Research approach

Often the theory focused academic research does not coincide with the interests of organisations operating in the economy of the real world.[8] That is why choosing a research approach which manages to communicate the benefit of its insights is key to establishing the relevance of the research.

Because rigorous, standardized approaches for the development of maturity assessment methods, specifically maturity models for Information Systems (IS)[9], have been developed and broadly validated as also being suitable for developments outside of the IS context,[10,11,12,13, 14,15,16,17] development of the MMACUDIE will be based on

[7] Creswell, John W. (2014).
[8] Holmström, Jan et al. (2009), p. 65.
[9] Becker, Jörg et al. (2009).
[10] Schumacher, Andreas (2015).
[11] Mettler, Tobias (2011).
[12] García-Mireles, G.A. et al. (2012).
[13] Maier, Anja M. et al. (2012).
[14] Bruin, Tonia De and Rosemann, Michael (2005).
[15] Becker, Jörg et al. (2009).
[16] Schumacher, Andreas (2015).
[17] Mettler, Tobias (2009).

these approaches. According to Cleven “IS research is largely summarized by two paradigms, namely Behavioural Science and Design Science. Behavioural Science concentrates on the development and verification of theories, Design Science focuses on the development of solutions for practical problems and, thereby, on accomplishing utility”.[18] Because the assessment method being developed in this MT seeks to develop a solution for a practical problem, the Design Science research approach has been chosen as suitable.

## 2.2 Design Science

Design science has been derived from classic engineering approaches and has the objective to “develop technology-based solutions to important and relevant business problems”[19] in the form of so called artifacts. Simon[20] defines these artifacts as something artificial that does not occur naturally, such as programming languages, management systems, symbols, models, et cetera. Artifacts therefore represent engineered solutions to potentially complex problems. In the case of this MT, the artifact is the assessment method that is being developed.

The methods by which artifacts are obtained can be qualitative as well as quantitative which places the Design Science Approach within the mixed methods. During the development process, care should be taken to integrate both methods into the development process.

### 2.2.1 Design Science guidelines

The capability of the artifacts created using the Design Science approach strongly depend on the capabilities of the researcher. They are based on the formulated and tested theories, conclusions and insights the researcher has drawn and therefore their quality varies with the competence and creativity of the researcher. To enable the development of meaningful artifacts and increase their scientific validity, Hevner[21] has established a set of 7 requirements that need to be fulfilled when complying with the Design Science approach (Table 1)

[18] Cleven, Anne et al. (2009), p. 1.
[19] Hevner, Alan and Chatterjee, Samir (2010), p. 12.
[20] Simon, Herbert Alexander (2008).
[21] Hevner, Alan R. et al. (2004).

**Table 1: Design Science Research requirements**

| Requirements | Description |
|---|---|
| **R1. Design as an artifact** | Design science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation |
| **R2. Problem Relevance** | The objective of design science research is to develop technology-based solutions to important and relevant business problems |
| **R3. Design evaluation** | The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods |
| **R4. Research contributions** | Effective design science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies |
| **R5. Research rigor** | Design science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact |
| **R6. Design as a research process** | The search for an effective artifact requires utilization of available means to reach desired ends while satisfying laws in the problem environment |
| **R7. Communication of research** | Design science research must be presented effectively to both technology-oriented and management-oriented audiences |

## 2.2.2 Design Science approach for developing maturity models

Becker[22] adapted the Design Science requirements that were developed by Hevner[23] in order to develop a procedural model for the design of MMs in 2009. This adaption defined a new set of requirements (Table 2) that needs to be fulfilled, based upon Hevner's principles.

[22] Becker, Jörg et al. (2009).
[23] Hevner, Alan R. et al. (2004).

**Table 2: Application of Design Science principles to MM[24]**

| Requirements | Description |
|---|---|
| **R1. Comparison with existing MM** | The need for the development of a new maturity model must be substantiated by a comparison with existing models. The new model may also just be an improvement of an already existing one |
| **R2. Iterative Procedure** | Maturity models must be developed iteratively, i.e., step by step. |
| **R3. Evaluation** | All principles and premises for the development of a maturity model, as well as usefulness, quality and effectiveness of the artifact, must be evaluated iteratively |
| **R4. Multimethodo-logical procedure** | The development of maturity models employs a variety of research methods, the use of which needs to be well-founded and finely attuned. |
| **R5. Identification of problem relevance** | The relevance of the problem solution proposed by the projected maturity model for researchers and/or practitioners must be demonstrated |
| **R6. Problem definition** | The prospective application domain of the maturity model, as well as the conditions for its application and the intended benefits, must be determined prior to design. |
| **R7. Targeted presentation of results** | The presentation of the maturity model must be targeted, with regard to the conditions of its application and the needs of its users. |

The adapted requirements by Becker[25] will be considered during the planning and development of the MACUDIE.

[24] Becker, Jörg et al. (2009).
[25] Ibid.

## 2.3 Developing a guide to conducting a Systematic Literature Review

The point of a literature review is to enable researchers to build upon the insights of previously conducted research and thereby provide a reliable foundation upon which to carry out their work. It should generate an understanding for the scope of the field, provide relevant background information and reveal research gaps, putting the research question into context.[26]

If literature reviews are being carried out with traditional methods, researchers' perceptions tend to get influenced by popular biases. To minimise the impact of this bias, a more scientific approach to literature reviews was developed; the Systematic Literature Review.[27,28,29,30] SLRs can be defined as a "systematic, explicit and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars and practitioners."[31]

Since any type of literature review is objective by nature, the documentation of steps should be conducted simultaneously to carrying them out and not be altered in retrospect. By sticking to a previously defined explicit approach, an attempt is made to avoid subjective conclusions based on prevailing bias.

Based on a variety of literature[32,33,34,35,36,37] a guide to conducting a SLR was developed for this MT (Table 3).

[26] Levy, Yair and Ellis, Timothy J. (2006).
[27] EPPI-Centre (2018).
[28] Okoli, Chitu and Schabram, Kira (2010).
[29] Fink, Arlene (2013).
[30] Levy, Yair and Ellis, Timothy J. (2006).

[31] Fink, Arlene (2013), p. 3.
[32] Okoli, Chitu and Schabram, Kira (2010).
[33] Fink, Arlene (2013).
[34] Levy, Yair and Ellis, Timothy J. (2006).
[35] Crossan, Mary M. and Apaydin, Marina (2010).
[36] Tranfield, David et al. (2003).
[37] Schumacher, Andreas (2015).

**Table 3: Guide to conducting a SLR for this MT**

| Stage | Step | Explanation |
|---|---|---|
| **Planning** | 1. Separation of research topics | Separation of the relevant research topics into logical blocks of research and definition of search keywords for each topic |
| | 2. Purpose of the literature review | Clear identification of the purpose and intended goals for the review, stating what questions need to be answered. |
| | 3. Quality definition | Explicit description of the criteria used for judging the quality of literature |
| | 4. Development of a screening protocol | Explicit description of how literature will be obtained, what criteria will qualify literature for a review and all assessment criteria |
| **Execution** | 5. Literature Search | Search for literature based on the keywords defined in step 1. |
| | 6. Literature assessment | Assessment of the quality of the literature extracted in step 4 |
| | 7. Data extraction | Extraction of the applicable information from each study. |
| **Reporting** | 8. Synthesis of studies | Conclusive analysis and combination of the facts from the various studies |

## 2.4 Industrial enterprises

In order to clearly define the application scope of this MT a definition of the characteristics of an industrial enterprise is required. An enterprise is commonly described as a "consciously, coordinated social entity, with relatively identifiable boundaries that functions on a relatively continuous basis to achieve a common goal or set of goals."[38] However, this definition is broad and can be applied to anything from a group of students trying to simulate launching a rocket into space for a school project, to a commercial company actually launching rockets into space. It lacks any definition relating to its goals or context of operation. This is addressed when put into an industrial context though. An industry is an institution "which, intending to make a monetary profit, applies knowledge and utilizes natural and human resources to produce goods or services to meet needs of man."[39]

From these definitions the following characteristics can be deduced for generally characterising industrial enterprises:

- Consciously coordinated – Presence of some form of leadership or hierarchy
- Social entity – Presence of collaborating (human) beings
- Boundaries – Distinct areas or expertise, tasks, responsibilities
- Continuous function – Persistence of the structure throughout various tasks
- Goals – Incentive driven by the striving for monetary profit
- Transformation of natural or human resources
    - Production of physical goods
    - Provision of services

[38] Robbins, Stephen P. (1983), p. 4.
[39] Hendricks, Robert et al. (1980), p. 14.

## 2.5 Utilisation of data in industrial enterprises

### 2.5.1 The value of data

To understand why enterprises today are trying to utilise data, it is important to understand what makes data valuable. Figure 3 visualises the role data plays in the knowledge creation process.

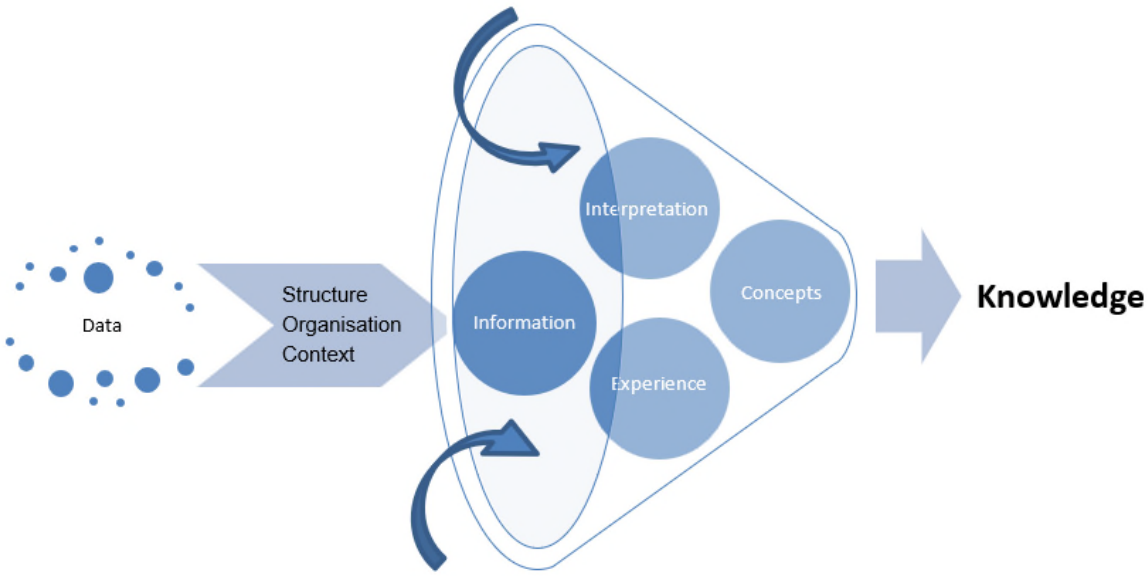


**Figure 3: Knowledge creation process conceptualisation**

Sets of data are facts that are discrete and objective[40], with little to no value in themselves, that enable the derivation of information. However, information is not data. Information is meaning that is represented by sets of structured and organised sets of data within a given context[41]. Therefore, when enterprises express the wish to utilise data, they are really expressing the wish to derive information from data and create knowledge through the combination of information with experience, interpretation, concepts, and so on.

Knowledge can be understood as the capacity to take effective actions which produce an anticipated and desired effect[42,43] and is the foundation of ensuring organisations' sustained operation. The bounded rational economic model of decision-making, devised by Herbert Simon in 1979[44], implies that the quality of made decisions is directly proportional to the decision-makers knowledge of reality (see Figure 4).

[40] Abecker, Andreas et al.eds (2002).
[41] Ratzan, Lee (2004).
[42] Bennet, Alex and Bennet, David (2004).
[43] Davenport, Thomas H (1998).
[44] Simon, Herbert Alexander (2008).

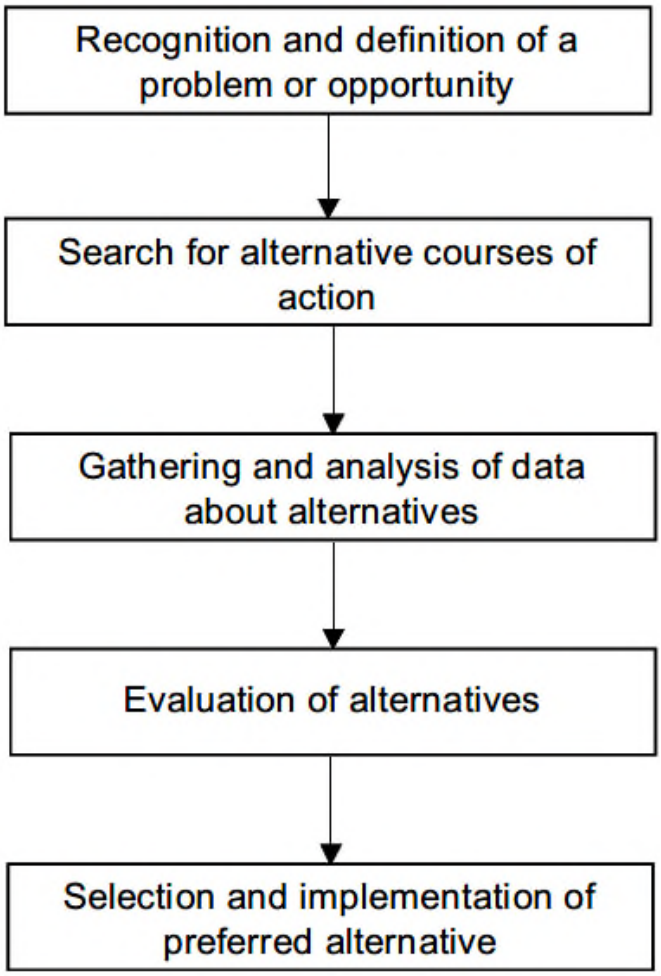


**Figure 4: Rational economic model of decision making[45]**

Therefore, utilising data to provide decision makers with the best knowledge has become a major part of management efforts in enterprises today. The success of the knowledge creation and application process is depended on a complex socio-technical system that requires the consideration of both organisational and technical aspects. This has led to the development of various fields of study (see Table 4), which will provide much of the theoretical foundation for this MT.

[45] Huczynski, Andrzej and Buchanan, David A. (2013).

**Table 4: DU related fields of study**

| Field of study | Description |
|---|---|
| Data Quality Management (DQM) | "Data quality management (DQM) as an organisational function comprises all practices, methods, and systems for analysing, improving and maintaining the quality of data."[46] It is focused on optimising systems that generate and process data. |
| Business Intelligence Management (BIM) | Business Intelligence is focused on supporting organisational decision making by embracing the "intelligent exploration, integration, aggregation and multidimensional analysis of data originating from various information resources"[47]. |
| Knowledge Management (KM) | "KM is the organisational policy and set of practices aimed at recognizing, creating, categorizing, maintaining, sharing, and applying the collective knowledge of people assisted by IT."[48] |
| Big Data Utilisation (BDU) | Big Data Utilisation differs from traditional DU through volume, velocity and variety. Most other aspects are very similar though, meaning that the critical dimensions for Big Data Utilisation will be very similar to traditional DU and that primarily the definition of what constitutes maturity may differ (especially regarding IT-Infrastructure). |
| Business Process Management (BPM) | Business Process Management (BPM) consolidates objectives, frameworks, methodologies, tools concepts etc. stemming from various other areas such as DQM, BIM, KM, BDU etc. into the processes already present in an organisation.[49] |

[46] Hüner, Kai M. et al. (2009).
[47] Olszak, Celina M. and Ziemba, Ewa (2007).
[48] Becerra-Fernandez, Irma and Leidner, D. E (2008).
[49] Bruin, Tonia De and Rosemann, Michael (2005).

### 2.5.2 Potentials and challenges of DU

Never before were the opportunities to make informed decisions greater, than they are now. Data is generated and managed almost exclusively electronically, enabling central storage and connectivity of data across the entire data stream. New analytical tools and technology are expanding the traditional field of analytics towards "discovery analytics" revealing abstract correlations previously inaccessible, while advanced artificial intelligence algorithms are performing complex analytical tasks that previously required years of experience and training.

Organisations riding on the wave of these new analytical possibilities can stay informed and quickly adapt to a modern, volatile world in which others are struggling to keep up. "The exponential growth of data… presents the most significant challenge and the greatest opportunity that businesses face"[50]. Because "products are generally born from cooperation between companies, each of which is responsible for some part of the product …the task of the principal (company)… is the management of the whole network and the coordination of cooperative effort."[51] The systems to manage this network, have typically grown organically which is the reason why enterprises are often faced with "problems related to the existence of multiple platforms, diverse database designs and data structures, highly variable data quality, and incompatible network infrastructure. From an organisational perspective, these technical processes often involve new work processes, mobilization of limited resources, and evolving inter-organisational relationships."[52]

Structuring these growing streams of data into frictionless and efficient systems is possible but has proven to be difficult. Depending on the pursued strategies, enterprise focus, innovation awareness etc. an enterprises' capabilities may be vastly different across the various DU aspects. This "misalignment of evolutionary progress produces *dimension tension* and suboptimal results. The lagging evolutionary dimension becomes the weakest link and inevitably drags down the merits of more evolutionary mature dimensions."[53] Therefore, one of the major challenges in making a DU system more effective, is reducing these dimension tensions, by evolving less developed dimensions. This allows for an efficient use of the typically scarce resources[54] because the restrictions imposed by lagging capabilities are lifted off the more evolved dimensions, while the lagging capabilities are developed.

[50] Davis, Jim et al. (2006), p. 9.
[51] Saaksvuori, Antti and Immonen, Anselmi (2008).
[52] Gottschalk, Petter (2009), p. 76.
[53] Davis, Jim et al. (2006), p. 47.
[54] Tan, Chee-Sok and Sim, Yee-Wai (2011).

Figure 5 is a representation of how the various functions within organisations are exchanging and utilising data.

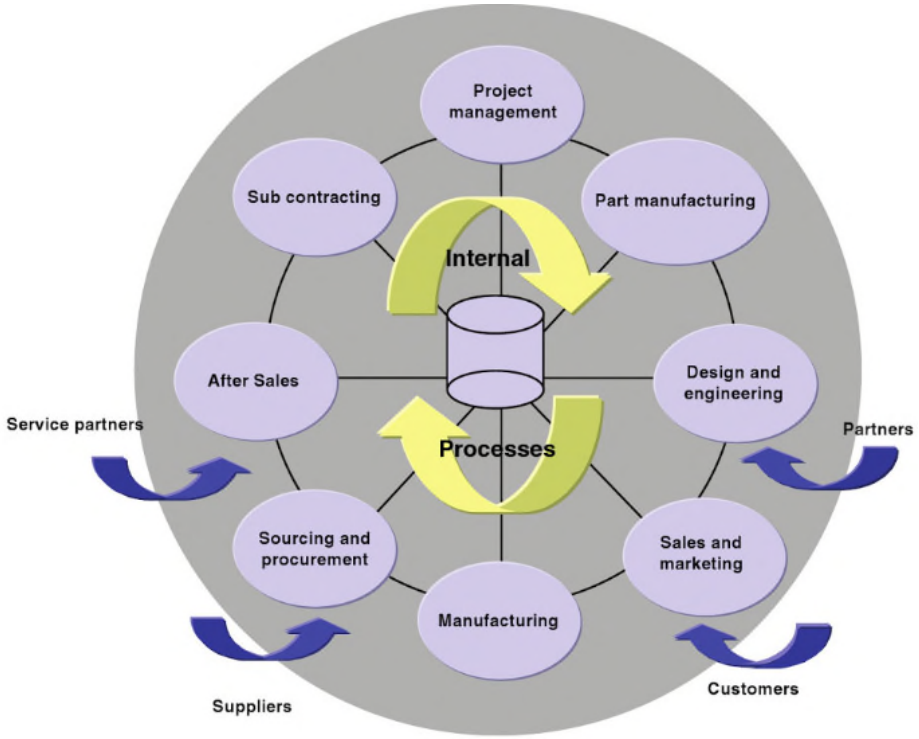


**Figure 5: Data utilisation in modern enterprises[55]**

Commonly recognised dimensions relevant to DU systems are: [56,57,58, 59]

- Data management (quality, integration, traceability, structure, etc.)
- Human factors (ability, acceptance, awareness, culture, etc.)
- Strategy & Governance (knowledge, formalisation, synergy creation, etc.)
- Infrastructure (available hard- and software, tools, etc.)

## 2.6 Maturity models

In a global market, organisations are constantly searching for means to gain an advantage over their competitors. Out of the incentive to identify strengths and weaknesses within the organisation and improve their performance, maturity models were developed. They were made popular largely through the introduction of the **C**apability **M**aturity **M**odel (CMM) by the Carnegie Mellon University Software Engineering Institute in the late 80s/ early 90s. **M**aturity **M**odels (MM) are tools that

[55] Saaksvuori, Antti and Immonen, Anselmi (2008), p. 14.
[56] Olszak, Celina M. and Ziemba, Ewa (2007).
[57] Köhler, Martin (2014).
[58] Näslund, Dag et al. (2014).
[59] Ryu, Kyung Seok et al. (2006).

enable the assessment and rating the as-is state of distinct capabilities of organisations in terms of maturity, a high level of maturity identifying a close to perfect, a low level identifying a chaotic state of the respective capability.[60,61,62,63,64]

Using MMs as the basis for the evaluation of an organisations' capabilities has the advantage of avoiding conflicts of interest within the organisation by applying an externally developed and formalised tool as a comparative basis for improvement. This allows identifying development gaps, which can then be closed by subsequent improvement actions.[65,66] Not being able to effectively close these gaps, is often a hinderance for organisations to evolve their capabilities to a higher level of maturity.[67]

Due to these apparent advantages, MMs have been developed for a wide spectrum of applications that have been extensively discussed in other literature. Many of the developed MMs are very project specific however, and lack the scientific rigor, comprehensibility and theoretical basis to be reliably applicable to other contexts.[68,69,70,71,72,73,74] This may in part be due to the fact that although a broad range of MMs are available, the theoretical foundation and documentation for developing MMs that are extensively tested and accepted is scarce.[75] This and the fact that many MMs often do not provide steps for closing the gaps they make apparent, is why MMs are sometimes criticised as being ill suited when applied as improvement tools and do not always guarantee success.[76]

Because MMs are common and have the potential to fulfil the requirements set for the assessment method for DUIE, they present a reasonable assessment approach. With the potential pitfalls that are common to MM development in mind, special care will be taken to apply rigorous methods to the assessment method being developed in this MT.

[60] Paulk, M. C. et al. (1993).
[61] Von Rosing, Mark et al. (2014), chap. BPM and Maturity Models.
[62] Bruin, Tonia De and Rosemann, Michael (2005).
[63] De Bruin, Tonia et al. (2005).
[64] Becker, Jörg et al. (2009).
[65] De Bruin, Tonia et al. (2005).
[66] Fraser, Martin D. and Vaishnavi, Vijay K. (1997), p. 97.
[67] Mettler, Tobias (2009).
[68] Kaner, Maya and Karni, Reuven (2004).
[69] Mettler, Tobias (2009).
[70] Mettler, Tobias (2011).
[71] Tan, Chee-Sok and Sim, Yee-Wai (2011).
[72] Schumacher, Andreas (2015).
[73] Becker, Jörg et al. (2009).
[74] Dayal, Umeshwared (2009).
[75] De Bruin, Tonia et al. (2005).
[76] Mettler, Tobias (2009).

# 3 Systematic literature review (SLR)

The guide to conducting a SLR that was developed in the chapter 2.3 defines three distinct stages: Planning, Execution and Reporting. They contain a total number of seven steps. In steps 1 (separation of research topics) and 2 (quality definition), general criteria are established by which the literature review will be carried out.

## 3.1 SLR planning

The planning stage of the SLR aims to structure the review in a manner that enables its transparent, reproducible and efficient execution.

### 3.1.1 Separation of research topics

In order to make the SLR precise and transparent, it was separated into three primary research topics. For each of these topics, keywords that were used during the search process were defined to increase the comprehensiveness of the conducted SLR process. These are listed in Table 5.

**Table 5: Primary research topics and keywords for SLR**

| |
|---|
| **MMs in general:**<br>Maturity AND model, maturity model presentation, maturity model limitations, maturity model benefits |
| **MMs related to DUIE:**<br>Maturity AND model AND data, maturity model data utilisation, maturity model business intelligence, maturity model knowledge management, maturity model business analytics |
| **MM development:**<br>Method maturity model, maturity model design, development maturity model |

### 3.1.2 Purpose of the literature review

The purpose of this literature review is to supply the researcher with an extensive overview over the application potential and development methods of MMs, as well as assessing the current state-of-the art for DU related MMs.

Because SLRs aim at answering specific questions rather than giving overall summaries, review questions are defined (see Table 6)

**Table 6: Review Questions for SLR**

- What is maturity and how can it be assessed in the context of MMs
- Does an established best practice for developing MMs exist and what is it?
- How can MMs be populated?
- What aspects make MMs useful?
- Do comparable MMs exist and is the development of a new one justified?
- What should the MMACUDIE identify?
- What is a suitable model structure?
- What are suitable dimension and attribute definitions?
- What is a suitable approach to defining maturity levels?
- How can the results of a MM assessment be presented?
- How can MMs be validated

### 3.1.3 Quality definition

The advancement of scientific research is generally based on furthering the insights and knowledge that was generated by preceding generations of researchers. Sir Isaac Newton famously characterized this in a letter from the year 1675 in which he wrote: “If I have seen further it is by standing on the shoulders of Giants.”[77] However, this also means that the quality of the insights that are being generated is directly dependent on the quality of the research that it is being based on.

