A FRAMEWORK TO EVALUATE THE BENEFITS OF CONFIGURATION MANAGEMENT IN THE AEROSPACE INDUSTRY

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ABSTRACT

This thesis has been written to deliver a contribution to knowledge in the field of measuring the value of Configuration Management (CM). CM is a management method that ensures that the customer receives the product according to his requirements and can operate it according to the specification and functional as well as physical attributes over the entire life cycle. This study will bridge the knowledge gap which exists within this field of study and will provide both theoretical insights for academics and the general research community, as well as practical knowledge for practitioners working within the Aerospace Industry. The methodology used in the study is the constructivist approach.

In order to meet the research aims and objectives an exploratory, qualitative data collection process has been adopted using semi-structured interviews. A sample size of thirteen semi structured interviews were undertaken with the experts in Configuration Management of several Aerospace Companies. The main purpose of the thesis was to explore important issues related to the measuring process and optimisation of Configuration Management. A thematic approach was used to analyse the data.

From the results, a theoretical framework has been created to show the possibilities of measuring the value of CM, with a view to convincing senior management of the usefulness and practical implications of this discipline. It has been shown that totally new business models are possible through the appropriate use of CM.

The existing measuring systems have more or less elaborate metrics. The central result of the work is that not every company needs the same degree of CM, rather a weighting is necessary in the application of CM, which has to be carried out primarily on the basis of the three themes complexity, individualization and potential. A certain level of input from CM application does not lead to the same level of output for every company. It is ensured that the result is relevant for the development potential of the investigated company and there is concrete economic significance for the future.

DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Gloucestershire and is original except where indicated by specific reference in the text. No part of the thesis has been submitted as part of any other academic award. The thesis has not been presented to any other education institution in the United Kingdom or overseas.

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LIST OF PUBLICATIONS

Conference Papers

1. Manuel Maier (2015). A Framework to Evaluate the Benefits of Configuration Management in the Aerospace Industry and its Relevance for other Industries. **12th International CIRCLE Conference** University of Szczecin, Poland

2. Manuel Maier (2016). What impacts have the use of Configuration Management to steer the business process infrastructure on the future of Management **13th International CIRCLE Conference** Naples, Italy

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ABBREVIATIONS

ATA	Air Transport Association
BSC	Balanced Scorecards
CI	Configuration Item
CA	Constituent Assembly
CAT	Category
CHM	Change Management
CM	Configuration Management
CMII	Configuration Management II (old writing style)
CM2	Configuration Management 2 (new writing style)
Cw	Compare with
DC	Dataset Control
DE	Determination Element
DIA	Degree of Implementation Actual
DIT	Degree of Implementation Target
DM	Data Management
DOA	Design Organisation Approval
DoD	Department of Defence
DQN	Design Query Note
EBIT	Earnings Before Interest and Tax
EC	External Complexity
ESA	European Space Agency
EST	Enabling Software Tools
EVA	Earned Value Added
FAL	Final Assembly Line
FDR	Final Design Review
ICAO	International Civil Aviation Organization
ICM	Institute of Configuration Management
IPX	Institute for Process Excellence
IV	Influencing Value
MGT	Management
MHI	Mitsubishi Heavy Industries
MLGB	Main Landing Gear Bay

MOD	Modification
MSN	Machine Serial Number
MTBS	Maintenance Time Between Stoppages
N	Performance Indicator
NASA	National Aeronautics and Space Administration
NP	Net Profit
NRC	Non Recurring Cost
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
PCA	Physical Configuration Audit
PDCA	Plan-Do-Check-Act
PDM	Product Data Management
PDR	Preliminary Design Review
PLM	Product Lifecycle Management
PM	Project Management
POA	Production Organisation Approval
Q	Quality Department
QDI	Quotient of the Degree of Implementation
QM	Quality Management
RC	Recurring Cost
RCM	Records Management
RFP	Request for Proposal
RFD	Request for Deviation
RLM	Release Management
RM	Requirement Management
TAKSY	Technisch Administratives Konfigurationsdaten System
TDP	Technical Data Package
TRS	Technical Repercussion Sheet
V	Value (in case of subjective assessment)
WC	Working Capital

DEFINITIONS

Important terms of this work are defined as follows:

CDR Critical Design Review:

A technical review assesses the system final design as captured in item detail specifications for each configuration item in the initial product baseline, and ensures that technical data package of each configuration item is included in the product baseline. It establishes the initial product baseline (DAU, 2018a).