[77] Isaac Newton (1675).

That is why it is imperative to establish a set of criteria by which the quality of the available literature may be assessed. The criteria by which a piece of literature will be primarily assessed have been assembled into a quality assessment form (Table 7). For each criterium that a piece of literature fulfils, it is awarded a point, resulting in a point rating ranging from 0 – 5, 5 signifying the highest and 0 signifying the lowest quality. Only literature with a quality rating of 3 or higher will be considered for this MT.

**Table 7: Primary quality assessment form**

| **Criteria** | **Result** | |
|---|---|---|
| Is the literature **relevant** to answering the **review questions**? | ☐ Yes | ☐ No |
| Does the literature **add additional value** to the research? | ☐ Yes | ☐ No |
| Was a ***systematic*** or ***standardized method*** used? | ☐ Yes | ☐ No |
| Are the research results **reliable** and **valid**? | ☐ Yes | ☐ No |
| Has the literature been ***peer reviewed***? | ☐ Yes | ☐ No |

**Relevance** – In order for a piece of literature to add value, it must be relevant to answering the review questions that are defined in chapter 3.1.2.

**Added Value** – Although a piece of literature may be relevant to answering the review questions, it may not progress the insights gained through the SLR. Only the literature that adds additional value should be taken into account for the sake of maintaining a good overview of significant sources.

**Method of research** – The benefits of systematic and standardized research methods have already been described. Their application is an indicator of dedication to reproducible and qualitative research.

**Reliability and validity of data** – "Examining the data for reliability and validity assesses both the objectivity and credibility of the research. Validity relates to the honesty and genuineness of the research data, while reliability relates to the reproducibility and stability of the data."[78]

[78] Anderson, Claire (2010), p. 2.

**Peer Reviewed** - In order to assess and progress scientific research, as well as to ensure its quality, the Peer Review Process was established over the course of the last 500 years[79]. This process, though it may be flawed, has been and will remain a backbone of scientific research for years to come and is an indicator for a certain degree of quality.[80,81,82,83,84]

### 3.1.4 Development of a screening protocol

To ensure that the SLR process comprehensive, it is important to document by which means literature was obtained and by which criteria it will be reviewed. All the literature will be obtained via web-based databases of scientific publishers, universities and scientific search engines. These will primarily be Google Scholar[85] and the library catalogue of the TU Vienna[86]. Other databases may be incidentally accessed if critical information is not available in either of the primary databases. The initial and refined screening criteria, as well keywords that will be used in the search terms are listed in Table 8.

**Table 8: Initial Screening Criteria for the SLR**

| **Initial screening criteria** |
|---|
| • Relevant time frame: 2000 – 2018<br>• Language of literature: English (primary) and German (secondary)<br>• Relevance to MT<br>• Types of literature: Research articles (journals or conferences), technical reports, government reports, international or national norms, books, dissertations, theses<br>• Amount of text required: 100%<br>• Minimum number of screened publications per keyword and database: 30<br>• Maximum number of screened publications per keyword: 150 |
| **Refined screening criteria if literature is MM** |
| • Explicit definition of dimensions<br>• Explicit definition of maturity levels<br>• Presence of two or more dimensions deemed relevant to this MT |

[79] Spier, Ray (2002).
[80] Smith, Richard (2006).
[81] Levy, Yair and Ellis, Timothy J. (2006).
[82] Davison, Robert M. et al. (2005).
[83] Alberts, B. et al. (2008).
[84] Scott, Alister (2007).
[85] Google Scholar (2018).
[86] UB TU Vienna (2018).

Since each keyword will yield varying amounts of usable literature and the keywords will have varying impact on developing the MMACUDIE, the amount of literature to be screened in the initial screening process has been limited to a range between 30 and 150 publications per keyword. The upper bound has been imposed due to the time constraints of this MT, the lower bound has been imposed to guarantee the quality of the SLR. The amount of screened literature will be documented and presented along with the quality assessment.

Because the SLR is trying to answer a diverse set of review questions, a second screening process will take place specifically for the literature describing actuall MMs. This second review process will focus on identifying suitable literature from which specific dimensions, attributes and level definitions may be deduced. Its goal is to exclude maturity models that are vague in describing these aspects and only provide very broad generalisations of maturity rather than specific attributes.

According to the Publication Manual of the American Psychological Association it is good scientific practice to only “use secondary sources sparingly, for instance, when the original work is out of print, unavailable through usual sources, or not available in English.”[87] In order to comply with this practice, any seemingly relevant literature that is referenced in the primary literature will also be searched for and evaluated according to the same quality criteria (see Table 5). The literature that has been included in this MT on this basis is documented and attached in table form in Annex 6.3 of this MT to ensure a good comprehensibility of the SLR.

[87] American Psychological Associationed (2010), p. 178.

### 3.1.5 Concept map

In order to visualise the process flow for the SLR, the concept map in Figure 6 was created.

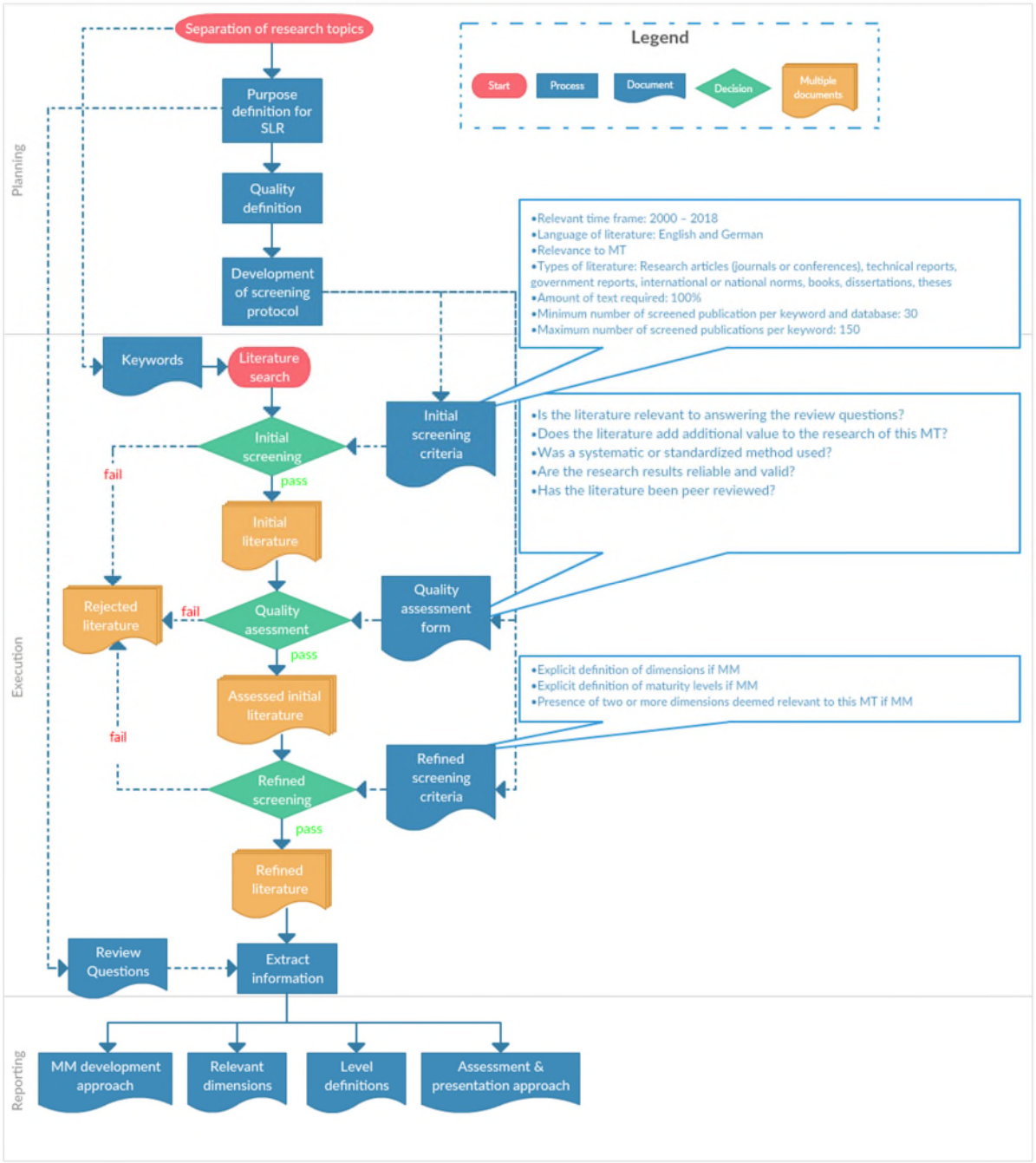


**Figure 6: Concept map for SLR**

## 3.2 SLR execution

During the execution stage, all the literature that passes the initial screening criteria will be further assessed according to the refined screening criteria, which include the qualitative requirements defined in chapter 3.1.3. The literature resulting from this second screening process will be the referred to as “refined literature” and will form the basis for answering the specific review questions that were defined in chapter 3.1.2.

### 3.2.1 Literature screening

The keyword searches, with the applied initial screening criteria in place resulted in over 1000 pieces of initial literature undergoing the initial screening process. Out of these initial pieces of literature, 66 were identified as unique and being relevant to the development of the MMACUDIE. They were assessed according to the defined quality definitions (see Table 9: Quality assessment of relevant literature), leading to the conclusion that only 38 of them reach the required quality level of 3 or higher.

**Table 9: Quality assessment of relevant literature**

| Literature source | Quality assessments initial literature | | | | |
|---|---|---|---|---|---|
| | QL1 | QL2 | QL3 | QL4 | QL5 |
| Primary | 7 | 14 | 14 | 8 | 7 |
| Secondary | 0 | 4 | 4 | 1 | 4 |
| Sum | 7 | 18 | 18 | 9 | 11 |

The refined screening criteria identified 15 pieces of literature with precise dimension and level definitions. Table 13: Overview of common dimension in chapter I8 lists these 15 pieces of literature with the dimensions contained in them.

### 3.2.2 Data extraction

#### I1. MM relevant terminology

The terminology that is being applied throughout the literature regarding MMs varies. To ensure good comprehensibility in this MT, the following Table 10 contains a list of terms with explanations that were identified as relevant during the SLR.

**Table 10: List of terms used**

| Term | Definition |
|---|---|
| Analytical Services | DU processes that provide contextual information by utilising data or other information |
| Assessment Layer | Level of abstraction into which dimensions can be grouped |
| Assessment Level | Level at which capabilities are assessed (entity, layer, dimension, etc.) |
| Assessment Level Approach | The assessment approach can be continuous (higher levels encompass all previous levels) or staged (levels require a specific set of criteria to be fulfilled for each level) |
| Assessment partner | Interview partner for the investigator who provides the information required to assess the entity |
| Attribute | Distinguishable and identifiable traits that define the maturity level for each capability. |
| Capability | Ability to fulfil an intended purpose |
| Data | Qualitative and quantitative facts that were obtained through Metrics and have not been transformed |
| Data and information flow | Movement of data and information through the DU system |
| Data Loading processes | Loading data chunks into data warehousing architecture in repetitive time cycles rather than continuously |
| Data Marts | Data Stores that are focused on specific business functions within the entity |
| Data Policy | Naming standards, privacy, security |
| Data transformation | Evolving data into information and combining sets of information |
| Data Warehouses | Data Stores that are focused on integrating data from all business functions throughout the entity into one single structure |
| Defined | Informally agreed and maybe not documented |
| Dimension | Distinct aspects of a domain that are involved in the process of utilising data and are assessed for their maturity level. |
| Dimensional Tensions | Varying levels of sophistication between dimensions which lead to inefficiencies and waste |
| DU task ownership role | Formalised role though which DU related responsibilities and privileges are defined |
| DU-Tools | Software and hardware that is involved in the DU process |
| Enterprise Data Warehouse | A singular data store that integrates and makes the whole information of the enterprise widely available |
| Entity | Abstract object to which the maturity model can be applied |
| External Data | Data that is not generated within the entity itself |
| Formalised | Formally agreed and documented. |

| | |
|---|---|
| Information | Results of structuring and processing data and other documents enabling knowledge |
| Internal data | Data that is generated within the entity |
| Investigator | Person conducting the maturity assessment |
| KPIs | Key Process Indicators that make performance quantifiable |
| Listed information | Changes to the listed information are not dynamically reflected throughout all instances of its existence and may require manual change |
| Management Reports | Static reports that are distributed to employees in regular time intervals |
| Manual collection of data | Data is recorded by hand in a non-digital format |
| Maturity Level | A linear scale quantifying different stages of maturity evolution, ranging from rudimental to exceptional. |
| Metadata | Data that enables an assessment of the data it contains information about |
| Metrics | Measurements focused on reporting performance of processes |
| Scope | An area of observation, application or general relevance |
| SLAs | Service Level Agreement for the creation of reoccurring reports or other services |
| Spread Marts | Spread sheets or desktop databases that function as surrogate data-marts |
| Tracked information | Changes to the tracked information are reflected homogenously throughout all instances of its existence in a largely automated and dynamic process |

### I2. **What is maturity and how can it be assessed in the context of MMs**

Maturity is a measure to assess an entity's capability in a certain domain and describes an evolutionary path of sophistication[88]. It is usually quantified by assigning maturity levels to the dimensions that make up a certain capability. The more complex the nature of a capability is, the more dimensions it tends to be comprised of. A maturity rating is a reflection of the assessed level for a specific point in time and may change, if the state of the assessed dimension or the maturity definitions are altered.

The most popular way of evaluating maturity is applying so called "five-point Likert scales", where 5 represents the highest and 1 the lowest level of maturity.[89]

[88] Becker, Jörg et al. (2009).
[89] De Bruin, Tonia et al. (2005).

Because different dimensions and dimension-components require different approaches to level definition, a generic level definition was devised by Nightingale and Mize[90] for the development of the Lean Enterprise Self-Assessment Tool (LESAT) tool (see Table 11).

**Table 11: The LESAT Tool generic level definitions[91]**

| Level | Generic Definition |
|---|---|
| Level 1 | Some awareness of this practice; sporadic improvement activities may be underway in a few areas |
| Level 2 | General awareness, informal approach deployed in a few areas with varying degrees of effectiveness and sustainment |
| Level 3 | A systematic approach/methodology deployed in varying stages across most areas; facilitated with good metrics; good sustainment |
| Level 4 | Ongoing refinement and continuous improvement across the enterprise; improvement gains are sustained |
| Level 5 | Exceptional, well-defined innovative approach is fully deployed across the extended enterprise (across internal and external streams); recognized as best practice |

The LESAT tool was developed as a means for assessing the implementation of Lean practices within an organisation. Utilising data is typically part of a lean improvement effort, making the compatibility for application to the MMACUDIE very likely.

It is important to note, that higher levels of maturity do not guarantee better performance. Because every capability is dependent on a multitude of dimensions, the weakest part of the system, the lagging evolutionary dimensions, will also reduce the benefits of the other more mature dimensions.[92] This is commonly called dimension tension (see chapter 2.5.2). However, for harmonised and tensionless systems, a correlation between higher levels of maturity and business performance/leanness has been established.[93,94] An organisation's goal for improving business performance

[90] Nightingale, Deborah J. and Mize, Joe H. (2002).
[91] Ibid.
[92] Tan, Chee-Sok and Sim, Yee-Wai (2011).
[93] Lockamy, Archie and McCormack, Kevin (2004).
[94] Nightingale, Deborah J. and Mize, Joe H. (2002).

should therefore be to decrease dimension tension and evenly raise the overall system maturity, rather than to just increase individual dimension or dimension attribute maturity levels.

**I3. Does an established best practice for developing MMs exist and what is it?**

As discussed in chapter 2.2, the design science approach to developing MMs formulated by Becker et. al[95] has been broadly accepted as a tool for overcoming the most common issues related to low quality MMs. The therein defined procedure model demonstrates a sensible and easily applicable design approach that adheres to the principles of Design Science. However, its complex procedure flow is ill-suited as a structural template for this MT. A publication by De Bruin et. al[96] provides a more linear development phase flow model (Figure 7), which is better suited to this purpose. That is why the development structure of this MT will follow the development phases defined by De Bruin but still adhere to an adapted version of Becker's development process.

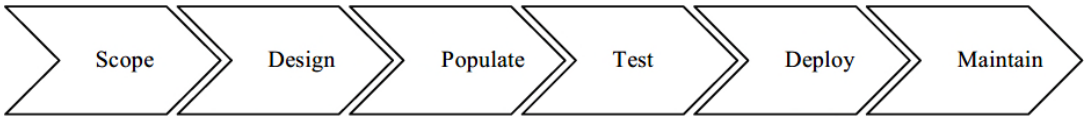


**Figure 7: MM development Phases[97]**

The following paragraphs will elaborate on the specifics of each development phase, based on the collective insights gained from the SLR.

The "Scope" of MMs sets the outer boundaries for the model application, creating so-called entities within that scope, which may then be assessed via MMs. These entities can be entire organisations or abstract sub-sets of these organisations such as sites at specific geographic locations, different divisions, business units, or even projects or processes. Defining these entities via the scope, strongly influences the following phases of development.

During the "Design" phase of MM development, the actual assessment model is conceptualised and designed. It needs to be tailored to the needs of the intended application and maintain a balance between accurate depiction of reality and simplicity.

[95] Becker, Jörg et al. (2009).
[96] De Bruin, Tonia et al. (2005).
[97] Ibid.

To ensure usability, the following questions should be considered during the design stage:

- Why is the model being applied (reason for initiation, desired outcome etc.)?
- What is the overall structure of the model? (Granularity, Level classification, etc.)?
- How will the model be applied to an organisation (method, tools, frequency, etc.)?

While the design phase seeks to build the overall model architecture, the "Populate" fills it. While populating the model, it is important define what will be measured. This means defining assessment layers, dimensions, attributes and level criteria, as well as conceptualising the assessment tool (questionnaire, rating criteria, etc.).

For the level definition of each dimension, each level should be named with a short label for clear identification and possess distinct, logically progressing qualification attributes. Level descriptions should be brief and to the point. Tools to define parameters of MMs include SLRs, Delphi technique, Nominal Group technique, case study interviews and focus groups. There are different benefits to all of them, although the literature and experience from other studies suggests that a mixture of methods typically leads to the best results.[98,99,100,101] When choosing the technique, it is important to keep the requirements of the involved stakeholders in mind.

When conceptualising assessment tools, the room for interpretation of the assessment criteria/questions should be minimal. Quantitative assessment tools (such as Likert scales) have proven to make assessments more reliable[102] and consistent and should be applied where possible. The skills and knowledge of both the assessment partners and investigators should be taken into consideration during population of the model.

"Testing" the model for relevance and rigor once it is ready for application is an important part of the iterative development process. There are two primary factors that require validation: "face validity" (FV), also called "construct validity", and "content validity" (CV).[103,104] FV describes the extent to which the model is perceived to fulfil its intent by stakeholders. It is usually assessed throughout the iterative population phase by the developer of the model and may be confirmed through initial pilot tests. CV describes the extent and accuracy with which the model describes the intricacies and

[98] Ibid.
[99] Brooks, Patti et al. (2015).
[100] Becker, Jörg et al. (2009), p. 218.
[101] Raber, David et al. (2012).
[102] De Bruin, Tonia et al. (2005).
[103] Spruit, Marco and Pietzka, Katharina (2015).
[104] Becerra-Fernandez, Irma and Leidner, D. E (2008).

different facets of reality and is typically judged after the initial completion of the MM through extended validation processes. These validation processes are usually part of the "Deployment" phase and will therefore not be included in this MT.

The "Maintenance" phase of MMs is carried out after the deployment phase and will therefore also not be a part of this MT.

### I4. How can MMs be populated?

In the population phase of MM development, the overall structure of the MM is filled with explicit assessment layers, dimensions, attributes and level definitions. Depending on the depth and width of the already available research, an identification of the most important components, may well be possible through an extensive literature review. For relatively new domains, the existing literature may not allow deriving a comprehensive list of dimensions and components, but, identified success factors and barriers to entry can provide great insights into requirements. That's why dimension components derived exclusively through SLRs usually only serve as good starting points for these new domains[105]. This should then be expanded upon by applying exploratory research methods like case studies, expert interviews, et cetera.

### I5. What aspects make MMs useful?

MM development is often argued to not be very scientific, reproduceable and based on successful projects rather than well founded research[106,107,108]. This has led to the development of MMs that are of little problem relevance for anyone not familiar with the original context of the development. Too ensure the problem relevance of this MT and add structure to the development process, the assessment needs, which the development of the MMACUDIE is trying to meet, should be clearly stated. The following paragraphs describe critical factors that should be considered during the design process.

***Granularity:*** When designing a MM, choosing the granularity of the assessment level is critical for its usability and meaningfulness of the assessment. Some MMs choose to rate a capability via a single overall maturity level, others choose to rate each dimension or even each individual attribute. Whatever choice researchers make, dimension components and sub-components should be mutually exclusive and collectively exhaustive[109]. More in depth assessment levels enable greater and more specific insights into potential capability improvement areas but may decrease the

[105] De Bruin, Tonia et al. (2005).
[106] García-Mireles, G.A. et al. (2012).
[107] Mettler, Tobias (2011).
[108] Becker, Jörg et al. (2009).
[109] De Bruin, Tonia et al. (2005).

comparability between MM assessments of different entities or limit the application possibilities. The balance of these factors greatly impacts the usefulness of MMs and decisions should be made according to the needs of the intended target audience.[110,111,112]

***Model Design:*** Comprehensively identifying critical aspects making up a capability is one of the major struggles of effective MM development. The complex nature of more generalised capabilities (such as DU) typically involves a range of different dimensions, that enable the capability through their synergy.[113] Devising additional layers of detail allows maturity assessments to evaluate discrete areas of the organisation. These are represented by the domain, assessment layers and dimensions. This can lead to organisations gaining a deeper understanding of their relative strengths and weaknesses in each area and allow them to define specific improvement strategies for each of them.[114]

***Level classification:*** MM deployment usually takes place due to the need for an assessment of a status of a certain capability. This "measurement process can be a positive activity if the (Maturity) model provides feedback on where beneficial changes… could be made."[115] A precondition for providing useful feedback is a correct and consistent level assessment of the dimensions. A majority of MMs provide generic level definitions according to the LESAT tool (See chapter I2 Table 11) but lack a detailed set of criteria for determining the respective level. According to expert interviews[116] this usually results in subjective classifications with high degrees of inconsistency, depending on the assessment partner, and deteriorates the objective nature of MM assessments.

MMs that display good usability provide detailed descriptions of required attributes and their sophistication for each level. This may result in an entity incompletely fulfilling the attribute criteria for a certain level classification (e.g. two attributes at level 4 but one only at level 2). To make level classification consistent, the so called "stage-gate" approaches class dimensions by the weakest of any of their attributes. Models utilising this approach thereby dictate "a predefined road map for organisational improvement based on proven grouping and ordering of processes and associated organisational relationships."[117] This makes stage-gate MMs at least partially prescriptive.

[110] Ibid.
[111] Michael Rosemann and Tonia De Bruin (2005).
[112] Ofner, Martin H et al. (2009), p. 8.
[113] Brooks, Patti et al. (2015), p. 342.
[114] De Bruin, Tonia et al. (2005).
[115] Fraser, Martin D. and Vaishnavi, Vijay K. (1997), p. 97.
[116] Andreas Schumacher (2018).
[117] Ahern, D. M. et al. (2004), p. 84.

***Assessment method:*** Which assessment method will deliver a productive outcome and achieve the intended goals of a MM assessment, is largely dependent on the sophistication and evolution stage of the MM. Newly developed and poorly tested MMs are likely to benefit from further iteration and improvement cycles and the definition of dimensions etc. may not fulfil the criteria of being exhaustive and mutually exclusive. Not providing further context, room for configuration, clarifications or explanations of individual components will make the assessment process difficult for organisations. To avoid a dismissal of unevolved MMs, the more flexible context of personal interviews between the MM developer and assessment partners is more likely to result in a positive assessment experience for both sides. Personal assessments also avoid the issue of poor response rates that are often associated with remote assessment methods.

Highly evolved MMs that are populated with true and tried dimensions, attributes, assessment questions, et cetera, tend to be more comprehensible, making remote assessments feasible and productive. In this case, electronic deployment of quantitative methods such a survey is recommended, due to the ease of distribution and cost reduction in comparison to analogue distribution. The removal of the need for re-keying, also greatly increases the response rate of recipients.[118] Regardless of the exact distribution method, the resources that are available for an assessment will be the limiting factor in most cases.

Because “each company has its individual assessment context… the maturity model needs to be configurable to meet company specific requirements.”[119] This is where the possibility of a cascading implementation can provide the flexibility to make MMs relevant to a broader range of organisations.[120] However, dimensions should not be excluded from assessments lightly. There is a chance that an organisation is unaware of how dimensions affect each other and that the motivation for exclusion is based on difficulties in implementing certain aspects of that dimension. Because dimensions are so interdependent on each other, deciding which dimensions to exclude is difficult. [121]

**Topicality:** Basing a maturity assessment on outdated research or technological standards defeats the purpose. That is why, “like any other reference model, a maturity model too demands adaptation to new requirements over time.”[122] Useful MMs should therefore be up-to-date or at least easily maintainable through adaptions of individual dimensions or attributes.