Configuration Item:

A special identity given to a configuration to signify that it is being controlled by the configuration management process (Guess, 2012).

CM Configuration Management

Configuration management is a management discipline which ensures that the customer receives a product with individually compiled properties and that this product can be used over the entire product life cycle, as all the necessary individual product data can be accessed at any time, and is always kept up to date.

CM2

CM2 (old writing style CMII) is an industry and tool-neutral process that can be used throughout the company and covers all areas of configuration management. The core of CM2 is a closed change process. This ensures that, without bureaucratic overheads, requirements are defined first and then products are updated. The CM2 method, when fully implemented, provides the entire infrastructure for handling business processes.

DIA Degree of Implementation Actual

The DIA is the measured and weighted value between 0 and 1 at which the Configuration Management is operated in a company at the measured point of time.

DIT Degree of Implementation Target

The DIT is the measured and weighted value between 0 and 1 which when applied the configuration management in a specific company would bring the optimal benefit at the measured time.

FDR Final Design Review:

A formal technical review of prototype detailed design approach for a CI or CSCI including evaluation of progress, technical adequacy, and risk resolution on a technical, cost, and schedule basis (Lapham, 2006).

Performance:

This is a quantitative measure characterising a physical or functional attribute relating to the execution of an operation or function. Performance attributes include quantity (how many or how much), quality (how well), coverage (how much area, how far), timeliness (how responsive, how frequent), and readiness (availability, mission/operational readiness). Performance is an attribute for all systems, people, products, and processes including those for development, production, verification, deployment, operations, support, training, and disposal. Thus. supportability parameters, manufacturing process variability, and reliability are all performance measures (ANSI/EIA-649, 1998).

PDR Preliminary Design Review:

The PDR assesses the maturity of the preliminary design supported by the results of requirements trades, prototyping, and critical technology demonstrations. The PDR will establish the allocated baseline and confirm that the system under review is ready to proceed into detailed design (development of build-to drawings, software code-to documentation, and other fabrication documentation) with acceptable risk (DAU, 2018b).

PLM Product Lifecycle Management

Product lifecycle management (PLM) is a concept for the continuous integration of all information that is generated during the lifecycle of a product. The concept is based on coordinated methods, processes and organizational structures and usually uses IT systems for recording and managing the data.

QDI Quotient of the Degree of Implementation

The QDI reflects the current level of application of CM in a specific company. This value is obtained by dividing DIA and DIT. If the value is one, the CM is applied in the optimal amount for the specific company. If the value is less than one, too little CM has been applied and if the value is greater than one, too much CM has been applied.

Chapter One: INTRODUCTION

1.1 Research Motivation and Overview

The aerospace industry is a highly regulated industry (Harvey & Holdsworth, 2005). There are several reasons for this, but mainly due to high safety requirements. Normally, aircraft are used for a very long time, with usage times of 40 years and more not uncommon (Boller, 2001). This places special demands on Product Lifecycle Management (PLM) and Configuration Management (CM) in particular. This study defines CM as a management discipline which ensures that the customer receives a product with the individually compiled properties and that this can be used over the entire product life cycle, as all the necessary individual product data can be accessed at any time and is always kept up to date, which concurs with writers such as Guess (2013), Sorrentino (2009) and Hass (2003). In the aerospace sector, there are therefore strict official requirements as to which minimum requirements the specific companies in the aerospace sector must meet (Hinsch, 2017). For example, the installation of serial numbers of mandatory parts and assemblies must be precisely documented and the information must be kept for 20 years following the operating life of the aircraft in question. Airlines must also accurately document the replacement of serial numbers of mandatory parts during repairs and maintenance. In the other direction of the supply chain, the obligation to provide documentation sometimes goes back to the raw material. For raw material and chemical processing, such as chemical milling, this system-side documentation is particularly demanding and important, since no documentation is possible directly on the component. In this case, the machining process does not permit any physical marking on the component.