[118] De Bruin, Tonia et al. (2005).
[119] Ofner, Martin et al. (2013), p. 17.
[120] Rosemann, Michael et al. (2004).
[121] Michael Rosemann and Tonia De Bruin (2005).
[122] Ofner, Martin H et al. (2009), p. 10.

**I6. Do comparable MMs exist and is the development of a new MM justified?**

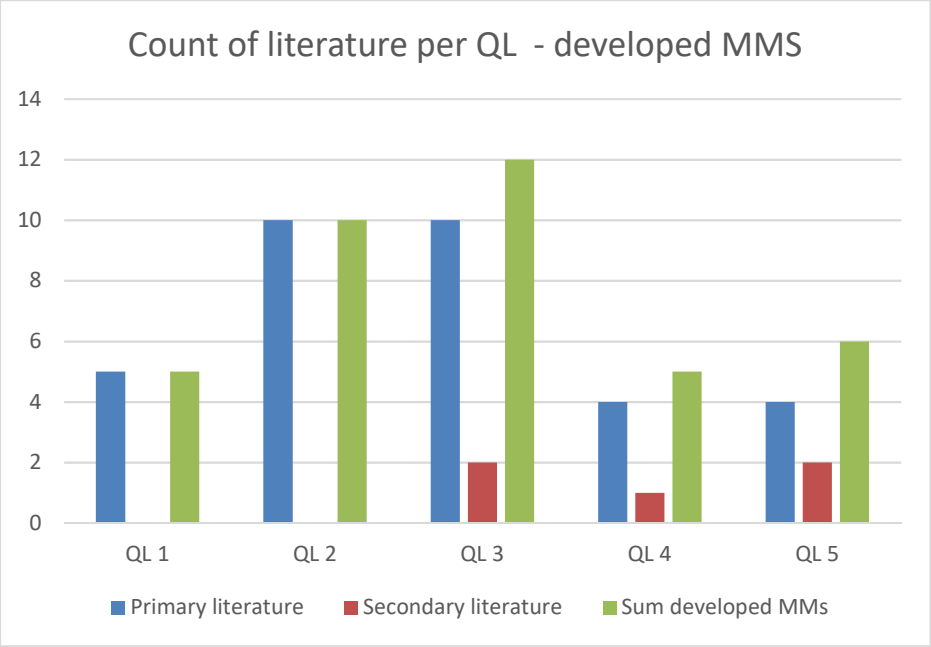


**Figure 8: Developed MMs assessed for Quality**

At the time this SLR was conducted, no MM specifically aimed at assessing an enterprises capability to utilise data was found. However, several MMs for closely related fields of study (see Table 4: DU related fields of study) were discovered. Out of the entire initial literature, 35 initially relevant developed MMs of related fields underwent a quality assessment (see Figure 8). However, only 23 reached a QL of 3 or higher and when further assessed only 15 MMs passed the secondary screening protocol (see chapter 3.1.4).

When these were further examined regarding their usefulness (see chapter I5), especially in terms of dimension and attribute definition (mutually exclusive and collectively exhaustive), only 5 MMs were judged as being truly useful (see Table 12). Although these 5 MMs share a lot of the same dimension assessments, some degree of deviation remains between them. This is likely due to the different specific scopes of each MM, for which some dimensions are more and some less relevant than for DUIE.

**Table 12: Useful MMs**

| Model | Shortcomings |
|---|---|
| BIMM (Näslund et. Al 2014)[123] | Human and data integration dimensions underdeveloped, no assessment method, lacking some dimensions |
| BDMM (Comuzzi & Patel 2016)[124] | Human and formalisation dimensions underdeveloped, lacking some dimensions |
| MMKM (Edgar Serna M. 2012)[125] | Poor separation of dimensions, no assessment method, lacking some dimensions |
| biMM (Dinter et. Al 2012)[126] | Level definition inconsistent, lacking some dimensions |
| IEM (Davis et. Al 2006)[127] | Unintuitive assessment method, lacking some dimensions |

Although the 5 identified MMs were judged to be useful at assessing the specific capabilities they were designed for, some severe shortcomings regarding DUIE and general usefulness were recognised in each of them (see Table 12). This makes the development of a new MM relevant and justifies the development of the MMACUDIE.

### I7. What should the MMACUDIE identify?

Achieving higher levels of maturity becomes progressively more resource intensive and difficult to achieve, seeing as lower maturity levels tend to encompass more rudimentary and aged approaches/technologies, for which information, acceptance, know-how, etc. tend to be more easily available. Improving lower levels of maturity therefore tends to be more resource efficient. Identifying and reducing dimension tensions that arise due to individual low levels of maturity in an otherwise overall more mature system, may therefore be the most efficient approach to improving the overall DU capability of an entity.

The primary objective of the MMACUDIE should therefore be to assess the maturity levels of all the dimensions that are relevant to DUIE, thereby revealing existing dimension tensions within the entity and providing a starting point for improvement initiatives.

[123] Näslund, Dag et al. (2014).
[124] Comuzzi, Marco and Patel, Anit (2016).
[125] Edgar Serna M. (2012).
[126] Dinter, Barbara (2012).
[127] Davis, Jim et al. (2006).

### I8. What is a suitable model structure?

Organisations possess various capabilities in an array of different capability areas. The scope of a maturity assessment can examine anything from specific dimensions or attributes of individual capabilities, to the synergy of various capabilities in achieving a higher goal. Therefore, the best suited model structure is primarily dictated by what scope it is trying to assess. The closer MMs are supposed to depict reality, the more complex they tend to be.[128] "There are three different (common) model structures that can be used to assess the maturity of a domain: one single maturity level, many parallel maturity levels, or hierarchical maturity levels. The third combines the first two"[129] and is deployed in most qualitative MMs.

In hierarchical model structures, different layers are defined by grouping dimensions and traits of similar complexity in a hierarchical structure. The more complex a dimension is, the higher up in the hierarchy it is grouped (see Figure 9). Keeping the number of dimensions and subcomponents low, within a layer or dimension respectively, helps to reduce the perceived complexity of the model and increases the comprehensiveness to assessment partners.[130]

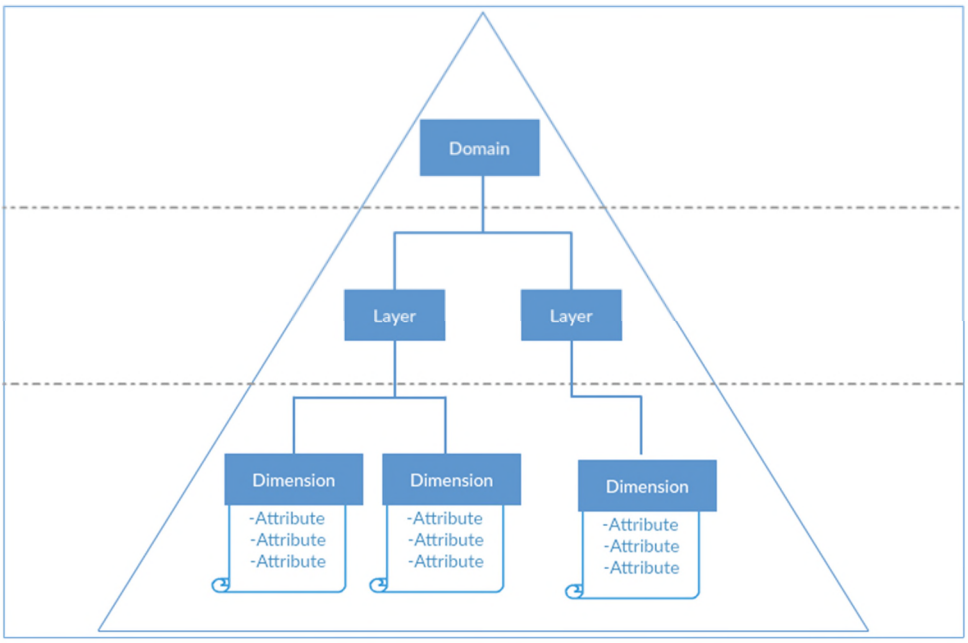


**Figure 9: Exemplary hierarchical model structure based on De Bruin[131]**

### I9. What are suitable dimension and attribute definitions?

The level of detail for the dimensions influences the depth of the maturity analyses. It should be chosen with the intended application in mind.[132] Finer levels of detail enable

[128] De Bruin, Tonia et al. (2005), p. 4.
[129] Ofner, Martin H et al. (2009), p. 4.
[130] De Bruin, Tonia et al. (2005).
[131] Ibid.
[132] Ibid.

more degrees of cascading implementation but make assessments more time consuming and difficult to comprehend. The goal for the definition of dimensions and attributes is a balance of good representation of reality while maintaining good usability.

Maturity evaluations have frequently been applied to unidimensional aspects of complex multidimensional topics (e.g. just warehousing architecture or Data management, etc.), which makes them poorly suited for improving entire domains.[133] Assessing capabilities in this unidimensional way neglects other critical aspects factoring into their success. That is why the focus for maturity assessment is shifting towards assessing the maturity of so called “organisational capabilities”. These are the combination of all the available skillsets, abilities, organisational structures, organisational culture, etc. that are necessary for success in an area of examination. In the case of this MT the assed organisational capability is DU.

To make models more comprehensible to assessment partner, dimensions are often grouped logically by their level of abstraction into so called layers. Common layers that present DU relevant literature are:[134,135,136, 137, 138, 139, 140, 141, 142, 143, 144,145, 146]

- Strategy maturity – extent to which the strategic alignment and allocation of resources within the organisation reflects the intent of achieving a certain capability
- Governance Maturity – system of ensuring compliance to established rules and regulations
- Process Maturity – based on a Total Quality Management (TQM) approach of analysing processes and rating the degree to which they are defined, managed, measured, controlled, and effective
- Object Maturity – assessment to which extent objects like products, reports or tools reach a level of sophistication

[133] Rosemann, Michael et al. (2004).
[134] Maier, Moultrie, und Clarkson, „Assessing Organisational Capabilities“.
[135] Mettler, Tobias (2009).
[136] Andersen, Erling S. and Jessen, Svein Arne (2003).
[137] Hammer, Michael (2007).
[138] Bruin, Tonia De and Rosemann, Michael (2005).
[139] Kee-Luen, Wong et al. (2017).
[140] Wettstein, T and Kueng, P (2002).
[141] Nabitz, U. et al. (2000).
[142] Comuzzi, Marco and Patel, Anit (2016).
[143] Cosic, Ranko et al. (2012).
[144] Näslund, Dag et al. (2014).
[145] Chuah, M. H. (2010).
[146] Rud, Olivia Parr (2009), p. 14.

- People capability - extent to which the people within the organisation enhance or hinder the proficiency in a certain capability

Several independent, highly usable, DU related and qualitatively high publications have identified an overlapping set of explicitly formulated dimensions to be relevant (see Table 13). The fact that these overlaps exist is a good indicator for their significance. However, there is a possibility that they are a result of popular biases and that other, specifically DU relevant criteria, may have been neglected. To account for this possibility, the set of explicitly formalised dimensions should be evaluated and assessed for completeness.

It should be noted, that Table 13 only contains the dimensions that passed the refined screening protocol, whereby any MMs that did not explicitly define dimensions, maturity level definitions or contain at least two dimensions that were deemed relevant to DU, are not included. Some of the dimensions listed in Table 13 represent groupings of dimensions that weren't consistently grouped throughout the literature in this way (e.g. grouping of "DU tool management" and "Analytical tools and services" into one dimension rather than two separate dimensions). In case dimensions were grouped together in this way, the decision of how to group them was based on prevalence of similar groupings throughout the literature.

**Table 13: Overview of common dimensions**

| Dimensions | DWP-M (Sen et. Al 2012) | EBIM (Tan et. Al 2011) | PMS (Wettstein & Kueng 2002) | DQMM (Ryu et. Al 2006) | DM-CMM (Kaner & Karni 2004) | BPMM (Lee et. Al 2007) | BIMM (Näslund et. Al 2014) | BDMM (Comuzzi & Patel 2015) | MMKM (Edgar Serna M. 2012) | MD3M (Spruit & Pitzka 2015) | K3M (Liebowitz & Beckman 2008) | KMM (Kulkarni & St. Luis 2003) | P-CCMM (Curtis et. Al 2009) | biMM (Dinter et. Al 2012) | IEM (Davis et. Al 2006) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Access to information | | | | | | | x | | | x | | | | | x |
| Analytical abilities | | x | | | x | | | | | | x | | x | | x |
| Analytical tools & services | | | | | x | | x | x | | | | | | x | x |
| Data collection & integration | | | x | x | | | | | | | | | | x | x |
| Data management | | x | | x | | | x | x | x | x | | | | x | x |
| Data warehousing architecture | x | x | x | x | | | x | x | | | | | | x | x |
| DU application | | | | | | | x | | x | x | x | | | | |
| DU awareness (management) | | | | | | | x | x | x | | | | | x | x |
| DU awareness (staff) | | | | | | | x | x | x | | | | | x | x |
| DU policy | | x | x | | | | x | x | x | x | x | | x | x | x |
| DU scope formalisation | | | x | | | x | x | | | | | | | | |
| DU tool management | x | | | | | | | x | | | | | | | x |
| DU workflow formalisation | | | x | | x | | x | | x | | | x | | x | x |
| DU workflow integration | | | x | | x | | x | | x | | | | | x | x |
| Information management | | | | | | | x | x | x | x | | | | | |
| Information Quality (IQ) awareness | | x | | x | | | x | | | x | | | | | |
| Knowledge asset sharing | | | | | | | | | x | | x | x | x | | x |
| Measurements | | | x | | x | x | | | | | | | | | x |

### I10. What is a suitable approach to defining maturity levels?

Before defining the individual level criteria, an overall understanding of each level should be provided. Some MMs include the definition for Level 0, which describes it as being non-existent, however this is not very common. Because the various dimensions should be describing a capability completely, the presence of a Level 0 maturity is highly unlikely, seeing as the complete absence of it would restrict this capability to the point of being non-functional. In this case, applying improvement tools other than MMs to the entity would likely yield better results.

Individual level definitions should contain every major requirement, qualifying it for the specific level. In case levels follow an evolutionary path of sophistication for each of its attributes and lower levels are compulsory predecessors to achieving higher levels of maturity, it can be sufficient to only list those aspects that are new to the level and not included in lower levels.[147] However, since this is rarely the case for more complex capability assessments, it can be beneficial to provide a complete description of every required attribute and its respective sophistication level for every individual level definition.

When defining maturity levels, either a both top-down or bottom-up approaches are legitimate. Top-down approaches first formulate definitions and then the required measures by which they are assessed. Bottom-up approaches set the requirements and measures first and then reflect definitions from these.[148] Basing level definitions on SLRs means applying bottom-up approaches.

### I11. How can the results of a MM assessment be presented?

Assessing maturity through levels, typically ranging from 1 to 5, is a common and "the practice, with the highest number representing high maturity and the lowest number representing low maturity, appears to have wide practical acceptance."[149] Visualising these maturity levels helps individuals comprehend the results of a maturity assessment more intuitively and can be done in numerous ways. Spider-web-representations appear to be common[150,151,152,153,154] but other visualisation techniques such as ladder, or profile representations can fulfil the same purpose. The most important factor when choosing a visualisation representation is ensuring that it allows

[147] De Bruin, Tonia et al. (2005).
[148] Ibid.
[149] Maier, Anja M. et al. (2012), p. 146.
[150] Nabitz, U. et al. (2000).
[151] Comuzzi, Marco and Patel, Anit (2016).
[152] Schumacher, Andreas (2015).
[153] Ofner, Martin et al. (2013).
[154] Michael Rosemann and Tonia De Bruin (2005).

an intuitive interpretation of the content by the viewer.[155] This choice will be significantly influenced by the overall structure of the model

Because organisations naturally wish to compare their capabilities to those of competitors or even themselves over time, the chosen representation method should comply with this wish. The temptation to compare the outcomes of similarly presented MMs, especially if these share common layers, dimensions and maturity representations, is great. However, the basis for comparability cannot generally be assumed without a close comparison of the MMs and their respective maturity definitions.[156]

### I12. How can MMs be validated?

The need for validation arises due to the wish to make a MM theoretically and practically sound. It should include an assessment of the model in general (structure, completeness of the identified dimensions, sub-dimensions and attributes for the specific domain, perceived time/benefit value), as well as of the instruments deployed to measure maturity. Templates that include questions that have proven to be useful can provide a good basis for formulating effective validation questions (see Salah, Dina et al (2014)[157]).

Both qualitative and quantitative methods can be useful in verifying MMs, although quantitative research has the benefit of being statistically comparable. However, as with any statistical analysis, this requires a minimum number of validation results to be significant.

## 3.3 SLR Reporting

A maturity rating of a specific capability reflects its evolutionary state at this specific point in time. The breadth of the evolutionary spectrum is usually divided into different levels, commonly 1 to 5, with higher numbers usually representing higher evolutionary states. Higher maturity states by themselves are no guarantee for better performance however, as performance is dependent on the synergy of various factors in combination with each other. That is why isolated under-evolved aspects of an otherwise highly evolved system can be detrimental to the overall performance in a specific capability. MMs can be useful in identifying this phenomenon, which is called “dimension tension”. MMs that accurately identify the critical aspects of a domain and are to some extent prescriptive, allow stakeholders to identify improvement fields and initiate effective improvement initiatives. The identification of dimension tensions is

[155] Norman, Donald A. (2013).
[156] Maier, Moultrie, und Clarkson, „Assessing Organisational Capabilities“.
[157] Salah, Dina et al. (2014).

prescriptive in the way of setting an objective scope for improvement initiatives. MMs that are accurately descriptive or prescriptive have usually undergone several development iterations. The restricting factors in how far MMs evolve, are usually the available time and resources.

SLRs can provide a good starting point for first iterations of a model, but usually further research methods are required to guarantee a good degree of accuracy. They are extensively described in the validated development methods for MMs (Becker[158], De Bruin[159]). The SLR conducted in this MT identified five qualitatively high, usable and DU relevant MMs from which initial dimension definitions and an overall structure can be deduced. However, none of these were suited for effectively assessing DUIE maturity due to severe shortcomings in isolated aspects of the model. This confirms the need for the development of the MMACUDIE. Generally, the usefulness of MMs is dependent on the overall MM structure/design, the deployed assessment method, comprehensibility and relevance of its content to the assessed capability.

To ensure maturity assessments are a productive learning experience for assessment partners, they must not only clearly understand what is being assessed in each dimension, but they must also be able to take away insights from it. That is why a comprehensible visualisation of results should be provided and, given that the deployment method allows it, a discussion of the assessment results should take place. If the deployment method allows it, investigators should limit the included visualisations to those that are relevant during the presentation of the results.

Validation of a MM should be done through experts who are not stakeholders in the MM development after the assessment. Validation tools often contain both qualitative and quantitative measures that are captured through a questionnaire, which can be deployed both remotely or personally. Conducting CVs through a formalised document ensures consistency between validations.

Based on the insights of the SLR, expert interviews and personal experience, a range of requirements for the development of the MMACUDIE in this MT was formulated (Table 14: Requirements for MMACUDIE). These requirements will serve as a reference for the actual development phase.

[158] Becker, Jörg et al. (2009).

**Table 14: Requirements for MMACUDIE**

| Requirement | Description |
|---|---|
| I. Descriptive | Must at least assess the as-is-state “maturity” of an industrial enterprise regarding data utilisation. |
| II. Maintainable | Must be maintainable to enable updating it to the current state-of-the-art of data utilisation in industrial enterprises |
| III. Flexible | Must be flexible to allow an application to entire enterprises as well as abstract fractions of them |
| IV. Comprehensible | Must be easy to understand and apply |
| V. Consistent | Must deliver consistent results under similar application scenarios |
| VI. Constructive | Must provide feedback about the areas which are suitable for improvement efforts |
| VII. Objective | Rating of maturity must be fact rather than opinion based whenever possible |
| VIII. Adjuvant | Must be based on well-established techniques and insights of previous MMs to facilitate acceptance and application in enterprises |
| IX. Evolved | Must be developed to a stage where it can be field tested and evaluated |

# 4 Development of the MMACUDIE

The MMACUDIE was developed according to the phases formulated by De Bruin[160] under consideration of the guidelines for the design science approach defined by Becker et. al[161]. To visualise the development procedure and verify the fulfilment of the requirements stated by Becker et. al (see Table 2) a flow chart diagram (see Figure 10) was created.

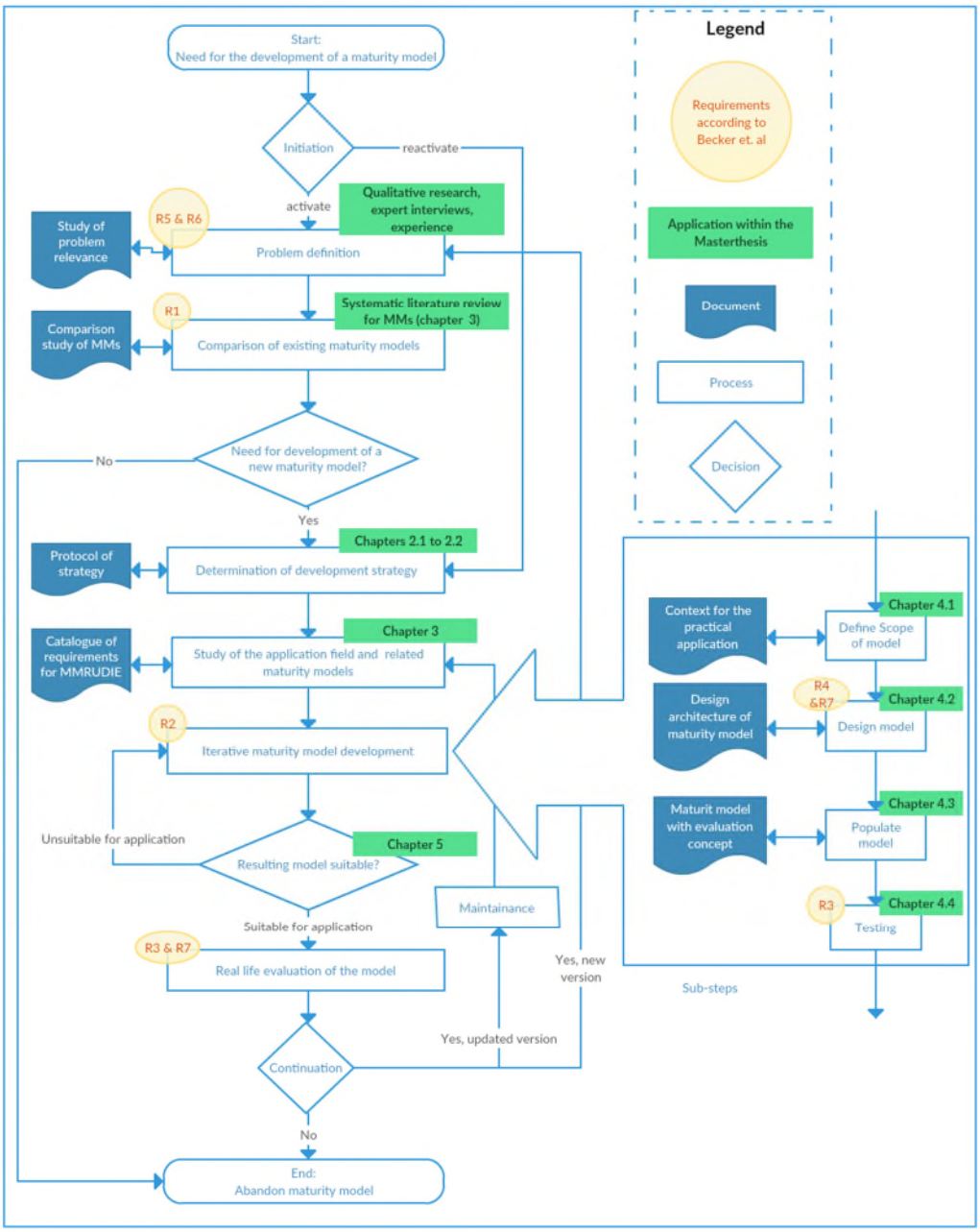


**Figure 10: Procedure Flow Chart for the development of the MMACUDIE**

[160] De Bruin, Tonia et al. (2005).
[161] Becker, Jörg et al. (2009).

The basis for the procedure flow chart is the original procedure flow chart diagram by Becker[162] and its adaption by Schumacher[163]. They were further adapted and improved upon to reflect the structure and development in the context of this MT.

## 4.1 MMACUDIE Scope definition

The scope supplies the context for the practical application of the MMACUDIE. Because the MMACUDIE has been designed as a tool to help organisations improve their capability for DU, it is likely to be deployed within the context of a formalised improvement initiative. Since the initiation and execution of such improvement efforts typically require considerable amounts of resources, it is unlikely that small businesses (number of employees <50)[164] will engage with MM assessments in the first place. This assumption has been confirmed by other MM authors, based on what type of companies were able to provide feedback for their models.[165,166]

Organisations for which an assessment through the MMACUDIE is reasonable are:

- Industrial enterprises
- Medium to large size (>50 employees)
- Formalising management systems
- Storing, managing and analysing data primarily in digital formats
- Planning to conduct improvement initiatives regarding DU

## 4.2 MMACUDIE design

The goal of the design phase is to develop an overall MM structure and maturity level definition approach, that provides a frame for the population phase. The MMACUDIE should be capable of assessing entities of varying complexity and structure within the boundaries of a single organisation that fits the scope defined in chapter 4.1. Reaching this goal is likely to require a multitude of iterations and its fulfilment will be judged, based on the validation process of the pilot testing phase in chapter 4.4.

### 4.2.1 MMACUIDE purpose

Considering the early evolution stage of the MMACUDIE, it is unlikely to be a perfect formalisation of the extremely complex processes, interdependencies and requirements of successful DUIE. However, the SLR and the development process

[162] Ibid.
[163] Schumacher, Andreas (2015).
[164] Loecher, Ulrich (2000).
[165] Näslund, Dag et al. (2014).
[166] Comuzzi, Marco and Patel, Anit (2016).

according to the design science approach provide a reliable and comprehendible basis for future iterations and improvements. Its primary purpose is to be as accurately descriptive as possible. However, the development of prescriptive implications has been an inevitable result due to the avoidance of vague level definitions.

The overall objective of the MMACUDIE is the identification of dimension tensions to provide starting points for improvement initiatives. Whether this general approach, as well as the specific level definitions and their respectively defined attributes, are an accurate depiction of reality, remains to be validated by experts, who can relate the model to practical knowledge and experience. Ambitions for evolving the MMACUDIE beyond being descriptive before this validation process is unlikely to yield any benefit and is not part of the objective for this MT.

### 4.2.2 MMACUDIE structure

In order to make complex information more accessible, it is usually broken down into layers of progressively less complex information. This is often referred to as “chunking down”. “Chunking is a simple technique… to vary the layer of detail of information you get from more abstract, down to more specific hierarchies of ideas.”[167] It is also possible to “chunk up” by progressively increasing the layer of abstraction. Because the abstraction layer on which assessment partners operate will vary, the structure needs to enable a flexible adaption of assessment, according to their layer of operation. This can be achieved by grouping dimensions according to their abstraction levels.

Business Process Management commonly defines three primary functional layers of abstraction that provide a framework into which the dimensions deduced from the SLR (see Table 13: Overview of common dimensions) can be categorised: strategy, tactics and operation.[168,169] On the strategic layer, the organisation wide requirements and policies are defined and formalised and the organisational goals are set. The tactical layer is focused on governing operational processes in such a way as to fulfil these strategic goals. Processes at the operational layers carry out the actions required to achieve the strategic goals and fulfil the tactical requirements.

By relating these abstraction levels back to the identified primary dimensions throughout MM literature (see point I9), equivalents for both the strategic and tactical layers can be identified, “strategy” and “governance” respectively. The operational layer can be related to both the process and the people dimensions. Because the object layer plays a dominant role throughout the DU literature, the decision was made

[167] Coachingleaders (2014).
[168] Von Rosing, Mark et al. (2014).
[169] Al-Mashari, Majed et al. (2003).

to include it as a fourth layer of abstraction into the structure of the MMACUDIE, rather than grouping it into the operational layer (see Figure 11).

According to Comuzzi et. al[170], this type of layered approach is appreciated by experts because it enables a layered application that reflects common structures of global enterprises, where tactical processes may be local, but strategies may be defined globally.

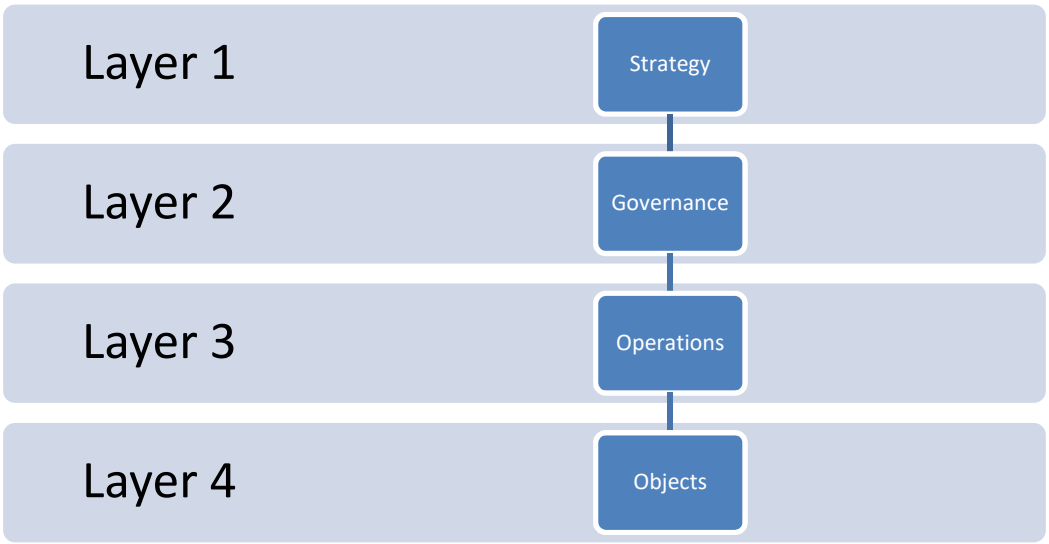


**Figure 11: Hierarchy of layers**

### 4.2.3 MMACUDIE analysis presentation method

The presentation of results provides the assessment partner with real learnings about the assessed entity. To make this a productive experience, presentation methods need to clearly communicate findings in an intuitive way. Seeing as the MMACUDIE's primary objective is identifying dimension tensions, a presentation method that clearly identifies the area and severity of these dimension tensions should be selected.

Spider-web-diagrams are a good fit for these requirements, because they provide an overview over a range of capabilities in a specific area, or layer, and allow an easy identification of outliers. The criticism sometimes expressed of radar charts (occlusion, confusion due to independent scales of axis, etc.)[171] was dismissed, because it isn't applicable in the application context of the MMACUDIE. In order to showcase dimension tensions, the diagrams should visualise both the most and the least mature sub-components of the visualised aspect.

[170] Comuzzi, Marco and Patel, Anit (2016).
[171] Scottlogic (2018).

## 4.3 MMACUDIE population

According to De Bruin et. al,[172] the mix of selected research methods for populating a model should be selected, based on previously made decisions and the desired model outcomes. That is why the population process of the MMACUDIE will be primarily based on the extensive SLR conducted in chapter 3 and pilot tests conducted in the context of personal assessments.

### 4.3.1 Maturity level definition

The SLR has shown that fixed maturity levels, typically ranging from 1 – 5, are most commonly used throughout the literature. However, "there are different categories of maturity levels. A model with fixed maturity levels has the weakness of expressing interdependencies between processes… (whereas) in contrast, flexible maturity models can be composed of more than five levels." [173] Because the development and population of the MMACUDIE is primarily based on the SLR, complying with this convention is reasonable and maturity will also be assessed via a Likert-scale ranging from 1 – 5. A generic level description (see Table 15: Generic maturity level description for the MMACUDIE) was deduced from the maturity level definition of the LESAT-tool[174]. Special care will have to be taken during the exact level definitions for each dimension, to ensure that levels are compatible with each other across dimensions and layers.

[172] De Bruin, Tonia et al. (2005).
[173] García-Mireles, G.A. et al. (2012), p. 281.
[174] Nightingale, Deborah J. and Mize, Joe H. (2002).

**Table 15: Generic maturity level description for the MMACUDIE**

| Level | Title | Description |
|---|---|---|
| Level 1 | Rudimentary | Attributes of the dimension are poorly developed and may be non-functional. Insufficient resources are designated to this dimension, rendering its Attributes largely ineffective. The dimension has little to no priority within the entity and no form of review process is in place. |
| Level 2 | Functional | Most attributes of the dimension are developed to the point of being functional but may be partially ineffective. Maintaining this sophistication level requires little designated resources and is usually the basis for enabling day to day operations. The dimension has a small priority within the entity and no structured review process is in place. |
| Level 3 | Commendable | Every attribute of the dimension is developed to the point of being effective. Maintaining this level of sophistication requires a reasonable amount of designated resources, common for the industry. The dimension is a priority within the entity and a structured review process may be inconsistently implemented. |
| Level 4 | Admirable | Every attribute of the dimension is highly developed, beyond the current industry standard and future oriented. Maintaining this level of sophistication requires substantial designated resources, uncommon for the industry. The dimension has high priority within the entity and attributes are periodically reviewed and continuously optimised. |
| Level 5 | Exceptional | Every attribute of the dimension is exceptionally well developed and at the forefront of innovation. Maintaining this level of sophistication requires exceptional amounts of designated resources that are rare in the industry. The dimension has an extremely high priority within the entity and attributes are periodically reviewed through formalised, standardised and continuously optimised improvement processes that utilise KPIs where they are beneficial. |

To enable an accurate and practical assessment via the MMACUDIE, a stage gate approach to level definition will be deployed. This requires every dimension level description to contain the maturity state of each of the attributes that define it. Lower maturity attributes are not necessarily contained in higher maturity levels and during classification of maturity, attributes should be based solely on the dimension description of that level. This level classification approach will increase the consistency of level classification between assessment partners and instances of assessment.

## 4.3.2 MMACUDIE dimensions and attributes

The four-layer structure of the MMACUDIE was populated on the basis of the dimensions that were identified as being common in chapter I9 (see Table 13:

Overview of common dimensions). These common dimensions were each assessed and grouped into one of the four layers strategy, governance, operations and objects. Once they had been grouped, level classifications were formulated for each dimension, based on the collective literature in which the respective dimension is contained. Through iterative review processes and two rounds of testing the model in real life assessment situations (see description of pilot test in chapter 4.4), the dimensions were further adapted to make them mutually exclusive and collectively exhaustive. This resulted in the four layers of the MMACUDIE containing a total of 23, evenly distributed dimensions. The fact that an even distribution of dimensions was achieved despite this not being an explicit goal during development, is an indicator for a good balance of included dimensions and supports the notion of equal importance of each dimension.

Each dimension is defined through its specific attributes, which can potentially be present in varying levels of maturity though different instances that are present in the entity (e.g. several pieces of test equipment that are integrated into the DU system chain varyingly well). Because an assessment through the MMACUDIE is meant to identify the weakest aspects of a DU system, these weakest instances of attributes define the overall maturity classification of that attribute.

The following paragraphs describe each of the dimensions and the respective attributes in detail. It should be noted that only MMs which defined explicit maturity levels for the mentioned dimensions were considered when defining specific level definitions for the MMACUDIE. During dimension and maturity level definition, the choice regarding the included amount of detail, the granularity, was made with De Bruin et. al's[175] advice in mind; picking a granularity that makes the MM both accessible and comprehensible.

Because review processes are a key part of the generic level classification (see Table 15), they are not specifically discussed here. They are part of the actual assessment though and are explicitly listed in the dimension level definitions and assessment form (see Annex 6.1).

[175] De Bruin, Tonia et al. (2005).

## L1. Strategy

**Information Quality (IQ) awareness:** Awareness of the importance of good IQ (quantity, topicality, continuity, compatibility and context) and understanding that a strategy is needed to ensure it. Awareness for negative IQ impacts can be as sophisticated as considering both the monetary impact (bad decision making) and the non-monetary impact (frustration of staff, legal liabilities etc.). An effective IQ strategy considers maintenance of IQ as well as prevention of bad IQ.

**Metadata awareness:** Degree to which the management is aware of the potential of metadata utilisation and agrees on how it should be part of the entity strategy. This requires having factual knowledge of what metadata is and how it can improve specific areas of the entity, rather than just an abstract understanding of the concept.

**DU awareness (Management):** Degree to which the management is aware of the potential of DU utilisation and agrees on how it should be part of the entity strategy. This requires having factual knowledge of DU application potential and relating it to specific areas of the entity, rather than an abstract understanding of the concept.

**DU policy:** Degree to which DU has been implemented into the entity strategy and resources are being allocated towards it. Explicitly formalising DU aspects in the entity strategy provides the basis for formalising assessable goals. Also, explicit rather than implicit resource allocation can ensure their effective use for DU through a documentation process.

**DU scope formalisation**: Extent and way in which the DU scope (tasks, application areas, etc.) is being formally defined and mapped to specific sub-divisions, processes, et cetera. Mapping of DU processes enables integrating them into process flows and facilitates implementing and monitoring DU incentives. Encouraging the staff who are executing DU can provide critical practical feedback for improvement opportunities.

**DU workflow integration:** Degree to which the integration of DU processes is being ensured. Reoccurring formalised integration analysis provides a means to initiate and document this process, as well as initiating and formalising improvement actions which can be reviewed for their effectiveness.

## L2. Governance

**DU task Ownership formalisation:** Sophistication of the process by which DU tasks are assigned to staff. Formalising the roles accountable for DU tasks and assigning these roles to individual staff members clearly defines responsibility and provides accountability. Once ownership roles have been formalised it is possible to automate the allocation process and optimise it on the basis of KPIs (workload, success rate, etc.)

**Data management:** Degree to which data policies (naming standards, privacy, security) are formalised and metadata enables tracing data streams. The more capable the people defining these policies are, the more effective they will be. Redundantly stored data can lead to information asymmetries and deviations from the single state of truth within the entity. Good data management is especially important for decentralised entities with an extensive locational spread, because they typically possess a diverse portfolio of historically grown data acquisition systems.

**Information management:** Degree to which the information scope is formalised, extent of what this formalisation includes and ability to trace information streams through metadata. The more capable the people defining these policies are, the more effective they will be. Poorly traceable information streams make data unreliable and can result in information asymmetry and staff basing their decisions on outdated or false information.

**Access to information:** Sophistication of the systems and methods by which information is made available to staff. Sophisticated systems enable remote access to information through a minimal number of interfaces that are easily and heavily customisable and only display relevant and authorised information to the user, based on their formalised roles. The staff's awareness of what information is available and where to find it is critical to successful DU task fulfilment.

**DU tool management:** Sophistication of system by which the available DU-tools are being optimised and made available to staff. The ability to easily gain access to and utilise tools that can more effectively fulfil a DU tasks, makes their execution more efficient. Because highly effective tools are typically costly, tracking their use and availability can optimise the acquisition and provision of licences to users.

**DU workflow formalisation:** Sophistication of the formalised DU workflows. The higher the degree of formalisation is (required tools, tasks, outcomes, etc.) the easier an automation of these tasks becomes.

## L3. Operations

**DU awareness (staff):** Degree to which staff members throughout the entity understand the implications and general potential of DU. The more DU awareness staff possess, the more likely they are to start being proactive in its utilisation and their acceptance of DU based changes.

**DU engagement:** Degree to which staff embrace DU as a part of their work and start being proactive about the initiation and definition of DU tasks. High levels of engagement will raise awareness and inspire engagement in other staff

**Analytical abilities:** Degree to which the collective of staff members are capable of drawing meaningful information (consistent, accurate, valuable) from data by analytical processes. This collective ability depends on how good of an understanding the staff have of the tasks they are carrying out and whether analytical skills and knowledge are widely or narrowly distributed throughout the entity, enabling or hindering analytical collaboration. Improving a lacking skillset within the entity is typically the managements' responsibility.

**DU workflow synergy:** Level of synergy displayed by DU workflows and avoidance of unnecessarily carrying out DU tasks (transformation of data, creation of KPIs etc.)

**Information Quality (IQ) assurance:** Sophistication of method by which bad IQ is being identified, documented, prevented and overcome. The more sophisticated these methods are, the more preventive they operate, identifying potential issues before they occur and engineering long term solutions that will effectively prevent these issues in the future

**Knowledge asset sharing:** Degree to which knowledge asset sharing is taking place as part of the entity culture and sophistication of methods or mechanisms that are deployed to enable it. Implementing explicit reward mechanisms for knowledge sharing can elevate its value amongst employees and increase the degree of knowledge sharing that is taking place.

## L4. Objects

**Compatibility of the DU System-chain:** Required resource intensity to enable data flow along the various tools/systems in the DU system chain. High compatibility of the data itself is distinguished through its ability to be handled by other systems without transformations of format or form and compatible systems enable barrier free data flow.

**Data collection & integration:** Sophistication of the methods by which data is collected and integrated into the warehousing architecture. Handling data in non-digital and non-automated processes increases the risk of error and limits the continuity of the data stream during data integration. Formalised integration structures enable the setting of an optimisation focus.

**Data warehousing architecture:** Sophistication of the architecture deployed for the data warehouse. Merged data storage systems enable cross functional reporting and can provide a single state of truth throughout the entity, whereas more fractured systems can result in information asymmetry throughout the entity.

**Metrics Capability:** Sophistication of the measurements in describing processes and performance. The more sophisticated metrics are, the more suitable they are as a basis for validating decisions. Sophisticated systems typically also utilise metadata and thereby expand the scope of potential optimisation processes.

**Analytical tools & services:** The sophistication of the DU analysis tools (hard- and software) and services (analysis, visualisation, etc.) involved in the DU process can enable or limit the potential scope and actual execution of DU tasks. Increasing degrees of sophistication display increasing levels of diagnostic and predictive abilities, independency from users and improvement suggestion autonomy.

Table 16 provides a model overview of how these dimensions are allocated to their respective layers

### 4.3.3 MMACUDIE structure overview

**Table 16: MMACUDIE overview**

| Domain | Utilisation of data in industrial enterprises | | | |
|---|---|---|---|---|
| **Layer** | **Strategy** | **Governance** | **Operations** | **Objects** |
| **Dimensions** | Information Quality (IQ) awareness | DU task Ownership formalisation | DU awareness (staff) | Compatibility of the DU System-chain |
| | Metadata awareness | Data management | DU engagement | Data collection & integration |
| | DU awareness (Management) | Information management | Analytical abilities | Data warehousing architecture |
| | DU policy | Access to information | DU workflow synergy | Metrics Capability |
| | DU scope formalisation | DU tool management | Information Quality (IQ) assurance | Analytical tools & services |
| | DU workflow integration | DU workflow formalisation | Knowledge asset sharing | |

## 4.3.4 MMACUDIE application guidelines

Assessments through the MMACUDIE at the current evolution stage are likely to be more productive in a personal interview context, because it provides the necessary flexibility for the assessment partner to ask questions and the investigator to clarify issues. To enable a methodological documentation of this assessment process, an assessment sheet was developed (see Figure 12), in which the entire model, including layers, dimensions and attributes are listed. An “IA” box is provided to enable assessment partners to document their intuitive dimension maturity classification and see how it compares to the actual assessment (see Annex 6.1 Assessment sheets).

| **Utilisation of data in industrial enterprises** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Strategy*** | IA | AA | ***Governance*** | IA | AA | ***Operations*** | IA | AA | ***Objects*** | IA | AA |
| **Information Qualitiy (IQ) awareness** | | | **DU task Ownership formalisation** | | | **DU awareness (staff)** | | | **Compatability of the DU System-chain** | | |
| IQ impact awareness | | | Formalisation of DU task ownership | | | Embracement of DU by staff | | | Resources for overcomeing sub- system-bundaries | | |
| IQ maintainance and improvement requirement | | | Ownership allocation process | | | | | | Review of DU-system- compatability | | |
| | | | Review of ownership roles | | | | | | | | |
| **Metadata awareness** | | | **Data management** | | | **DU engagement** | | | **Data collection & integration** | | |
| Awareness for metadata potential | | | Formalisation of data policies | | | DU task proactivity | | | Collection sophistication | | |
| Metadata utilisation strategy | | | Data redundancy | | | DU focused change initiation | | | Integration sophistication | | |
| Review of metadata strategy | | | Review of data policies | | | Review of DU triggered changes | | | Integration structure formalisation | | |
| | | | | | | | | | Review of all data collection & integration processes | | |
| **DU awareness (Management)** | | | **Information management** | | | **Analytical abilities** | | | **Data warehousing architecture** | | |
| Embracement of DU by the management | | | Information scope formalisation process | | | Understanding of Analytical processes | | | Sophistication of data warehousing acrchitecture | | |
| Consideration of DU in entity strategy | | | Extent of formalised information scope | | | Consistancy of results | | | Review of the data warehousing architecture | | |
| Review of DU aspects in entity strategy | | | Review of information management system | | | Distribution of analytical capabilities | | | | | |
| | | | | | | Collaboration potential | | | | | |
| | | | | | | Ability improvement initiation | | | | | |
| **DU policy** | | | **Access to information** | | | **DU workflow synergy** | | | **Metrics Capability** | | |
| DU strategy formalisation | | | Remote access of information | | | Synergy level | | | Process performance | | |
| Resource commitment to DU | | | Access system sophistication | | | | | | Capability for validating decisions | | |
| | | | Access privilidges management | | | | | | Metadata collection and c | | |
| | | | Information access awareness | | | | | | | | |
| | | | Review of information access policy | | | | | | | | |
| **DU scope formalisation** | | | **DU tool management** | | | **Information Quality (IQ) assurance** | | | **Analytical tools & services** | | |
| DU scope formalisation process | | | Identification and implementation of tools | | | IQ issue identification | | | Effectiveness | | |
| Mapping of DU Processes | | | Tracking of users and tool portfolio | | | IQ issue documentation | | | Analytical scope | | |
| Encouragement of staff improvement input | | | Ease of tool access and expansion | | | IQ issue prevention | | | Predictive capability | | |
| Review of DU scope | | | Review of tool tool portfolio | | | | | | Tool usefuless independancy from user | | |
| | | | | | | | | | Formalisation of service requirements | | |
| | | | | | | | | | Review of tools and services | | |
| **DU workflow integration** | | | **DU workflow formalisation** | | | **Knowledge asset sharing** | | | | | |
| Integration analysis | | | Formalisation of DU Workflows | | | Culture | | | | | |
| Improvement actions formalisation | | | Decision making automation capability | | | Knowledge sharing mechanisms | | | | | |
| Review of integration levels and actions | | | Review of DU workflows | | | Reward mechanisms for knowledge sharing | | | | | |
| | | | | | | Review of knowledge sharing mechanisms | | | | | |

**Figure 12: MMACUDIE assessment sheet**

## 4.4 MMACUDIE testing

After populating a model, it needs to be for relevance and rigor. The testing should establish the validity, reliability and generalisability of both the structure and actual content of the model.[176] The MMACUDIE was tested in a pilot test in a local Viennese IE. The testing resulted in three iterations of the model, each integrating the feedback that was provided in its preceding test assessment. The focus of the pilot test was to iterate the MMACUDIE to the point of being functional and widely deployable, so assessments across different types of IEs and with different assessment partners would be possible for further improvement of the model. To enable assessments through investigators, who were not involved in the development process of the MMACUDIE, to carry out effective assessments, an assessment method was developed.

### 4.4.1 Assessment method development

This assessment method was developed specifically with a focus on how to conduct assessments in a personal interview context between an investigator and one, or potentially several, assessment partners. It includes considerations for briefing and providing anonymity for the assessment partners, as well as enabling flexible adaption of the assessment scope. According to Ofner,[177] maintaining flexibility in the assessment scope ability is important for adapting the assessment to the knowledge of the assessment partners.

Based on the experience of the pilot-tests, explicit assessment guidelines (see Table 17: Guidelines for applying the MMACUDIE in personal interviews) were developed to supply investigators with an assessment structure that has proven to provide a productive assessment experience for both the assessment partner and the investigator. These guidelines should be followed in chronological order from 1 to 11. The column “helpful documentation” refers to Handouts that are provided to assessment partners (see Annex 6.1)

[176] Ibid.
[177] Ofner, Martin et al. (2013).

**Table 17: Guidelines for applying the MMACUDIE in personal interviews**

| Nr. | Guideline | Description | Helpful Documentation |
|---|---|---|---|
| 1 | Purpose explanation | Explaining the basics of MMs and the purpose of the MMACUDIE specifically to the assessment partner:<br>The MMACUDIEs purpose is to identify improvement areas regarding the utilisation of data in industrial enterprises. It seeks to identify less evolved dimensions in an otherwise more evolved system to reveal existing dimension tensions and thereby provide effective starting points for improvement initiatives. | n/a |
| 2 | Discussing and ensuring anonymity | Participants and organisations partaking in the assessment may wish to remain anonymous. The wish for anonymity should be discussed prior to assessment. Should the participants wish to remain anonymous, alternative names should be provided. These should remain comprehensible to the investigator, but incomprehensible to others. | n/a |

| | | | |
|---|---|---|---|
| 3 | Model structure explanation | Explanation of the overall model structure to give assessment partners a better understanding of what is being assessed through each layer:<br>The MMACUDIE is designed for examining an industrial enterprises capability for utilising data. It was specifically designed for industrial enterprises producing physical goods. The MMACUDIE can be applied to entire organisations or abstract fractions of these. Setting the scope for what defines this so-called entity is part of the application process described in guideline Nr. 5.<br>The model structure is divided up into 4 different layers, each of which is described through a set of dimensions which are defined further by their specific attributes. The dimensions of the MMACUDIE are mutually exclusive and collectively exhaustive in describing the capability for data utilisation (DU) in industrial enterprises. Each layer (Strategy, Governance, Operations, Object) provides a description of the entity on a different level of abstraction. | • Model overview<br>• Assessment sheet |
| 4 | Maturity Level classification | Explanation of the concept of maturity and the definition of maturity levels:<br>Maturity levels represent a measurement of sophistication, the evolutionary path of which is typically dictated through the changing stages. In the MMACUDIE maturity levels are classed through discrete whole numbers between 1 - 5, 5 representing the most evolved, 1 representing the least evolved degree of maturity. The maturity level classification for individual dimensions is defined through that dimensions least mature attribute. The MMACUDIE seeks to identify the least mature instance of any attribute in the entity, because it seeks to identify weaknesses, not strengths. To ensure this, assessment partners should begin the assessment of each dimension by first identifying the weakest instance of each attribute. | • Generic Level Definition<br>• Assessment sheet |

| | | | |
|---|---|---|---|
| 5 | Scope definition | To enable flexible adaptations of the assessment scope, an explanation of each layer content should be sketched out to the assessment partner, prior to the assessment. Following this, the scope for the assessment should be agreed upon between the investigator and the assessment partner, during which irrelevant layers should be excluded from assessment. Great care should be taken not to exclude layers just because entities may achieve low maturity scores in those layers. Although "it is difficult to identify which process area is an obvious candidate for being ignored."[178] Valid exclusion criteria are a lack of knowledge or insignificant relevance to the entity | |
| 6 | Assessment methodology | For each of the four layers, the individual dimensions' maturity levels are assessed one by one. First, the scope of the currently assessed dimension is generally explained through the descriptions listed on the dimension sheets and attributes that make up that dimension. The assessment partner then intuitively rates the overall dimension according to the generic maturity level definition from 1 - 5 and documents this on the assessment handout (IA). Then the assessment partner checks if attributes of the intuitively chosen maturity level fulfil the definition of that level (lowest instance of attribute) with the help of the dimension sheets. If the assessment partners feel like an attribute should be classed in a higher or lower maturity, the respective level definition for that attribute should be examined. The assessment partner should communicate his reasoning to the investigator and ask for any clarifications in case these are necessary. The "definition of terms" (see Annex 6.1) document may be helpful in clarifying uncertainties. Every attribute should be | • Model overview<br>• Generic level definition<br>• Assessment sheet<br>• Dimension description<br>• Definition of terms |

[178] Michael Rosemann and Tonia De Bruin (2005).

| | | | |
|---|---|---|---|
| | | classified before moving on to the next dimension. | |
| 7 | Maturity classification agreement | The investigator validates the assessment partner's classification, based on what he or she has communicated. The investigator and assessment partner must agree upon a maturity classification, before it is officially documented. | • Assessment<br>• Dimensions |
| 8 | Documentation | Once a classification has been agreed upon, it should be documented digitally in the Assessment tool through the investigator, as well as on the physical handout of the assessment for redundancy and assessment partner engagement. | • Assessment |
| 9 | Processing of assessment | Processing of the assessment takes place through the investigator and includes the identification of dimension tensions and visualisation through spider-web charts or other meaningful presentation tools. | n/a |
| 10 | Presentation of assessment results | The results of the maturity assessment should be presented to the investigation partner, who should be supplied with copies of the assessment in both physical and digital form. The presentation of results should include any meaningful insights that the investigator was able to draw from the assessment and describe what the insights of the assessment state about the entities capability to utilise data. | n/a |
| 11 | Validation of model | Feedback should be collected from the assessment partner to continue the iterative improvement and development process of the MMACUDIE. In order to make this feedback comparable, the formalised validation sheet should be used. In case assessment partners wish to provide feedback that does not fit the form or content of the validation sheet, it should also be recorded and reviewed for implementation into the validation sheet. | • Validation |

## 4.4.2 MMACUDIE validation

Feedback forms are an advantageous way to collect feedback, because they standardise the received feedback, making it comparable, and are suitable for both personal and remote assessments. Also, "using a previously validated and published questionnaire will save time and resources."[179] That is why the validation of the MMACUDIE will be conducted through a SLR based, standardised feedback form, which is an adaption from the one formalised by Salah et. al,[180].

The validation form contains questions asking the assessment partner to rate the key requirements (completeness, relevance, comprehensiveness and ease of use[181]) from "strongly disagree" to "strongly agree" in a five-point Likert scale (see Table 18). Reallocating the answers to numbers between 1 – 5, enables a limited degree of quantitative analysis of the MMACUDIE validations over time and makes the effects of iterations to the model tangible.

Because the assessment of the MMACUDIE is based on the human interaction with the model, qualitative feedback is likely to provide a deeper understanding of improvement potential for the MMACUDIE than a purely quantitative approach.[182] That is why a set of qualitative questions asking for improvement suggestions is included in the validation form (see Table 19).

**Table 18: Quantitative validation form**

| **Criteria** | Strongly Disagree | Slightly Disagree | Neutral | Slightly Agree | Strongly Agree | **Comments** |
|---|---|---|---|---|---|---|
| **Maturity Levels** | | | | | | |
| The maturity levels are sufficient to represent, all maturation stages of the domain (Sufficiency) | | | | | | |
| There is no overlap detected between descriptions of level maturity (Accuracy) | | | | | | |
| **Layers and dimensions** | | | | | | |
| Layers and dimensions are relevant to the domain (Relevance) | | | | | | |

[179] Boynton, Petra M and Greenhalgh, Trisha (2004), p. 1313.
[180] Salah, Dina et al. (2014).
[181] De Bruin, Tonia et al. (2005).
[182] Creswell, John W. (2014).

| | | | | | | |
|---|---|---|---|---|---|---|
| The layers and dimensions cover all aspects impacting/ involved in the domain (Comprehensiveness) | | | | | | |
| The layers and dimensions are clearly distinct (Mutual Exclusion) | | | | | | |
| The level classification for the dimensions are correctly assigned to their respective maturity level (Accuracy) | | | | | | |
| **Maturity model** | | | | | | |
| ***Comprehensiveness*** | | | | | | |
| The maturity levels are understandable | | | | | | |
| The assessment guidelines are understandable | | | | | | |
| The documentation process is understandable | | | | | | |
| ***Ease of Use*** | | | | | | |
| The maturity classification scheme is easy to use | | | | | | |
| The assessment guidelines are easy to use | | | | | | |
| The documentation process is easy to use | | | | | | |
| ***Usefulness and Practicality*** | | | | | | |
| The MMACUDIE is useful for conducting maturity assessments | | | | | | |
| The MMACUDIE is practical for use in industry | | | | | | |

**Table 19: Qualitative validation form**

| Question | Answer |
|---|---|
| Q1. Would you add any maturity levels? Please explain what and why? | |
| Q2. Would you update the maturity level description? Please explain what and why? | |
| Q3. Would you remove any of the layers? Please explain which and why? | |
| Q4. Would you remove any of the dimensions? Please explain which and why? | |
| Q5. Would you redefine/update any of the layers? Please explain what and why? | |
| Q6. Would you suggest any updates or improvements related to the classification? Please explain what and why? | |
| Q7. Would you suggest any updates or improvement related to the assessment? Please explain what and why? | |
| Q8. Would you like to elaborate on any of your answers? | |
| Q9. Could the model be made more useful? How? | |
| Q10. Could the model be made more practical? How? | |

### 4.4.3 Scope of the pilot test

The pilot testing was conducted in collaboration with a mid-sized Viennese industrial production service provider with ~200 employees. The production site was merged into a global enterprise approximately 15 years ago, which has resulted in the co-existence of historically grown and newly implemented structures. The structure of the site is divided up into separate Workcells, which are each responsible for the manufacturing processes of different products but share common structures such as data management systems.

Two assessment partners were available for the conduction of the pilot test. These were:

1. The Technical Lead of a Workcell (CK), who has been heavily engaged in conducting DU and is responsible for ~8 employees who are also engaged in DU.
2. The Workcell manager (US) for that same Workcell, who is responsible for ~30 employees

Overall, three practical assessments were carried out over the course of the pilot test of the MMACUDIE, all of which assessed the same scope (production department of

the Workcell). The assessment took place in the context of a personal interview between the investigator and a single assessment partner. The only tools used to carry out the assessment, were the assessment sheets (see Annex 6.1) and the formalised guidelines (see Table 17).

The initial iteration of the model was tested with CK after the completion of its theoretical formalisation. This revealed severe shortcomings in clarity and separation of dimensions and gave some insights about how the assessment process of the assessment might be improved upon. It was not completed, because some definitions were too unspecific, and an assessment would have provided little benefit. Based on the feedback, a second iteration of the model was devised, which focused on separating dimensions that were unclear in the first iteration.

The second iteration proved to be much more practically applicable and dimensions were easier to differentiate from each other, making the scope of each dimension clearer. Although some dimensions were still identified as not being specific and separated enough from others, the assessment could be largely completed for the defined scope.

This led to a third iteration of the model, in which unspecific dimensions were further separated and their attributes partially reallocated to other dimensions. Any newly defined dimensions, as well as any previously assessed dimensions which were affected by this reiteration were reassessed after the completion of the third iteration. The following dimensions were excluded from the assessment scope:

**Strategy - DU scope formalisation** dimension because assessment partner was unable to rate it separately from DU policy. Entity is ISO 9001 certified, which does not differentiate between scope formalisation and policy.

***Objects – Data warehousing architecture*** dimension because assessment partner was unable to provide reliable information

***DU tool management – "tracking of users and tool portfolio" & "review of tool portfolio"*** attributes because assessment partner was unable to provide reliable information. DU tool management was still included in assessment because one of the other attributes was classed at level 1, which automatically classed the entire dimension at level 1.

For the final assessment, a "chunking down" approach was chosen for guiding the assessment partner through the MMACUDIE assessment. This progression towards less abstract views of operation from the assessment partners usual more abstract view proved to be effective at making the overall structure and process comprehensible and accessible.

## 4.4.4 Results of pilot test

The results of the pilot test were documented in the assessment sheet (Figure 13: Assessment sheet pilot test) according to the assessment guidelines.

*Date: 05.Sep.2018 & 06.Sep.2018*
*Name (Optional): US*
*Position: Workcell Manager*
*Contact Information: n/a*
*Entity: definition: Production department*

**Utilisation of data in industrial enterprises**

| *Strategy* | IA | AA | *Governance* | IA | AA | *Operations* | IA | AA | *Objects* | IA | AA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Information Quality (IQ) awareness** | **2** | **2** | **DU task Ownership formalisation** | **3** | **3** | **DU awareness (staff)** | **2** | **3** | **Compatability of the DU System-chain** | **1** | **1** |
| IQ impact awareness | | 2 | Formalisation of DU task ownership | | 3 | Embracement of DU by staff | | 3 | Resources for overcomeing sub-system-bundaries | | 1 |
| IQ maintainance and improvement requirement | | 2 | Ownership allocation process | | 3 | | | | Review of DU-system- compatability | | 1 |
| | | | Review of ownership roles | | 4 | | | | | | |
| **Metadata awareness** | **1** | **1** | **Data management** | **2** | **1** | **DU engagement** | **3** | **2** | **Data collection & integration** | **2** | **2** |
| Awareness for metadata potential | | 2 | Formalisation of data policies | | 3 | DU task proactivity | | 2 | Collection sophistication | | 3 |
| Metadata utilisation strategy | | 1 | Data redundancy | | 1 | DU focused change initiation | | 3 | Integration sophistication | | 2 |
| Review of metadata strategy | | 1 | Review of data policies | | 1 | Review of DU triggered changes | | 3 | Integration structure formalisation | | 2 |
| | | | | | | | | | Review of all data collection & integration processes | | 4 |
| **DU awareness (Management)** | **3** | **3** | **Information management** | **2** | **2** | **Analytical abilities** | **3** | **3** | **Data warehousing architecture** | **n/a** | **n/a** |
| Embracement of DU by the management | | 3 | Information scope formalisation process | | 4 | Understanding of Analytical processes | | 3 | Sophistication of data warehousing acrchitecture | | n/a |
| Consideration of DU in entity strategy | | 3 | Extent of formalised information scope | | 2 | Consistancy of results | | 3 | Review of the data warehousing architecture | | n/a |
| Review of DU aspects in entity strategy | | 4 | Review of information management system | | 4 | Distribution of analytical capabilities | | 3 | | | |
| | | | | | | Collaboration potential | | 3 | | | |
| | | | | | | Ability improvement initiation | | 3 | | | |
| **DU policy** | **2** | **2** | **Access to information** | **2** | **2** | **DU workflow synergy** | **1** | **1** | **Metrics Capability** | **4** | **3** |
| DU strategy formalisation | | 3 | Remote access of information | | 2 | Synergy level | | 1 | Process performance | | 3 |
| Resource commitment to DU | | 2 | Access system sophistication | | 2 | | | | Capability for validating decisions | | 3 |
| | | | Access privilidges management | | 2 | | | | Metadata collection and c | | 3 |
| | | | Information access awareness | | 2 | | | | | | |
| | | | Review of information access policy | | 2 | | | | | | |
| **DU scope formalisation** | **n/a** | **n/a** | **DU tool management** | **2** | **1** | **Information Quality (IQ) assurance** | **1** | **1** | **Analytical tools & services** | **2** | **2** |
| DU scope formalisation process | | n/a | Identification and implementation of tools | | 3 | IQ issue identification | | 1 | Effectiveness | | 2 |
| Mapping of DU Processes | | n/a | Tracking of users and tool portfolio | | n/a | IQ issue documentation | | 2 | Analytical scope | | 2 |
| Encouragement of staff improvement input | | n/a | Ease of tool access and expansion | | 1 | IQ issue prevention | | 2 | Predictive capability | | 2 |
| Review of DU scope | | n/a | Review of tool tool portfolio | | n/a | | | | Tool usefuless independancy from user | | 2 |
| | | | | | | | | | Formalisation of service requirements | | 2 |
| | | | | | | | | | Review of tools and services | | 2 |
| **DU workflow integration** | **1** | **1** | **DU workflow formalisation** | **1** | **1** | **Knowledge asset sharing** | **3** | **2** | | | |
| Integration analysis | | 1 | Formalisation of DU Workflows | | 1 | Culture | | 3 | | | |
| Improvement actions formalisation | | 1 | Decision making automation capability | | 1 | Knowledge sharing mechanisms | | 2 | | | |
| Review of integration levels and actions | | 1 | Review of DU workflows | | 1 | Reward mechanisms for knowledge sharing | | 2 | | | |
| | | | | | | Review of knowledge sharing mechanisms | | 2 | | | |

**Figure 13: Assessment sheet pilot test**

The processing of the MMACUDIE assessment showed that two primary relevant information layers could be analysed through the pilot test.

The first assessable information layer was the deviation of the intuitive maturity assessment (IA) from actual maturity assessment (AA). This deviation is a good indicator of the awareness of what constitutes maturity for a respective attribute and dimension. Small degrees of deviation are likely to result in higher acceptance of the insights gained from the MMACUDIE assessments. This assumption is made, based on the fact that people are generally more willing to accept descriptions of reality that they themselves perceive to be true.

These deviations, which were determined through the second and third assessment with US, are visualised in the following figures (Figure 14 to Figure 17). Overall, a small degree of deviation (maximum of 1 level difference) was observed, which suggests that the assessment partner was able to gauge maturity of individual dimensions well and could explain the high acceptance of the MMACUDIE findings.

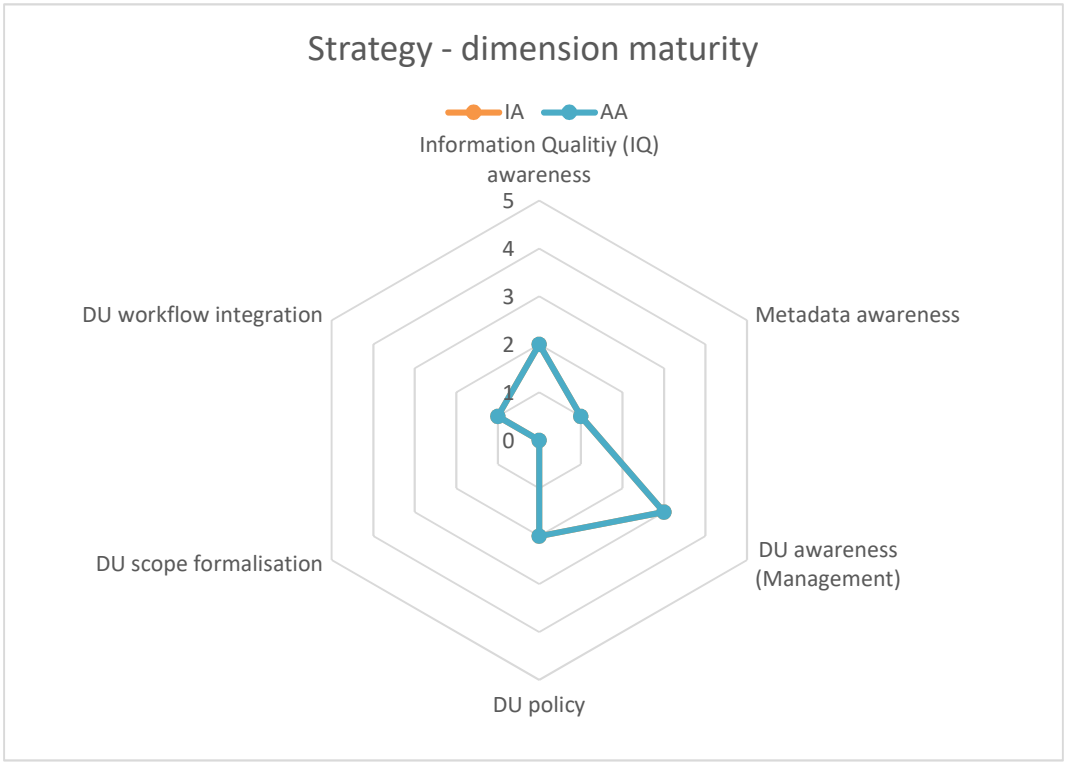


**Figure 14: IA vs. AA for Strategy dimension**

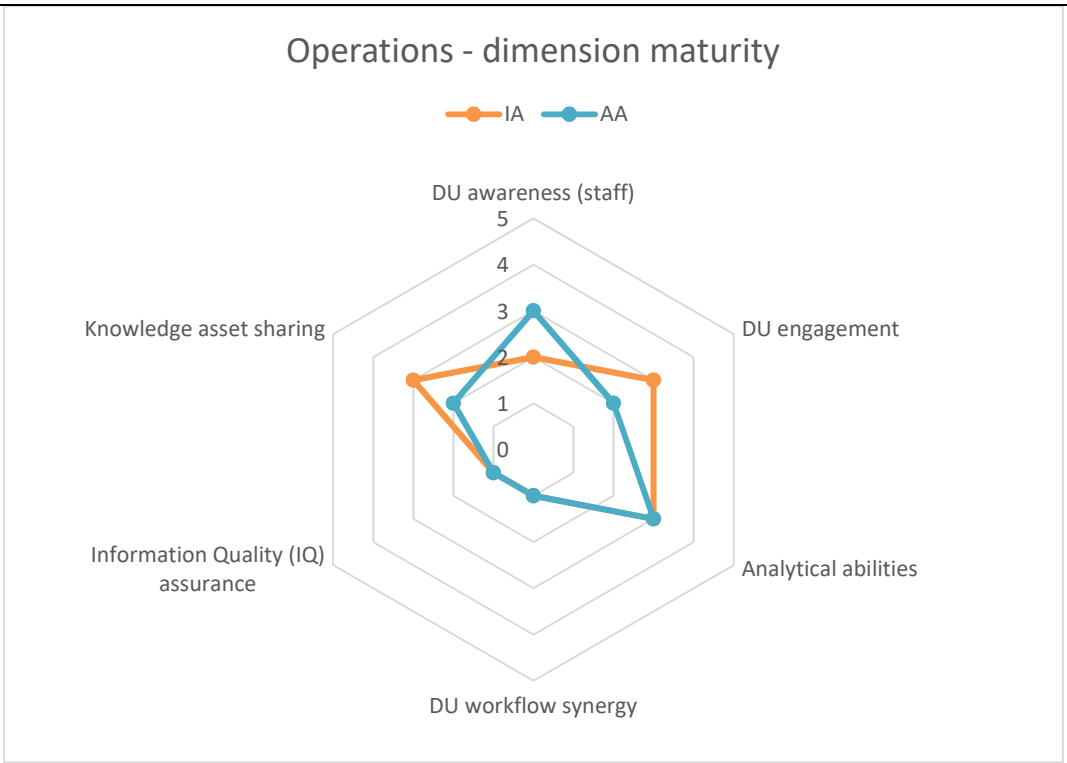


**Figure 15: IA vs. AA for Operations dimension**

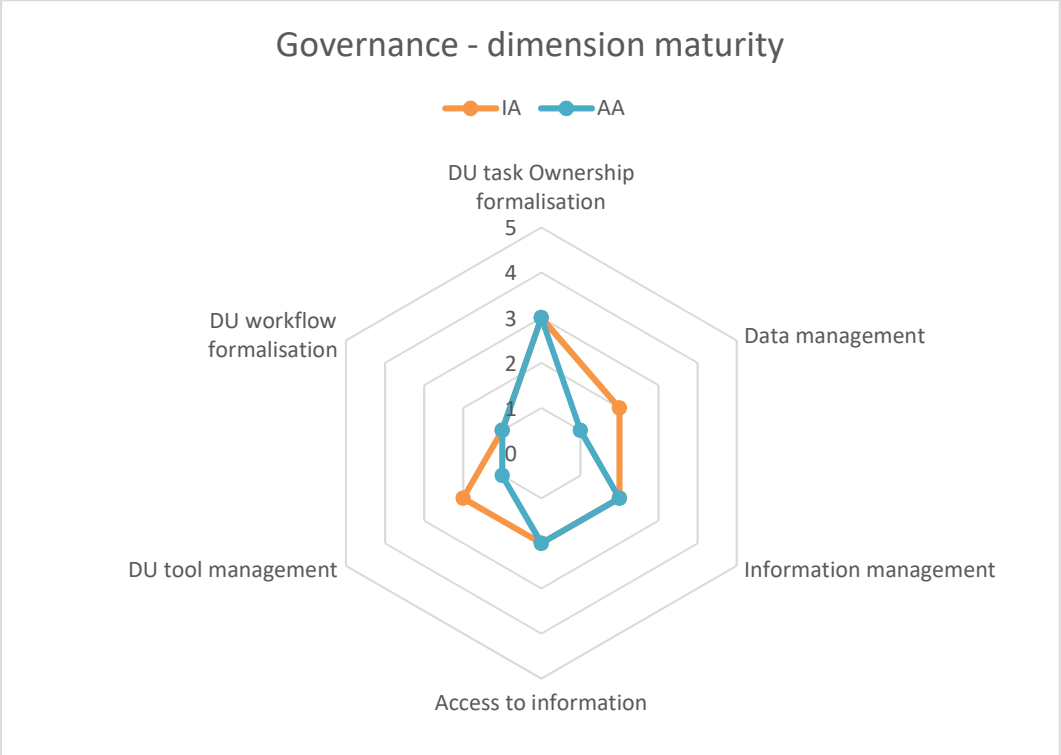


**Figure 16: IA vs. AA for Governance dimension**

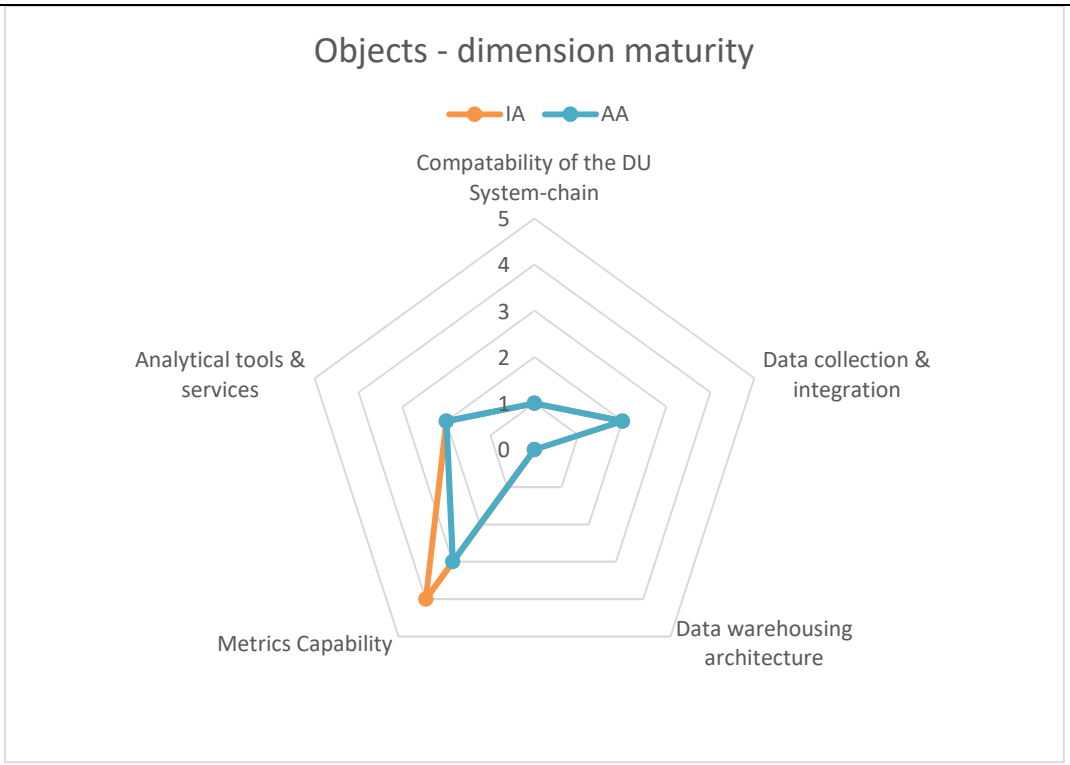


**Figure 17: IA vs. AA for Objects dimension**

The second assessable information layer was the identification of dimension tensions. The utilisation of radar charts proved to be especially well suited for this purpose, because larger tensions display larger deviations in shape and homogenously mature sub-components coincide and occlude each other.

Strikingly, each layer contains the same dimension tension between the most and least mature dimensions contained in that layer, achieving a maturity of 3 and 1 respectively (see Figure 18).

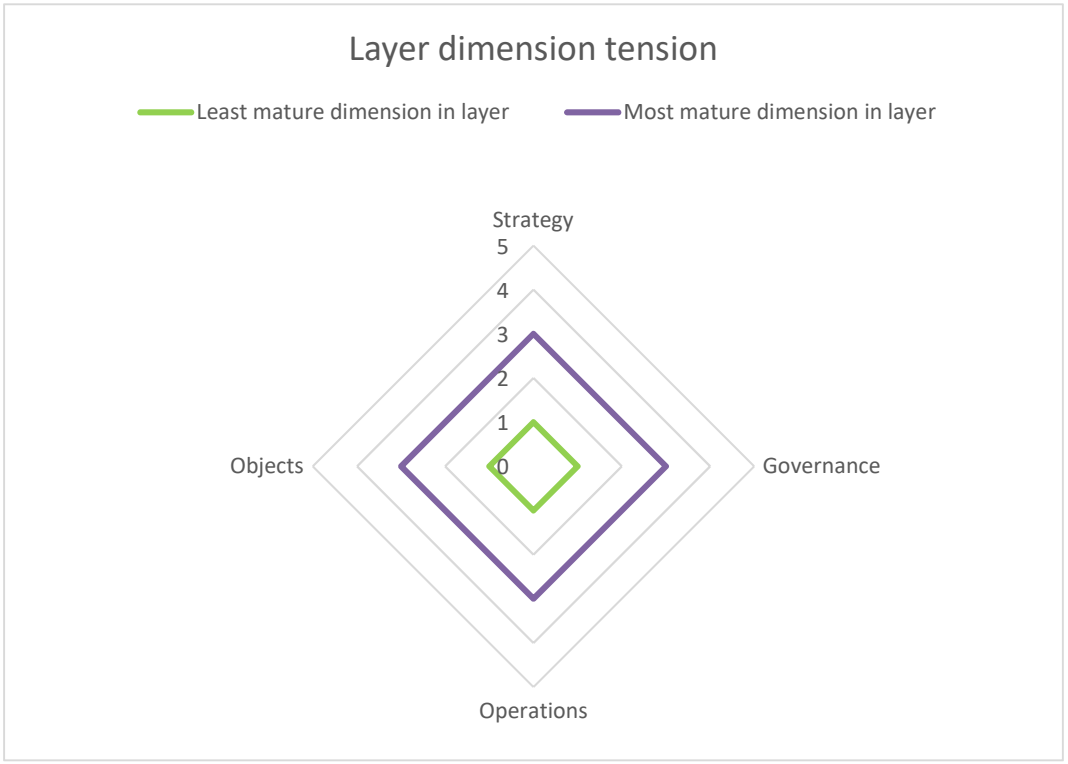


**Figure 18: Layers dimension tension**

However, each layer displayed varying degrees of tension between the various attributes making up each dimension (see Figure 19 to Figure 22).

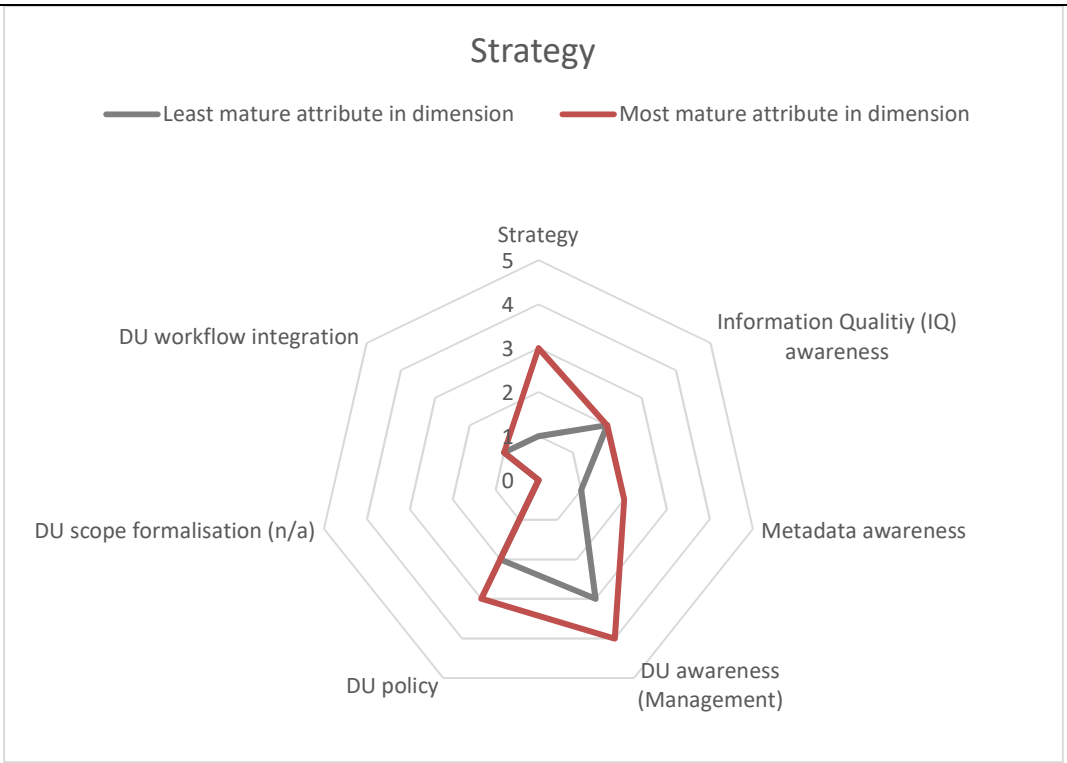


**Figure 19: Strategy dimension tensions**

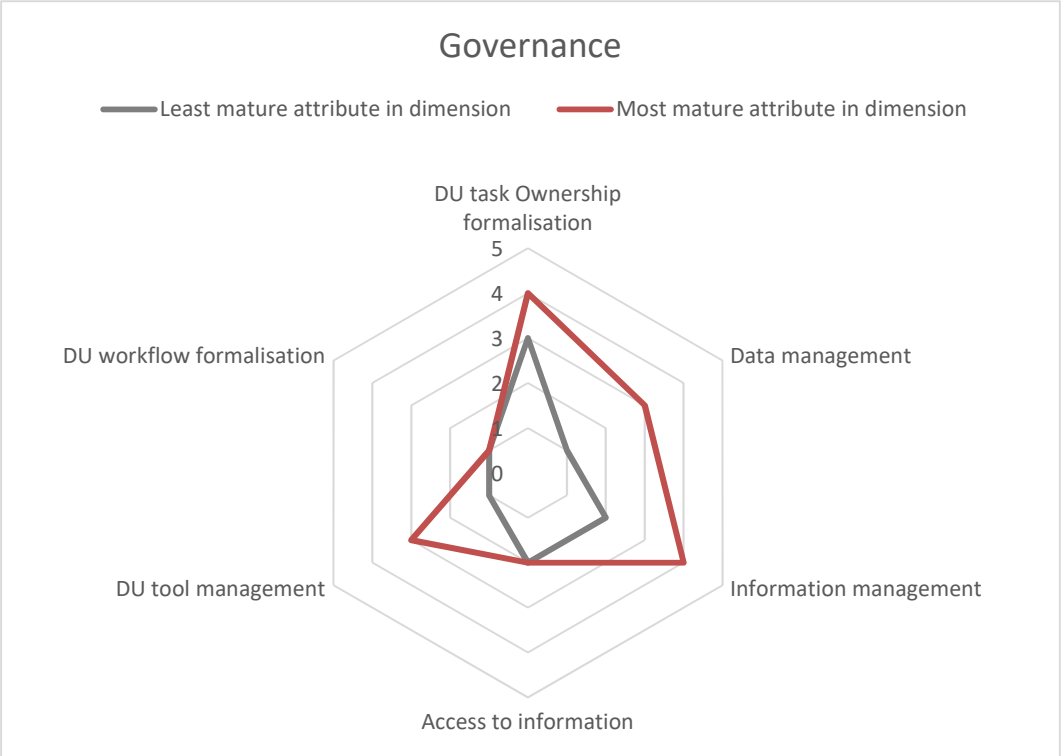


**Figure 20: Governance dimension tensions**

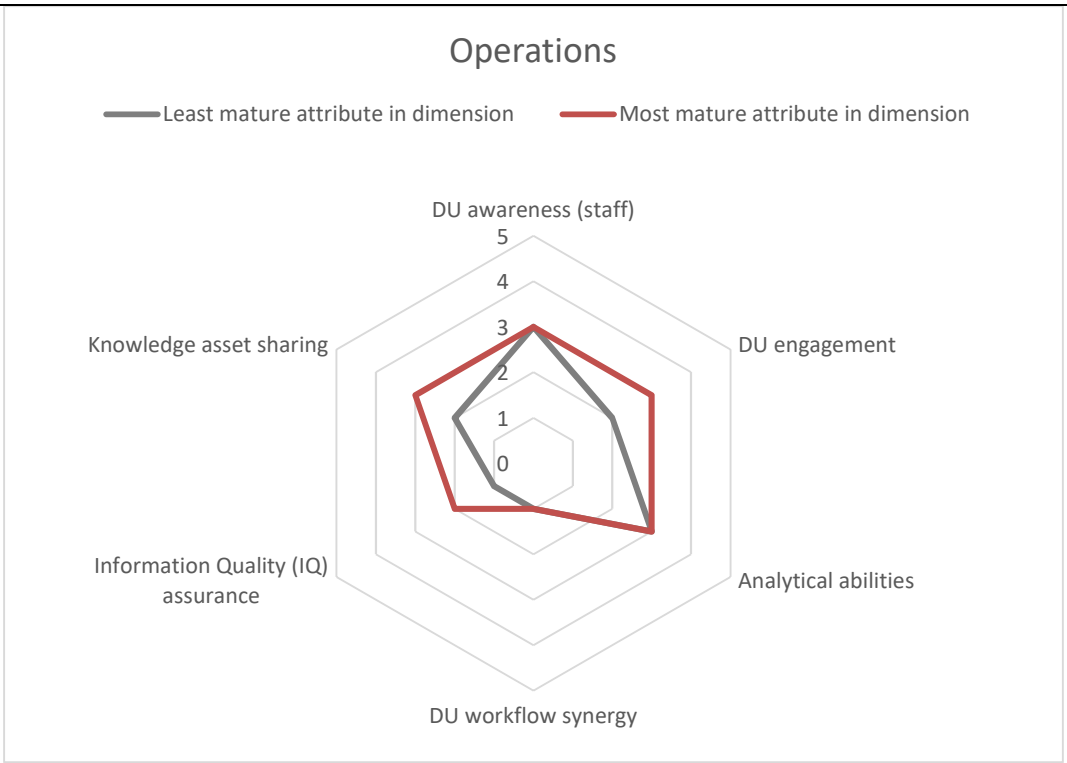


**Figure 21: Operations dimension tensions**

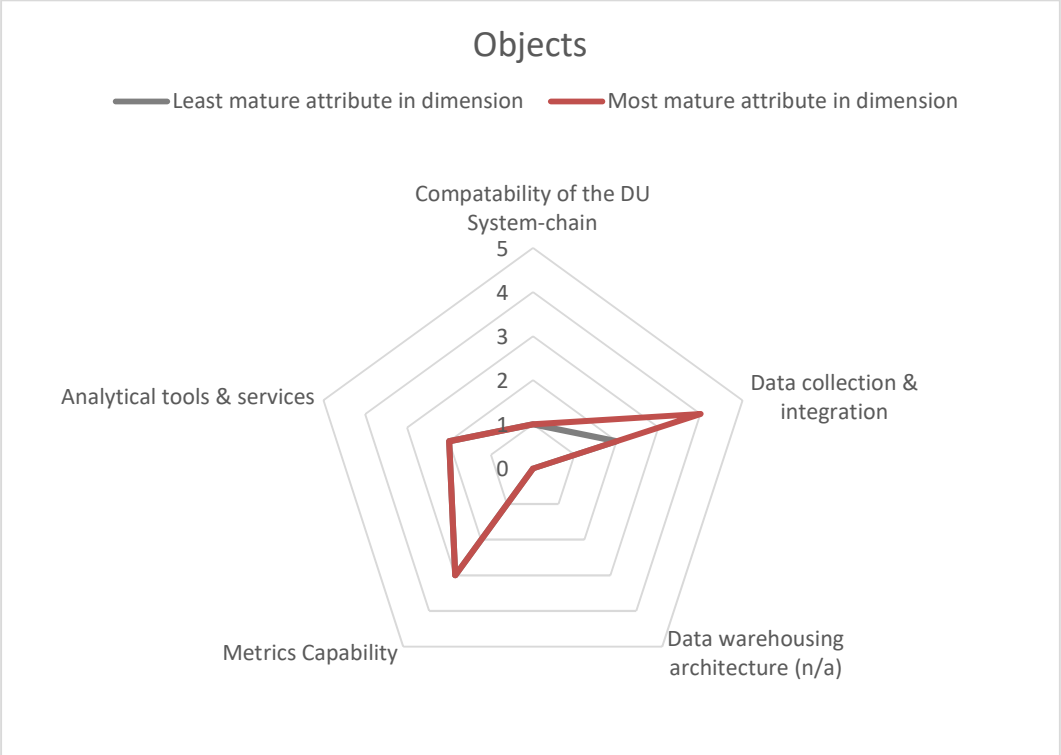


**Figure 22: Objects dimension tensions**

Out of all 4 layers, the governance layer was assessed to contain the least uniform attribute maturity, with 50% of dimensions displaying attribute maturity deviations of 2. The reasons for this, are the high degree of formalisation and the review processes that are dictated through the global structure of the overall enterprise and the lacking sophistication of what these formalisations include on a local level.

Noticeably, 8 out of the total 23 (35%) dimensions only reach a maturity level of 1. With level 1 representing a barely functional maturity level, the attributes leading to this classification level thereby substantially inhibit the organisations ability to be functional in their DU processes. Apart from decreasing the dimension tensions, especially on the governance layer, raising these inhibitive attributes to an at least functional level of 2 or more should be part of any future DU improvement initiative for the assessed entity.

### 4.4.5 Pilot test validation result

As the changes made from the first to the current iteration of the model were quite dramatic, they are difficult to compare with each other. Most of the given feedback and improvement suggestions received for earlier iterations of the model are difficult to relate to its current state and were already considered during the redevelopment of earlier iterations.

That is why only the validation results of the third and last iteration are presented and discussed here. The feedback was provided through the completion of the validation form (see Annex 6.2), as well as through personal feedback.

The model was generally perceived as being both useful and usable, with the good separation of dimensions being explicitly stressed. It was in fact so well received, that the assessment partner expressed the wish to repeat the assessment in the future with his now improved understanding of the MMACUDIE structure and function. The following further qualitative feedback was given personally:

- DU scope formalisation & DU policy are closely related in organisations that are ISO 9001 certified and difficult to separate from each other, which makes their assessment difficult
- A compulsory “comment” section in which the rated instance of an attributes is listed could help to validate assessments between different assessment partners within the same organisation and initiate improvement processes
- Personal explanation of dimension context was essential for understanding and intuitive assessment. More detailed descriptions would be required if assessment was not in a personal interview setting

# 5 Discussion and outlook

This MT aimed to develop an assessment method for assessing an industrial enterprises capability for effective data utilisation. The underlying research question for this development was:

**“What are the requirements for an effective utilisation of data in industrial enterprises and how can the fulfilment of these requirements be assessed”**.

This resulted in the need to clearly define how DU relevant factors can be described through an easily accessible and comprehendible model, as well as a definition of what factors exhaustively describe relevant DU aspects. The deployed methods through which this was achieved, as well as suggestions for further development and validation of the MMACUDIE are discussed in the following paragraphs.

## 5.1 Summary of results and findings

In the course of this MT, both a maturity model and an assessment method for its application were developed. The developed model, the MMACUDIE, is meant to be applied to industrial enterprises of medium to large size. An assessment through the model should be the result of a proactive wish from the enterprises side to gauge and improve their Data Utilisation abilities. The current evolutionary stage of the MMACUIDE can be characterised through the following aspects:

- Domain: “assessment of capability for utilising data in industrial enterprises”
- 4 layers of application inspired by traditional business process management; structure, governance, operations and objects
- Primarily based on aspects derived from a SLR
- 23 dimensions across all 4 layers
- 72 attributes defining these 23 dimensions
- 5 progressively evolving distinct maturity level definitions for each of the 23 dimensions
- A stage-gate approach to maturity level classification

The developed application method is currently defined through:

- An assessment context of a personal interview between an investigator and assessment partners
- A set of specific guidelines to guide investigators through the application method of the MMACUDIE
- A set of assessment sheets to facilitate and document the assessment experience.
- Two layers of accessible information: expectations deviation and dimension tension
- Inclusion of a validation process for the MMACUDIE
- Presentation of results through spider-web-diagrams
- Software required for presentation: Microsoft Office Excel

Both the MMACUDIE and the assessment method were derived from an extensive Systematic Literature Review in their initial iteration and further developed through feedback collected from their application in a pilot test spanning a total of three assessments. This led to the MMACUDIE in its current 3rd iteration.

To systematically plan and document the SLR process, a guide for conducting SLRs was developed specifically for this MT, which contained the three phases of planning, execution and reporting and respective tasks related to each of these phases. The SLR was focused on:

- Gaining an understanding of maturity as a concept and finding approaches through which it could be assessed
- The discovery of highly qualitative and relevant MMs with comparable assessment scopes to judge the need for the development of a new MM
- Deducing a range of common dimensions, attributes and maturity level definitions for the population phase of the MMACUDIE development
- Discovering potential assessment approaches for deploying MMs
- Discovering validation approaches for the MMACUDIE

The SLR involved 3 distinct literature assessment stages through which the literature was evaluated and rated for quality, relevance and reliability. This led to a selection of 38 highly qualitative pieces of literature being selected from a total of 1000 totally viewed pieces. From these 38, 15 were further identified as being a suitable basis for deriving explicit dimensions and attributes. After completing iterations of the MMACUDIE and the assessment method that were deemed evolved enough for pilot testing, they were deployed in the context of personal interviews with two assessment partners from an industrial enterprise in Vienna. The first assessment (done with the Technical Lead of the production department) provided valuable feedback and resulted

in extensive changes to the model. The second assessment was done with the Workcell manager, who provided some minor constructive feedback. This resulted in some smaller changes, specifically focused on separating dimensions more clearly from each other. These were integrated into the model for the third and final assessment in which altered dimensions were reassessed.

The validation of the MMACUDIE and assessment method were formalised through a validation form but also personally collected after the assessment. The assessment partners both perceived the MMACUDIE assessment to having been relevant to them and described it as a good learning experience, bringing aspects of DU to their attention that they were not consciously aware of. The rating of the entities' capability was perceived as disappointing, but likely to be realistic by the assessment partners. According to them, the assessment through the MMACUDIE provided valuable insights into potential improvement areas that are likely to result in the initiation of improvement tasks, especially in dimensions with strong dimension tension.

## 5.2 Discussion of the used methods

The MMACUDIE development was based on guidelines by De Bruin[183], which are expansions of the original Design Science approach by Hevner[184], and its adaption by Becker[185]. The defined guidelines R1 to R7 were followed as closely as possible through the course of this MT. The ***Problem Definition (R6)*** was dictated through the practical experience of the Fraunhofer Austria Research GmbH and their need for a tool to enable assessments of industrial enterprises' capabilities for data utilisation. A ***Comparison with existing MMs (R1)*** was carried out in the SLR to first confirm the ***Problem Relevance (R5)***. Insights gained from the SLR were then used in combination with the pilot tests (***Multimethodological Procedure (R4)***) to develop the MMACUDIE and an assessment method for its application through an ***Iterative Procedure (R2)***. The final iteration of the MMACUDIE was judged to be usable and useful by the assessment partners and was validated through a formalised ***Evaluation (R3)***, after a ***Targeted Presentation of Results (R7)***. This targeted presentation took place in the form of a personal discussion of results for which assessment results had been visualised and made available to the assessment partners through spider-web-diagrams and the completed assessment sheet.

[183] De Bruin, Tonia et al. (2005).
[184] Hevner, Alan R. et al. (2004).
[185] Becker, Jörg et al. (2009).

Although these guidelines are specifically designed to ensure the development of rigorous, practically relevant, qualitative and comprehensible MMs, the MMACUDIE remains flawed and at an early evolutionary stage:

- Resource and time restraints did not enable the validation of the MMACUDIE through a broad panel of experts and CV remains to be effectively proven and dimension definition relied heavily on the SLR. A large-scale deployment and validation would provide the opportunity for experts to suggest further expansions.
- The model was only pilot tested and rated as useful through members of a single organisation. It is currently unknown if an application to other organisations (different sizes, structures, etc.) will also be as productive. When further validating the MMACUDIE, care should be taken to deploy it in a variety of organizational structures and sizes.
- Maturity of the entity in which the MMACUDIE was pilot tested was generally low and due to time restrictions, only dimension levels that were relevant to the assessment partner were discussed. At this point, no form of extensive FV or CV of most of the higher levels (4 & 5) has been given. Further validations though experts should include validation of higher maturity levels.
- The current assessment method is tailored to personal interviews and requires a good understanding of the dimensions and attributes that define them. No assessments were carried out by investigators not involved in the development process and handing the MMACUDIE off to other investigators has not been field tested. Handing off the assessment to investigators that were not involved in the development process should be tested, resulting issues documented and the model and method reiterated to solve these issues.
- The MMACUDIE is a virtual projection of what the perceived general requirements for effective DUIE are, based on literature. Although FV may have been established, CV can only truly be achieved through a practical application that results in tangible improvements. The success of actions derived from the MMACUDIE should be evaluated in a review process.
- The danger of personal bias is a part of any assessment and in the MMACUDIEs current iteration, no mechanisms have been implemented that can effectively prevent it. Cross examining self-assessments of various assessment partners and requiring justification for decisions could help making assessments more objective and reliable.

Despite these apparent shortcomings, both assessment partners reported a productive learning experience through the MMACUDIE assessment and the Workcell manager even expressed the wish for another reassessment, now that he is acquainted with the methodology and structure of the MM.

The development of the MMACUDIE elevates itself from most other available MMs through its methodological focus (systematic, goal-orientated, repeatable).[186] Although an abundance of MMs exists, many do not give enough consideration to their practical application and do not consider how the theoretical model may be applied in a real-life scenario. The MMACUDIE was explicitly developed for this purpose and its practicality and easy comprehensibility was a key focus throughout the entire development process.

## 5.3 Outlook and further research direction

Based on the feedback that was received through the pilot tests, the following research scopes are suggested for further iterations and improvements to the MMACUDIE:

- Establishing CV through extended assessments and expert validations
- Increased focus on the human aspect of DU and their role in enabling or hindering effective DU
- Inclusion of a process that identifies stakeholders for the respective dimensions into the assessment
- Implementation of mechanisms to reduce personal bias. Feedback has suggested that the inclusion of a comment box underneath each attribute on the assessment sheet might be a liable implementation. This box should be used to document, which specific attribute instance was considered for the maturity classification of an assessment to make it comparable and verifiable through other assessment partners classifying that same attribute within the entity. Further research should evaluate this or alternative options.
- Examination of whether the acceptance and perceived accuracy of the MMACUDIE assessment is linked to the degree of deviation between intuitive and actual dimension maturity classifications.
- Exploration of techniques that enable a better visualisation of attribute maturity distribution within one dimension such as Focus Area maturity models, which provide “more detailed guidance to setting priorities in capability development… (It) makes this kind of model well suited to express the, sometimes complex, combinations of different factors that determine the effectiveness of a function. Departing from the five fixed maturity levels makes the focus area-oriented model more flexible in defining both focus areas and interdependencies between focus areas.” [187]

[186] Mettler, Tobias (2009).
[187] van Steenbergen, Marlies et al. (2010), p. 319.

- Exploration of maturity grids and their potential benefits for implementation into the MMACUDIE compared to MMs

**Table 20: Differentiation between maturity models and maturity grids[188]**

| **Differentiating factor** | **Maturity Grids** | **maturity models (CMM)** |
|---|---|---|
| *Work orientation* | Define best practices for processes in any industry and characterise what defines a high-performance process | Define best practices for processes in specific industries and evaluate how companies comply with them |
| *Mode of assessment* | Assessment via multidimensional scales in which levels of maturity are allocated against key aspects of performance or key activities | Assessment vie Unidimensional scales such as Likert, Thurston or Guttman scales |
| *Intent* | Standalone assessment or part of a bigger improvement initiative | Applied in a standard format that enables certification of performance |

[188] Maier, Anja M. et al. (2012).

## 5.4 Conclusion

Coming back to the original research question of the requirements existing for DU and how they can be assessed, the MMACUDIE provides extensive answers. Through the model design and structure, 4 primary abstraction levels and 23 mutually exclusive and collectively exhaustive dimensions were defined as critical, which contain a total of 72 distinct attributes. This provides organisations that are looking for a formalised, state of the art overview and explanation with an easily accessible and comprehensible reference. Due to the methodological focus during the development of the model and the complementing assessment approach developed alongside it, assessments through the MMACUDIE have been shown to be a practical, useful, objective and insightful experience for assessment partners that increase the awareness for critical factors required for effective DU.

However, assessments may also unveil the harsh truths of how lacking an entity's capabilities regarding DU really are. This may dampen initial ambitions for improving DU capabilities, if they are not based on a deep understanding of the potential benefits of effective DU and an internally driven commitment to tapping into this potential. If this is not the case, high DU capability maturity may not be a good fit for an organisation. However, as the number of organisations that are effectively utilising data increases, so will the pressure for other organisations to do the same. An assessment through the MMACUDIE may be able to provide the awakening call that some organisations need.

# 6 Annex

## 6.1 Assessment sheets

Assessment Guidelines

Prior to the actual assessment of an entity through the MMACUDIE, a brief introduction to MMs in general and the specific assessment method of the MMACUDIE should be provided to the assessment partner. The following guidelines should help investigators who are new to the MMACUDIE to prepare assessment partners appropriately.

| Nr. | Guideline | Description | Helpful Documentation |
|---|---|---|---|
| 1 | Purpose | The purpose of the MMACUDIE is to identify improvement areas regarding the utilisation of data in industrial enterprises. It seeks to identify less developed dimensions in an otherwise more evolved system to reveal existing dimension tensions and thereby provide effective starting points for improvement initiatives. | n/a |
| 2 | Discussing and ensuring anonymity | Participants and organisations partaking in the assessment may wish to remain anonymous. The wish for anonymity should be discussed prior to assessment. Should the participants wish to remain anonymous, alternative names should be provided. These should remain comprehensible to the investigator, but incomprehensible to others. | n/a |
| 3 | Model structure | The MMACUDIE is designed for examining an industrial enterprises capability for utilising data. It was specifically designed for industrial enterprises producing physical goods. The MMACUDIE can be applied to entire organisations or abstract fractions of these. Setting the scope for what defines this so-called entity is part of the application process described in guideline 5. The model structure can be divided up into 4 different layers, each of which is described through a set of dimensions which are defined by specific attributes. The dimensions of the MMACUDIE are mutually exclusive and collectively exhaustive in describing the capability for data utilisation (DU)in industrial enterprises. Each layer (Strategy, Governance, Operations, Object) provides a description of the entity on a different level of abstraction. | •Model overview<br>•Assessment sheet |

Assessment Guidelines

| | | | |
|---|---|---|---|
| 4 | Maturity Level classification | Maturity levels represent a measurement of sophistication, the evolutionary path of which is typically dictated through the changing stages. In the MMACUDIE maturity levels are classed through discrete whole numbers between 1 - 5, 5 representing the most evolved, 1 representing the least evolved degree of maturity. The maturity level classification for individual dimensions is defined through that dimensions least mature attribute. The MMACUDIE seeks to identify the least mature instance of any attribute in the entity, because it seeks to identify weaknesses, not strengths. To ensure this, assessment partners should begin the assessment of each dimension by first identifying the weakest instance of each attribute. | • Generic Level Def.<br>• Assessment sheet |
| 5 | Assessment methodology | For each of the four layers, the individual dimensions' maturity levels are assessed one by one.<br>First the scope of the assessed dimension is generally explained through the descriptions listed on the dimension sheets and attributes that constitute that dimension. The assessment partner then intuitively rates the overall dimension according to the generic maturity level definition from 1 - 5 and documents this on the assessment handout (IA). Then the assessment partner checks if attributes of the intuitively chosen maturity level fulfil the definition of that level (lowest instance of attribute) with the help of the dimension sheets. The assessment partner should communicate his reasoning to the investigator and ask for any clarifications in case these are necessary. The "definition of terms" document may be helpful in clarifying uncertainties. Every attribute should be classified before moving on to the next dimension. The overall time needed for completion of the assessment should also be recorded. | • Model overview<br>• Generic Level definition<br>• Assessment sheet<br>• Dimensions<br>• Dimension description<br>• Definition of terms |

Assessment Guidelines

| | | | |
|---|---|---|---|
| 6 | Maturity classification agreement | The investigator validates the assessment partner's classification, based on what he or she has communicated. The investigator and assessment partner must agree upon a maturity classification, before it is officially documented. | • Assessment<br>• Dimensions |
| 7 | Documentation | Once a classification has been agreed upon, it should be documented digitally in the Assessment tool through the investigator, as well as on the physical handout of the assessment for redundancy and assessment partner engagement. | • Assessment |
| 8 | Processing of assessment | Processing of the assessment takes place through the investigator and includes the identification of dimension tensions and visualisation through spider-web charts or other meaningful tools available to him or her. | n/a |
| 9 | Presentation of assessment results | The results of the maturity assessment should be presented to the investigation partner and he should be supplied with copies of the assessment in both physical and digital form. | n/a |
| 10 | Validation of model | In order to continue the iterative development process of the MMACUDIE, feedback should be collected from the assessment partner. In order to make this feedback comparable, the validation sheet should be used. In case assessment partners wish to provide feedback that does not fit the form or content of the validation sheet, it should also be recorded and reviewed for implementation into the validation sheet. | •Validation |
| 10 | Validation of model | In order to continue the iterative development process of the MMACUDIE, feedback should be collected from the assessment partner. In order to make this feedback comparable, the validation sheet should be used. In case assessment partners wish to provide feedback that does not fit the form or content of the validation sheet, it should also be recorded and reviewed for implementation into the validation sheet. | •Validation |

Model Overview

| Domain | Utilisation of data in industrial enterprises | | | |
|---|---|---|---|---|
| **Layer** | **Strategy** | **Governance** | **Operations** | **Objects** |
| **Dimensions** | Information Qualitiy (IQ) awareness | DU task Ownership formalisation | DU awareness (staff) | Compatability of the DU System-chain |
| | Metadata awareness | Data management | DU engagement | Data collection & integration |
| | DU awareness (Management) | Information management | Analytical abilities | Data warehousing architecture |
| | DU policy | Access to information | DU workflow synergy | Metrics Capability |
| | DU scope formalisation | DU tool management | Information Quality (IQ) assurance | Analytical tools & services |
| | DU workflow integration | DU workflow formalisation | Knowledge asset sharing | |

Generic Level Definition

| Level | Title | Description |
|---|---|---|
| Level 1 | Rudimentary | Attributes of the dimension are poorly developed and may be non-functional. Insufficient resources are designated to this dimension, rendering its Attributes largely ineffective. The dimension has little to no priority within the entity and no form of review process is in place. |
| Level 2 | Functional | Most attributes of the dimension is developed to the point of being functional but may be partially ineffective. Maintaining this sophistication level requires little designated resources and is usually the basis for enabling day to day operations. The dimension has a small priority within the entity and no structured review process is in place. |
| Level 3 | Commendable | Every attribute of the dimension is developed to the point of being effective. Maintaining this level of sophistication requires a reasonable amount of designated resources, common for the industry. The dimension is a priority within the entity and a structured review process may be inconsistently implemented |
| Level 4 | Admirable | Every attribute of the dimension is highly developed, beyond the current industry standard and future oriented. Maintaining this level of sophistication requires substantial designated resources, uncommon for the industry. The dimension has high priority within the entity and attributes are periodically reviewed and continuously optimised. |
| Level 5 | Exceptional | Every attribute of the dimension is exceptionally well developed and at the forefront of innovation. Maintaining this level of sophistication requires exceptional amounts of designated resources that are rare in the industry. The dimension has an extremely high priority within the entity and attributes are periodically reviewed through formalised, standardised and continuously optimised improvement processes that utilise KPIs where they are beneficial. |

Dimension description

| Dimension | Description |
|---|---|
| Access to information | Sophistication of the systems and methods by which information is made available to staff |
| Analytical abilities | Degree to which the collective of staff members are capable of drawing meaningful information from data by analytical processes |
| Analytical tools and services | Sophistication of the DU analysis tools (hard- and software) and services (analysis, visualisation, etc.) involved in the DU process |
| Compatability of the DU system-chain | Required resource intensity to enable data flow along the various tools, systems, in the DU system chain |
| Data collection & integration | Sophistication of the methods by which data is collected and integrated into the warehousing architecture |
| Data management | Degree to which data policies are formalised and metadata enables tracing data streams |
| Datawarehousing architecture | Sophistication of the architecture deployed for the data warehouse (merging of data storage systems, enabling cross functionality, single state of truth) |
| DU awareness | Degree to which the management is aware of the potential of DU utilisation and |
| DU awareness (staff) | Degree to which staff members throughout the entity understand the implications of DU for their work |
| DU engagement | Degree to which staff embrace DU as a part of their work |
| DU policy | Degree to which DU has been implemented into the entity strategy and resources are being allocated towards it |
| DU scope formalisation | Extent and way in which the DU scope is being defined |
| DU task ownership formalisation | Sophistication of the process by whichDU tasks are assigned to staff |
| DU tool management | Sophistication of system by which the available DU-tools are being optimised and made available to staff. |
| DU workflow formalisation | Sophistication of the formalised DU workflows |
| DU workflow integration | Degree to which the integration of DU processes is being ensured |
| DU workflow synergy | Level of synergy displayed by DU workflows |
| Information management | Degree to which the information scope is formalised, extent of what this formalisation includes and ability to trace information streams through metadata. |
| IQ assurance | Sophistication of method by which bad IQ is being prevented and overcome |
| IQ awareness | Awareness of the importance of good IQ and strategy to ensure it. |
| Knowledge asset sharing | Degree to which knowledge asset sharing is taking place and sophistication of methods that are deployed to enable it |
| Metadata awareness | Degree to which the management is aware of the potential of metadata utilisation and agrees on how it should be part of the entity strategy. |
| Metrics Capabilities | Sophistication of the measurements in describing processes and performance |

***Date:***
***Name (Optional):***
***Position:***
***Contact Information:***
***Entity: definition:***

**Utilisation of data in industrial enterprises**

| *Strategy* | IA | AA | *Governance* | IA | AA | *Operations* | IA | AA | *Objects* | IA | AA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Information Quality (IQ) awareness | | | DU task Ownership formalisation | | | DU awareness (staff) | | | Compatbility of the DU System-chain | | |
| IQ impact awareness | | | Formalisation of DU task ownership | | | Embracement of DU by staff | | | Resources for overcoming sub- system-boundaries | | |
| IQ maintainance and improvement requirement | | | Ownership allocation process | | | | | | Review of DU-system- compatibility | | |
| | | | Review of ownership roles | | | | | | | | |
| Metadata awareness | | | Data management | | | DU engagement | | | Data collection & integration | | |
| Awareness for metadata potential | | | Formalisation of data policies | | | DU task proactivity | | | Collection sophistication | | |
| Metadata utilisation strategy | | | Data redundancy | | | DU focused change initiation | | | Integration sophistication | | |
| Review of metadata strategy | | | Review of data policies | | | Review of DU triggered changes | | | Integration structure formalisation | | |
| | | | | | | | | | Review of all data collection & integration processes | | |
| DU awareness (Management) | | | Information management | | | Analytical abilities | | | Data warehousing architecture | | |
| Embracement of DU by the management | | | Information scope formalisation process | | | Understanding of Analytical processes | | | Sophistication of data warehousing architecture | | |
| Consideration of DU in entity strategy | | | Extent of formalised information scope | | | Consistancy of results | | | Review of the data warehousing architecture | | |
| Review of DU aspects in entity strategy | | | Review of information management system | | | Distribution of analytical capabilities | | | | | |
| | | | | | | Collaboration potential | | | | | |
| | | | | | | Ability improvement initiation | | | | | |
| DU policy | | | Access to information | | | DU workflow synergy | | | Metrics Capability | | |
| DU strategy formalisation | | | Remote access of information | | | Synergy level | | | Process performance | | |
| Resource commitment to DU | | | Access system sophistication | | | | | | Capability for validating decisions | | |
| | | | Access privileges management | | | | | | Metadata collection and capabilty | | |
| | | | Information access awareness | | | | | | | | |
| | | | Review of information access policy | | | | | | | | |
| DU scope formalisation | | | DU tool management | | | Information Quality (IQ) assurance | | | Analytical tools & services | | |
| DU scope formalisation process | | | Identification and implementation of tools | | | IQ issue identification | | | Effectiveness | | |
| Mapping of DU Processes | | | Tracking of users and tool portfolio | | | IQ issue documentation | | | Analytical scope | | |
| Encouragement of staff improvement input | | | Ease of tool access and expansion | | | IQ issue prevention | | | Predictive capability | | |
| Review of DU scope | | | Review of tool portfolio | | | | | | Tool usefulness independency from user | | |
| | | | | | | | | | Formalisation of service requirements | | |
| | | | | | | | | | Review of tools and services | | |
| DU workflow integration | | | DU workflow formalisation | | | Knowledge asset sharing | | | | | |
| Integration analysis | | | Formalisation of DU Workflows | | | Culture | | | | | |
| Improvement actions formalisation | | | Decision making automation capability | | | Knowledge sharing mechanisms | | | | | |
| Review of integration levels and actions | | | Review of DU workflows | | | Reward mechanisms for knowledge sharing | | | | | |
| | | | | | | Review of knowledge sharing mechanisms | | | | | |

Strategy

**Strategy**

| Sub-Domain | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
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| **Information Quality (IQ) awareness** | **Unaware:** There is little awareness of what impact bad IQ will have on the business and the need for IQ maintainance is not defined. | **Semi-aware:** There is some awareness of what impact bad IQ will have on the business but IQ maintainance is not a consistently implemented requirement. | **Aware:** There is an awareness for the monetary impact of bad IQ and IQ maintainance is a consistently implemented process. | **Pro-Active:** There is a good awareness for the monetary and some awareness for the non-monetary impact of bad IQ. Maintainance and improvement of IQ is a core process | **Vigilant:** There is good awareness of both the monetary and non-monetary impact of bad IQ. Maintainance and improvements IQ is a core process that is guided by KPIs. |
| **Metadata awareness** | **Unaware:** The strategic implications and potential of metadata utilisation is not thoroughly understood by the management. There is no general agreement on what role it should play in the entity strategy. Metadata strategy is not reviewed. | **Semi-aware**: The strategic implications and potential of metadata utilisation are acknowledged by the management, but there is uncertainty about how exactly the entity could benefit from its utilisation. There is agreement of what role it could play in the entity strategy. No systematic process for reviewing the metadata strategy is in place. | **Aware:** The strategic implications and potential of metadata utilisation is thoroughly understood by the management and it is clearly aware of how the entity could benefit from its utilisation. There is general agreement of what role metadata plays in the entety strategy. Meta data strategy may be reviewed incidentally. | **Pro-Active:** The strategic implications and potential of metadata utilisation is fully embraced by the management and it is actively promoting awareness of its benefits amongst their employees. There is homogenous agreement of what role metadata plays in the entity strategy and metadata strategy is reviewed periodically. | **Vigilant:** The management regard metadata utilisation as a strategic imperative for the entity and it is actively promoting the awareness of its beenefits throughout the entire entity. There is homogenous agreement of what role metadata plays in the entity strategy and metadata strategy is reviewed periodically through defined KPIs. |

Strategy

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| **DU awareness (Management)** | **Unaware**: The strategic implications of DU are not thoroughly understood by the management. There is no general agreement on how DU should be integrated into the entity strategy. DU aspects of the entity strategy may not be rewieved. | **Semi-aware**: The strategic implications of DU are acknowledged to possess potential by the management, but they are unsure about how the entity will benefit from it. There is moderate agreement on how DU should be integrated into the entity strategy. No structured review process to assess DU aspects of the entity strategy is in place. | **Aware:** The strategic implications of DU are embraced by the management and they are aware of how it can benefit the entity. There is general agreement of where and how DU should be integrated into the entity strategy. DU aspects of the entity strategy may be incidentally reviewed. | **Pro-Active:** The management agree that innovating DU processes throughout the entity is a core value of the entity and they are actively promoting awareness of its benefits amongst their employees. There is homogenous agreement of where and how DU should be integrated into the entity strategy. DU aspects of the entity strategy are periodically reviewed. | **Vigilant:** The management regard DU as a strategic imperative for the entity and are actively promoting the awareness of its importance throughout the entire entity. There is explicit commitment to where and how DU will be integrated into the entity strategy. DU aspects of the entity strategy are periodically reviewed using defined KPIs. |
| **DU policy** | **Volatile**: DU does not appear in the official entity strategy and there are no resources dedicated explicitly to DU improvement. | **Kick-off**: Some form of DU strategy may be in development, but any existing implications of a DU strategy are vague. Resources may not be explicitly commited to improving DU , but they may be implicitly taken into | **Initiated**: A DU-strategy-roadmap has been initiated and may be partially implemented. The management is explicitly commiting resources to enable DU. | **Implemented**: A DU strategy has been implemented according to a previously defined roadmap. Resources are being commited explicitly to improving DU. | **Epitomized:** An established DU strategy is in place. Resources are being commited explicitly to improving and reviewing DU strategy. |
| **DU scope formalisation** | **Absent:** The DU-scope may have been defined, but has not been formalised or mapped. Improvement suggestions through the staff are not explicitly encouraged. The DU-scope may not be reviewed. | **Inconsistent:** The DU-scope has been been formalised and may have been mapped through decentralised processes. Improvement suggestions by the staff may be implicitly encouraged. No structured review of the DU scope is in place. | **Consistant:** The DU-scope has been centrally formalised and mapped for the entity. Improvement suggestions by the staff are explicitly encouraged. The DU-scope may be reviewed incidentally. | **Refined:** The DU-scope has been centrally formalised and mapped for the entity. Improvement suggestions by the staff are explictly encouraged and rewarded. The DU-scope is reviewed periodically. | **Optimised:** DU-processes have been formalised and mapped consistently throughout the entity. Improvement suggestions by the staff are explicitly encouraged and explicitly rewarded through defined KPIs. The DU scope is reviewed periodically through defined KPIs. |

Strategy

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| **DU workflow integration** | **Not attuned:** No DU-workflow integration analysis has been initiated and no integration improvement actions have been formalised. Integration levels and improvement actions are not reviewed. | **Semi-attuned:** An entity wide DU-workflow integration analysis may have been initiated but no integration improvement actions have been formalised yet. No structured review process for integration levels and improvement actions is in | **Attuned:** An entity-wide DU-workflow integration analysis has been conducted and findings have led to formalised improvements actions. Integration levels and improvement actions may be inconsistantly reviewed. | **Integrated:** Entity wide DU-workflow integration analysis are conducted periodically and result in formalised improvement actions. Integration levels and improvement actions are periodically reviewed. | **Fully integrated**: Entity wide DU-workflow integration analysis are being conducted periodically and result in formalised improvement actions. Integration levels and improvement actions are periodically reviewed through defined KPIs. |

Governance

| Governance | | | | | |
|---|---|---|---|---|---|
| **Sub-Domain** | **Level 1** | **Level 2** | **Level 3** | **Level 4** | **Level 5** |
| **DU task ownership formalisation** | **Ad-hoc:** Ownership of DU tasks is not formalised or tracked. DU task allocation happens on an ad-hoc basis. DU task ownership roles are not reviewed. | **Inconsistant:** Ownership of some of the DU tasks is formalised and tracked. DU task allocation is inconsistantly based on DU task ownership roles. No structured review process for DU tasks ownership roles is in place. | **Consistent:** Ownership of all DU tasks is formalised and tracked. DU task allocation is consistantly based on DU task ownership roles. DU task ownership roles may be incidentally reviewed. | **Partially automated:** Ownership of all DU tasks is formalised and tracked. DU task allocation is partially automated and based on DU task ownership roles. DU task ownership roles are periodically reviewed. | **Automated:** Ownership of all DU tasks is formalised and tracked. DU task allocation is largely automated based on DU task ownership roles and other KPIs. DU task ownership roles are periodically reviewed and adapted based on defined KPIs. |
| **Data management** | **Siloed**: Data policies are locally defined within sub-divisions/ functions of the entity but may not be formalised. Redundantly stored data is unidentifyable and the norm. The data policies may not be rewieved. | **Semi-centralised:** Data policies are formalised at least within sub-divisions/ functions of the entity. Redundantly stored data may be incidentally identifyable but is still common. No structured review process for the data policies may be in place. | **Centralised:** Data policies (including metadata policies) are formalised centrally for the entire entity. Redundantly stored data is generally identifyable but may exist incidentally. The data policies may be incidentally reviewed. | **Homogenous:** Data policies (including metadata policies) are centrally defined by explicitly appointed groups or individuals. Redundantly stored data is the exception. The data policies are periodically reviewed. | **Symbiotic:** Data policies (including metadata policies) are highly prioritised and centrally defined by explicitly appointed groups. No redundant data is stored. The data policies are periodically reviewed through defined KPIs. |
| **Information management** | **Independent:** The information scope may be defined but is not formalised. The scope does not include the required tools, data or storage structure. The information scope definition is not reviewed. | **Solitary:** The information scope is formalised at least within sub-divisions/ functions of the entity.The scope is inconsistent in including the required tools, data and storage structure. No structured review process for the information scope may be in place. | **Central:** The information scope is centrally formalised for the entity. The scope includes the required tools, data and storage structure and may inlcude external data. The information scope may be incidentally reviewed. | **Collaborative:** The information scope is centrally formalised for the entity by explicitly selected groups or individuals. The formalisation includes the required tools, data (external & internal), storage structure and the metadata scope. The information scope is periodically reviewed. | **Collaborative:** The information scope formalisation is highly prioritised and carried out by explicitly selected groups. The formalisation includes the required tools, data(external & internal), storage structure and metadata scope. The information scope is periodically reviewed through defined KPIs. |

## Governance

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| **Access to information** | **Diffused**: Not all information can not be accessed from remote user interface(s) and no queries for accessing large batches of data have been implemented. Access priviliges are unclear and cause issues. Staff may not know where to find all of the relevant information. The information access policy and systems may not be reviewed. | **Fragmented:** Most information can be accessed both remotely and locally and data queries enable accessing large batches from various user interfaces. Cross-functional queries may be incidentally possible. Access priviliges are vaguely defined and can sometimes cause issues. Staff know where to find most of the relevant information. No structured review process for information access policy and systems is in place. | **Centralised:** All Information can be accessed remotely and a single user interface enables cross functional queries of large batches of data. Access priviliges are clearly defined and access expansionis possible through non standardised processes. Staff know where to find all of the information relevant to them. The information access policy and systems may be incidentally reviewed. | **Tailored:** All Information can be accessed remotely and a single user interface that is tailored to the users needs enables cross functional queries for large batches of data. Access priviliges are clearly defined for all staff and the access expansion process is standardised. Staff are aware of what information they do and do not have access to. The information access policy and systems are periodically reviewed. | **Dynamic:** Information can be accessed from a single remote user interface in a format that is tailored to the users needs. Access priviliges are clearly defined for all staff and the access expansion is automated based on staffs defined roles. Staff are aware of what information they do and do not have access to. The information access policy and systems are periodically reviewed in a standardised form. |
| **DU tool management** | **Difficult**: Tools to perform or assist in DU have not been formally identified but might be incidentally implemented.The DU tool portfolio and ist users are not listed or tracked. Access and an expansion of the available DU tools are impossible without substantial help from IT-functions and strong management endorsement. The tool portfolio may not be rewieved. | **Possible:** Tools to perform or assist in DU have been formally identified and partially implemented throughout the entity.The DU tool portfolio and its users are listed but not tracked. Access to and expansion of the available tools requires help from IT-functions, acquiring new DU tools requires endorsed by the management. No structured review of the tool portfolio is in place. | **Easy:** Tools to perform or assist in the DU have been formally identified and implemented throughout the entity.The DU tool portfolio and its users are tracked. Access to DU tools requires approval, but little help from IT-functions. Acquiring new DU tools requires approval by the management. The tool portfolio may be reviewed incidentally. | **Effortless**: Tools to perform or assist in the DU have been formally identified and implemented throughout the entity.The DU tool portfolio and its users are tracked and periodically evaluated to identify improvement opportunities. Staff requiring access to DU tools can access them via an automated process that requires no direct help from the IT-functions. Acquiring new DU tools requires approval by the management. The tool portfolio is reviewed periodically. | **Seamless:** Tools to perform or assist in the DU have been formally identified and implemented throughout the entity. The DU tool portfolio and its users are tracked and periodically evaluated to identify improvement opportunities. Staff requiring access to DU tools can tap into them seamlessly throughout the entity, without help from the IT function or approval processes. The portfolio is reviewed periodically in a standardised process that includes a market survey of available tools. |

## Governance

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| **DU workflow formalisation** | **Defined:** Decision-making-workflows may have been defined but not formalised for DU related decision processes within the entity. Decision making automation is not possible. DU workflows may not be reviewed. | **Inconsistent:** Decision-making-workflows may have been formalised inconsistently for DU related decision-processes within the entity. A limited degree of decision making automation may be possible. No structured review process of DU workflows is in place. | **Consistent:** Decision-making-workflows have been consistently formalised for DU related decision-processes within the entity. Decision making automation may be inconsistantly implemented. DU workflow reviews may take place incidentally. | **Efficient:** Decision-making-workflows have been consistantly formalised for DU related decision-processes. Decision making automation is consistantly implemented. DU workflows are periodically reviewed. | **Optimised:** Decision-making-workflows have been formalised for all standard decision-processes, enabling full automation for those decision-processes and the need for human decision-making is rare. DU workflows are periodically reviewed through defined KPIs. |

Operations

| Operations | | | | | |
|---|---|---|---|---|---|
| **Sub-Domain** | **Level 1** | **Level 2** | **Level 3** | **Level 4** | **Level 5** |
| **Data utilisation (DU) awareness (staff)** | **Obliged:** Few if any staff understand how DU can positively impact their work on an operational level and help achieve entity objectives, but the majority do not. | **Interested:** Some staff understand how DU can positively impact their work om an operational level and help them achieve entity objectives, others remain unaware of its benefits. | **Engaged:** Most staff understand how DU can positively impact their work on an operational level and help them achieve entity objectives | **Embraced:** Most staff understand how DU can positively impact their work on and beyond an operational level and help them achieve entity objectives | **Invested:** All staff understand how DU can improve processes on and beyond an operational level and recognise it as a key component to achieve entity goals |
| **Data utilisation (DU) engagement** | **Reluctant**: Assigned DU tasks are carried out primarily when it is required and there may be some resistance to DU focused changes. DU application may not be reviewed. | **Isolated:** Assigned DU tasks are accepted and staff with strong technological skills may begin initiating DU related tasks independantly. DU focused changes are generally accepted. There is no structured review system to assess DU application. | **Engaged:** Assigned DU tasks are carried out willingly and staff may begin initiating DU focused changes alongside more technologically skilled staff out of their own initiative. DU application may be incidentally reviewed. | **Proactive:** All staff engage proactively with their assigned DU roles and regularly initiate DU focused changes out of their own initiative. DU application is periodically reviewed | **Inspired:** All staff engage proactively with their assigned DU roles and regularly initiate DU focused changes out of their own initiative. They feel empowered to experiment with DU beyond the limits of their assignment. Individual staff members may become DU promoters, sharing their positive experience and stressing the importance of DU. DU application is periodically reviewed through KPIs. |

## Operations

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| **Analytical abilities** | **Poor:** Staff engaged in analytics do not understand most of the involved processes and analytical results are inconsistant. Staff with good analytical abilities are the exception, making analytical collaboration ineffective. Staffs' analytical abilities are not formally assessed and there is little to no effort to improve their analytical abilities. | **Modest:** Staff engaged in analytics understand the involved processes to some degree but analytical results are not always consistant. The staff with good analytical abilities are responsible for the majority of the analytical tasks and analytical collaboration is possible. Staffs' analytical abilities may be subjectively assessed through the management, but improvement of abilities takes place primarily due to individual motiviation. | **Able:** Staff engaged in analytics understand the involved processes and the analytical results are fairly consistent. Most staff are engaged in analytical tasks and staff with higher analytical knowledge provide support when it is needed, making analytical collaboration effective. Staffs' analytical abilities may be incidentally assessed in a structured manner and the management is providing some support to improve staff member's abilities. | **Well-versed:** Staff engaged in analytics understand the involved processes well and the results are consistant. They are able to critically examine each others analysis and help improving upon the shortcomings of each others work, creating collaborative synergy. Staffs' analytical abilities are periodically assessed in an structured manner and the management is actively trying to improve staffs' abilities. | **Enlightened:** The staff engaged in analytical processes understand them completely and the results are consistent. They are able to critically examine each others analysis and help improving upon the shortcomings of each others work. The collaborative synergy is exceptional. Staffs' analytical abilities are periodically assessed in an strictly objective manner and some staff take on official teacher roles to actively improve other staff member's abilities and the general analytical process. |
| **DU workflow synergy** | **Not attuned:** DU-workflowes demonstrate poor synergy within the entity. | **Semi-attuned:** DU-workflowes demonstrate little synergy throughout the entity, although good synergy may exist within subsidivions | **Attuned:** DU workflows demonstrate some synergy throughout the entity. | **Integrated:** DU-workflows demonstrate a good level of synergy throughout the entity. | **Fully integrated**: DU-workflows demonstrate an exceptional level of synergy. |

## Operations

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| **Information Quality (IQ) assurance** | **Poor:** Sources for potential IQ issues have not been identified. Occurred or potential IQ-issue-sources are not documented or evaluated and IQ improvements are short-term solutions to overcome occurring issues. Preventive IQ improvements and long-term solutions are the exception. | **Moderate**: Some potential sources for IQ issues have been identified. Occurred and potential IQ-issue-sources are documented and may be inconsistantly evaluated. IQ improvements are both preventive and short-term solutions to overcome occurring issues, long-term solutions are the exception. | **Good:** All feasible potential sources for IQ issues have been identified, occurred and potential IQ-issue-sources are documented and are inconsistantly evaluated. IQ improvements are both preventive and long-term solutions, short term-solutions are the exception. | **Excellent:** All feasible potential sources for IQ issues have been identified, occurred and potential IQ-issue-sources are documented and periodically evaluated. Most IQ improvements are preventive long-term solutions the occurrence of unidentified IQ issues is the exception and regular IQ improvement initiatives are supported and initiated throughout the entity. | **Total:** All feasible potential sources for IQ issues have been identified, occurred and potential IQ-issue-sources are documented and periodically evaluated. Most IQ improvements are preventive and long-term solutions, the occurrence of unidentified IQ issues is the exception. Regular IQ improvement initiatives are supported and initiated throughout the entity, the potential cost of bad IQ has been calculated and sets the focus for IQ improvement initiatives. |
| **Knowledge asset sharing** | **Elective:** Knowledge asset sharing may take place between individual staff members. Generally, people who understand the value of it do it. Formalised mechanisms to facilitate the knowledge sharing do not exist and employees struggle to tap into available knowledge. Sharing is poorly rewarded by collegues or supervisors and the knowledge sharing mechanisms are not reviewed. | **Fractured:** Knowledge asset sharing may take place within subdivisions of the entity and its value is generally recognized. Informal mechanisms to facilitate the knowledge sharing process do exist but employees may be unaware of them. Sharing is implicitly rewarded by collegues but no structured review process for the knowledge sharing mechanism are in place. | **Consistent**: Knowledge asset sharing is a valued and practiced part of the entity's working culture and takes place throughout the entity. Formalised mechanisms to facilitate the knowledge sharing process do exist and employees are familiar with them. Sharing is implicitly rewarded by collegues and supervisors and the knowledge sharing mechanisms may be incidentally reviewed. | **Reliable**: Knowledge asset sharing is a core process of the entity's working culture and is a formalised requirement. Formalised mechanisms for the sharing process do exist and staff are aware of them. The extent to which staff are involved in knowledge sharing is trackable- Staff are explicitly rewarded for knowledge sharing. The knowledge sharing mechanisms are periodically evaluated. | **Ingrained**: Staff members have internalized the process of seeking out existing knowledge assets as a key part of their work approach and it is a formalised requirement.The extent to which staff are involved in knowledge sharing is consistently tracked and utilised to explicitly reward knowledge sharing. The knowledge sharing mechanisms are periodically evaluated through defined KPIs. |

Objects

| Objects | | | | | |
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| **Sub-Domain** | **Level 1** | **Level 2** | **Level 3** | **Level 4** | **Level 5** |
| **Compatability of the DU system-chain** | **Low**: Overcoming boundaries between sub-systems requires substantial resources. Compatability may not be rewieved. | **Partial**: Overcoming boundaries between sub-systems requires some resources. Compatability may not be rewieved. | **Compatible:** Overcoming boundaries between sub-systems requires negligible resources. Incidental reviews of compatability may take place but improvement tasks may not be formalised as a result. | **Coordinated:** Overcoming boundaries between sub-systems requires negligible resources. Compatibility issues are identified via periodic reviews, resulting in improvement tasks. | **Harmonised:** Overcoming boundaries between sub-systems requires negligible resources. KPIs are defined to monitor compatibility issues. The effectiveness of improvement tasks is evaluated. |
| **Data collection & integration** | **Manual:** The collection process of some significant internal data still takes place manually. Integration happens without a formalised structure. No external data is collected. Collection and integration processes may not reviewed. | **Internally semi-automated:** The collection process of significant internal data is largely digitalised and its integration may be partially automated. Data integration takes place via "Data loading" processes in repetetive time cycles during which acces to the data warehouse may be blocked. The integration structure is inconsistantly formalised.. There is no formalised structure to review the collection and integration processes. | **Internally automated:** The collection of all significant internal data is completely digitalised and automated. External data collection may not be automated. Data is continously integrated into the data warehouse. The integration structure is formalised and has a data integration focus. Collection and integration processes may be inconsistantly reviewed. | **Globally semi-automated:** The collection of relevant internal data and its integration into the data warehouse is continuous, completely digitalised and automated. External data collection is partially automated. The integration structure is formalised and has a process optimisation focus. Collection and integration processes are periodically reviewed. | **Globally Automated:** The collection of relevant internal and external data and its integration into the data warehouse is completely automated. The integration structure is formalised and has a process optimisation focus. Collection and integration processes are periodically reviewed through defined KPIs. |
| **Data warehousing architecture** | **Surrogate Data Marts:** Data is available through Management Reports or Spread Marts. No entity wide data warehousing architecture has been implemented. The warehousing architecture may not be rewieved | **Data Marts:** Data is available through Data Marts that are tailored to the needs of the data user and accessed via queries (seperate storage systems). No structured review process of data warehousing architecture is in place | **Data Warehouses:** Data is available through Data Warehouses that enable interactive reporting and cross-functional queries. The warehousing architecture may be reviewed incidentall. | **Enterprise Data Warehouses:** Data is available through Enterprise Data Warehouses that continuously merge all other analytic structures into themselves, leading to a single state of truth. The warehousing architecture is reviewed periodically | **Optimised Enterprise Data Warehouses:** Data is available through Enterprise Data Warehouses that continuously merge all other analytic structures into themselves, leading to a single state of truth. The warehouseing architecture is periodically evaluated through defined KPIs |

Objects

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| **Metrics Capabilities** | **Incoherent**: Available metrics do not provide a coherent picture of process performances within the entity and are poorly suited for validating decision processes. Metadata is not collected and tracing data and information streams (transformation, location or utilisation) is not possible. Improvement area identification is not possible. | **Inconsistent**: Available metrics provide an inconsistent picture of curret process performances within the entity and their suitability for validating decisions is limited. Metadata may be collected, enabling the tracing of data and information streams (transformation, location or utilisation). Improvement area identification is inconsistent. | **Consistent**: Available metrics provide a consistent picture of process performances within the entity and are suited to validating decision processes. Metadata is collected, enabling the tracing of data and information streams (transformation, location or utilisation). Improvement area identification may not be automated | **Advisory:** Available metrics provide a consistent picture of process performances within the entity, may provide automated improvement suggestions and are the basis for any decision processes. Metadata is collected, enabling the tracing of data and information streams (transformation, location or utilisation). Identification of metadata based improvements may be partially automated | **Prescriptive:** Available metrics provide a consistent picture of process performances within the entity, consistantly provide automated improvement suggestions and are the basis for any decision processes. Metadata is collected, enabling the tracing of data and information streams (transformation, location or utilisation). Identification of metadata based improvements is highly automated |

Objects

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| **Analytical tools and services** | **Incidentally descriptive:** Analytical tools and services are largely ineffective at fulfilling their purpose. They are exclusively descriptive, not automated and do not enable predictions. Usefulness of tools is highly dependend on the users' capabilities. The need for formalised analystical service requirements has not been defined. Tools and services are not reviewed. | **Inconsistently descriptive:** Analytical tools and services may be partially ineffective at fulfilling their purpose. They are exclusively descriptive, scarcely automated and do not enable predictions. Usefulness of tools is highly dependend on the users' capabilities. The need for formalised analytical services requirements has been defined, and an analysis of the analytical service requirements initiated. Specific service requirements have not yet been formalised. There is no formalised process to review tools and services | **Consistently descriptive:** Analytical tools and services are consistently effective at fulfilling their purpose. They are descriptive of both past and present states and may be partially prescriptive and automated. Although they are not predictive themselves, they provide the means for staff with the respective capabilities to make informed predictions and formulate prescriptive actions. Usefulness of the tools is proportional to the users' capabilities. The requirements for most analytical services have been formalised. Tools and services may be inconsistantly reviewed. | **Partially Predictive:** Analytical tools and services are consistently effective at fulfilling their purpose and possess capabilities that surpass current requirements. They are descriptive of both past and present states and may be partially prescriptive and predictive. Tools are highly automated, making human intervention an exception. Usefulness of the tools may be influenced by the users' capabilites. The requirements for all analytical services have been formalised. The requirements for all analytical services have been formalised. Periodic reviews of the tools and services assess their usefulness. | **Predictive:** Analytical tools and services are consistently effective at fulfilling their purpose and possess capabilities that surpass current requirements. They are descriptive, prescriptive, extensively predictive and highly automated, making the need for human intervention an exception. Usefulness of the tools is not significantly influenced by the users'capabilities. The requirements for all analytical services have been formalised. KPIs are used to review the tools and services periodically |

Definition of Terms

| Term | Definition |
|---|---|
| Analytical Services | DU processes that provide contextual information by utilising data or other information |
| Assessment Level | Level at which capabilities are assessed (entity, layer, dimension, etc.) |
| Assessment Level Approach | The assessment approach can be continuous (higher levels encompass all previous levels) or staged (levels require a specific set of criteria to be fulfilled for each level) |
| Assessment partner | Interview partner for the investigator who provides the information required to assess the organisation |
| Attribute | Distinguishable and identifiable traits that define the maturity level for each capability. |
| Capability | Ability to fulfil an intended purpose |
| Data | Qualitative and quantitative facts that were obtained through Metrics and have not been transformed |
| Data and information flow | Movement of data and information through the DU system |
| Data Loading processes | Load data chunks into data warehousing architecture in repetitive time cycles rather than continuously |
| Data Marts | Data Stores that are focused on specific business functions within the entity |
| Data Policy | Naming standards, privacy, security |
| Data transformation | Evolving data into information and combining sets of information |
| Data Warehouses | Data Stores that are focused on integrating data from all business functions throughout the entity into one single structure |
| Defined | Informally agreed and maybe not documented |
| Digitalised collection of data | Data is recorded digitally |
| Dimension | Distinct aspects of the organisation that are involved in the process of utilising data and are assessed for their maturity level. This is sometimes also referred to "as domain" |
| Dimensional Tensions | Varying levels of sophistication between dimensions which lead to inefficiencies and waste |
| Domain | See "Dimension" |
| DU task ownership role | Formalised role though which DU related responsibilities and privileges are defined |
| DU-Tools | Software and hardware that is involved in the DU process |
| Enterprise Data Warehouse | A singular data store that integrates and makes all of the information of the enterprise widely available |
| Entity | Abstract object to which the Maturity Model can be applied |
| External Data | Data that is not generated within the entity itself |
| Formalised | Formally agreed and documented. |
| Information | Results of structuring and processing data and other documents enabling knowledge |
| Internal data | Data that is generated within the entity |
| Investigator | Person carrying out the maturity assessment |

Definition of Terms

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| KPIs | Key Process Indicators that make performance quantifiable |
| Listed information | Changes to the listed information are not dynamically reflected throughout all instances of its existence and may require manual change |
| Management Reports | Static reports that are distributed to employees in regular time intervals |
| Manual collection of data | Data is recorded by hand in a non-digital format |
| Maturity Level | A linear scale quantifying different stages of maturity evolution, ranging from rudimental to exceptional. |
| Metadata | Data that enables an assessment of the data it contains information about |
| Metrics | Measurements focused on reporting performance of processes |
| Scope | An area of observation, application or general relevance |
| SLAs | Service Level Agreement for the creation of reoccurring reports or other services |
| Spread Marts | Spread sheets or desktop databases that function as surrogate data-marts |
| Tracked information | Changes to the tracked information are reflected homogenously throughout all instances of its existence in a largely automated and dynamic process |

Validation

| **Expert Information**<br>***Date:***<br>***Name (Optional):***<br>***Position:***<br>***Contact information:*** | | | | | | |
|---|---|---|---|---|---|---|
| **Criteria** | **Strongly Disagree** | **Slightly Disagree** | **Neutral** | **Slightly Agree** | **Strongly Agree** | **Comments** |
| **Maturity Levels** | | | | | | |
| The maturity levels are sufficient to represent, all maturation stages of the domain (Sufficiency) | | | | | | |
| There is no overlap detected between descriptions of level maturity(Accuracy) | | | | | | |
| **Layers and dimensions** | | | | | | |
| Layers and dimensions are relevant to the domain (Relevance) | | | | | | |
| The layers and dimensions cover all aspects impacting/ involved in the domain (Comprehensiveness) | | | | | | |
| The layers and dimensions are clearly distinct (Mutual Exclusion) | | | | | | |
| The level classification for the dimensions are correctly assigned to their respective maturity level (Accuracy) | | | | | | |
| **Maturity Model** | | | | | | |
| ***Comprehensiveness*** | | | | | | |
| The maturity levels are understandable | | | | | | |
| The assessment guidelines are understandable | | | | | | |

Validation

| | | | | | | |
|---|---|---|---|---|---|---|
| The documentation process is understandable | | | | | | |
| ***Ease of Use*** | | | | | | |
| The maturity classification scheme is easy to use | | | | | | |
| The assessment guidelines are easy to use | | | | | | |
| The documentation process is easy to use | | | | | | |
| ***Usefulness and Practicality*** | | | | | | |
| The MMACUDIE is useful for conducting maturity assessments | | | | | | |
| The MMACUDIE is practical for use in industry | | | | | | |

**Questions**

| | |
|---|---|
| Q1. Would you add any maturity levels? Please explain which and why? | |
| Q2. Would you update the maturity level description? Please explain how and why? | |
| Q3.Would you remove any of the layers? Please explain which and why? | |
| Q4. Would you remove any of the dimensions? Please explain which and why? | |
| Q5. Would you redefine/update any of the layers? Please explain which and why? | |
| Q6. Would you suggest any updates or improvements related to the classification? Please explain what and why? | |
| Q7. Would you suggest any updates or improvements related to the assessment? Please explain what and why? | |
| Q8. Would you like to elaborate on any of your answers? | |
| Q9. Could the model be made more useful? How? | |
| Q10. Could the model be made more practical? How? | |

## 6.2 Validation form pilot test

| **Expert Information**<br>***Date:11.Sep.2018***<br>***Position: Workcell Manager***<br>***Name: US*** | | | | | | |
|---|---|---|---|---|---|---|
| **Criteria** | Strongly Disagree | Slightly Disagree | Neutral | Slightly Agree | Strongly Agree | **Comments** |
| **Maturity Levels** | | | | | | |
| The maturity levels are sufficient to represent, all maturation stages of the domain (Sufficiency) | | | x | | | |
| There is no overlap detected between descriptions of level maturity (Accuracy) | | | | x | | boarders well defined |
| **Layers and dimensions** | | | | | | |
| Layers andl dimensions are relevant to the domain (Relevance) | | | x | | | |
| The layers and dimensions cover all aspects impacting/ involved in the domain (Comprehensiveness) | | | x | | | |
| The layers and dimensions are clearly distinct (Mutual Exclusion) | | | x | | | |
| The level classification for the dimensions are correctly assigned to their respective maturity level (Accuracy) | | | x | | | |

| **Maturity model** | | | | | | |
|---|---|---|---|---|---|---|
| ***Comprehensiveness*** | | | | | | |
| The maturity levels are understandable | | | | x | | |
| The assessment guidelines are understandable | | | | x | | |
| The documentation process is understandable | | | | x | | |
| ***Ease of Use*** | | | | | | |
| The maturity classification scheme is easy to use | | | | x | | |
| The assessment guidelines are easy to use | | | | x | | |
| The documentation process is easy to use | | | | x | | |
| ***Usefulness and Practicality*** | | | | | | |
| The MMACUDIE is useful for conducting maturity assessments | | | | x | | |
| The MMACUDIE is practical for use in industry | | | x | | | |

**Qualitative Questions**

| | |
|---|---|
| Q1. Would you add any maturity levels? Please explain what and why? | no, suggested updates were implement for the second assessment round |
| Q2. Would you update the maturity level description? Please explain what and why? | no, suggested updates were implement for the second assessment round |
| Q3. Would you remove any of the layers? Please explain which and why? | no, layers defined well |
| Q4. Would you remove any of the dimensions? Please explain which and why? | no, dimensions defined well |
| Q5. Would you redefine/update any of the layers? Please explain what and why? | no, layers defined well |
| Q6. Would you suggest any updates or improvements related to the classification? Please explain what and why? | classification definitions well done, differences well defined for understanding |
| Q7. Would you suggest any updates or improvement related to the assessment? Please explain what and why? | top to bottom questionnaire, high level explanation of classification, layers,… |
| Q8. Would you like to elaborate on any of your answers? | I would like to repeat the assessment going from high level to detailed questions |
| Q9. Could the model be made more useful? How? | see above |
| Q10. Could the model be made more practical? How? | no, clear structure and easily rateable |

## 6.3 Literature quality assessment

**Colour Legend**

**MT related literature**
**Maturity Models in general**
**Developed Maturity Models**
**Maturity Model Development Method**

| Primary Literature | |
|---|---|
| **Publication** | **Quality Score** |
| A capability maturity model for knowledge-based decisionmaking | 4 |
| A Capability Maturity Model for Scientific Data Management | 1 |
| A design science research perspective on maturity models in Information Systems | 5 |
| A framework for developing a domain specific business intelligence maturity model: Application to healthcare | 3 |
| A Knowledge Management Maturity Model and Application | 2 |
| A Maturity Model for Enterprise Data Quality Management | 4 |
| A maturity model for performance measurement systems | 3 |
| A Maturity Model of Enterprise Business Intelligence | 5 |
| A Model for Business Process Management Maturity | 3 |
| An innovation capability maturity model–development and initial application | 2 |
| An Overview of the Business Process Maturity Model (BPMM) | 3 |
| Assessing Enterprise's Knowledge Management Maturity Level | 2 |
| Assessing Organizational Capabilities: Reviewing and Guiding the Development of Maturity Grids | 4 |
| Business process management: 7th international conference, BPM 2009, Ulm, Germany, September 8-10, 2009, proceedings | 4 |
| Capability maturity for knowledge management | 1 |
| Closing the Loop: Evaluating a Measurement Instrument for Maturity Model Design | 3 |
| Construction supply chain maturity model–conceptual framework | 1 |
| Dealing with Complexity: A Method to Adapt and Implement a Maturity Model for Corporate Data Quality Management | 4 |
| Developing Maturity Models for IT Management: A Procedure Model and its Application | 5 |
| Development of maturity models: a systematic literature review | 3 |
| E-government maturity models: Extension of the Layne and Lee model | 2 |
| From Business Intelligence to Data Competencies: Insights from the CGMA Data Competencies Model | 1 |
| Gauge your data warehouse maturity | 1 |
| Holistic Development of Knowledge Management with KMMM® | 2 |
| Integrated management systems assessment: a maturity model proposal | 3 |
| IQM3: Information Quality Management Maturity Model | 3 |
| Maturity Assessment Models: A Design Science Research Approach | 3 |
| Maturity levels for interoperability in digital government | 4 |
| Maturity model of Knowledge Management in the interpretativist perspective | 3 |
| Maturity models in business process management | 2 |
| MD3M: The master data management maturity model | 5 |
| Measurement of knowledge management maturity level within organizations | 2 |
| Measuring chain digitisation maturity: an assessment of Dutch retail branches | 3 |

| | |
|---|---|
| Moving toward a knowledge management maturity model (K3M) for developing knowledge management strategy and implementation plans | 3 |
| Organizational self assessment of knowledge management maturity | 2 |
| Project management process maturity (PM) 2 model | 3 |
| Project maturity in organisations | 2 |
| TDWI Big Data Maturity Model Guide: Interpreting Your Assessment Score | 2 |
| The development of a supply chain management process maturity model using the concepts of business process orientation | 1 |
| The Integrated Knowledge Management Maturity Model | 3 |
| The Lean Management Maturity Self-assessment Tool Based on Organizational Culture | 1 |
| The Maturing of a Business Intelligence Maturity Model | 5 |
| Towards a business analytics capability maturity model | 5 |
| Towards a business process management maturity model | 4 |
| Towards a Capability Maturity Model for Information Quality Management A TDQM | 2 |
| Towards a Classification of Maturity Models in Information Systems | 2 |
| Towards a holistic knowledge management model | 2 |
| Towards a maturity model for corporate data quality management | 2 |
| Understanding_the_Main_Phases_of_Developing_a_Maturity_Assessment_Model.pdf | 5 |
| Intelligence | 4 |

| **Secondary Literature** | |
|---|---|
| **Publication** | **Quality Score** |
| A formal specifications maturity model | 3 |
| Assessing Organizational Capabilities: Reviewing and Guiding the Development of Maturity Grids | 5 |
| Capability maturity model, version 1.1 | 4 |
| Development of a lean enterprise transformation maturity model | 5 |
| How ISO 9001 compares with the CMM | 2 |
| Information asymmetry and information sharing | 2 |
| The Design of Focus Area Maturity Models | 5 |
| Which Maturity Is Being Measured? A Classification of Business Process Maturity Models | 2 |
| A Data Quality Management Maturity Model | 5 |
| Approach to building and implementing business intelligence systems | 3 |
| Business intelligence as a knowledge management tool in providing financial consultancy services | 2 |
| The BI-Based Organization | 3 |
| Information revolution: using the information evolution model to grow your business | 3 |
| Organization Theory: Structures, Designs, And Applications, 3/e | * |

* Full text could not be found, but direct quote was in primary literature

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# 10 Abbreviations

**BDU – B**ig **D**ata **U**tilisation

**BIM** – **B**usiness **I**ntelligence **M**anagement

**BPM** – **B**usiness **P**rocess **M**anagement

**CV** – Content Validity

**DQM – D**ata **Q**uality **M**anagement

**FV** – Face Validity

**IE** – **I**ndustrial **E**nterprises

**IS** – **I**nformation **S**ystems

**KM** – **K**nowledge **M**anagement

**LESAT** - **L**ean **E**nterprise **S**elf-**A**ssessment **T**ool

**MMACUDIE** - **M**aturity **M**odel for **A**ssessing the **C**apability to **U**tilise **D**ata in **I**ndustrial **E**nterprises

**MT** – **M**aster **T**hesis

**SLR** – **S**ystematic **L**iterature **R**eview