In view of the rapidly changing information and storage technologies, these requirements represent a major challenge (Burgess, McKee, & Kidd, 2005). This is particularly evident in very deep and complex supply chains worldwide. Computer systems and programs must therefore function under these requirements for at least 60 years, or the data must be migratable to newer systems without any problems. This requirement is particularly relevant and important in the aerospace industry. During the last decades the data structures

have become more and more extensive and complex due to new requirements and new computer systems, and therefore the data formats are changing.
In contrast to many other technology areas, the aerospace industry has an official obligation to perform CM according to certain basic requirements. An important reason is the need for traceability of parts, especially in the event of an accident. In this way, the machines, in which defective parts may have been installed, can be identified and checked without the entire fleet having to be decommissioned. Authorities therefore have a very large influence on CM in the aerospace industry.
The aerospace industry therefore differs significantly in the CM area from land vehicles, where the basic requirements are significantly lower. In the aviation industry, the OEM such as Airbus normally has to meet the highest requirements. The deeper you go into the supply chain, the lower the requirements usually are in CM. The basic requirements for CM must be met by all aerospace companies (Rusu, 2019).

1.2 Research Problem

Companies often only implement CM because it is required by authorities. Some companies seem to make enough CM but not the right type of CM for the specific requirements of the company (Lyon, 2000). The senior management must rely so far solely on statements from the specialized department CM. However, as these are mainly technical experts, there is no cross-departmental overview, which is essential for company-wide decisions. Therefore, no CM related decisions which have influence on costs and benefits for the whole company can be overviewed because the coverage of the CM on individual departments or on the whole company is not sufficiently understood (Ali & Kidd, 2013).
For many companies in the aerospace sector, however, a further application of CM can be advantageous. This has already been investigated in several scientific articles (Burgess et al., 2005). One example is the Swiss aircraft manufacturer Pilatus, which no longer sells the training aircraft to the operator. Pilatus sells only flying hours together with the necessary maintenance. This is only possible if CM is applied in a very advanced way because the operation centre can see exactly when specific works and spare parts are necessary.

Despite the importance of applying CM, it is currently very difficult to know the costs of performing CM, and it is equally difficult to know the costs and consequences of not performing CM (Burgess, Byrne, & Kidd, 2003). The information which is currently available from academic literature is limited. The existing literature is mainly restricted to the application of CM in a single company (Guess, 2013), and the findings are not applicable to an entire industry. Thus, a more generalised framework is called for (Burgess et al., 2003). Other studies such as Staats (2009) are restricted to studying only KPIs, but this is acknowledged by Burgess et al. (2003) to be insufficient. There is also a diversity problem regarding measuring CM. For example, many different companies in the aerospace sector often work together; each project and product has a long life cycle, and as the organisation of many projects and products are complex, there are many different functions which have to work together (Burgess et al., 2003). There are already models available to determine the current scope of CM used in a company (IPX, 2018). However, these models are not able to determine the requirements sufficiently. In addition, there is no market data published to date which shows or provides an indication of the influence of using CM and what it brings to a company from a financial perspective. In general, there is no sufficient weighting possibility to use the framework for different companies. It would therefore be necessary to determine what the company already does and to what extent it makes sense for the specific company. Advanced CM can open up new business models and move companies towards Industry 4.0. It has even been said several times that industry 4.0 is not possible without CM.

The following simple model can be seen as the basic starting point for this work.

Figure 1-1: Input and Output of CM

The basic question that arises in this work is therefore the question of how the optimal OUTPUT can be achieved for the specific company with the optimal INPUT from CM. In this model CM is represented as a black box because only the input and the output can be seen. What CM does and the fact that the internal connections are not visible in this simple model is the starting point for this thesis to investigate the CM to provide further depth of explanation. The black box CM has to be decoded and schematically prepared. The great complexity and multi-disciplinarity, which makes it difficult to see an overview, poses a significant challenge.

1.3 Research Objectives

The senior management has to be supported in its decisions because the system which is influenced by CM is too complex to have an overview (Watts, 2009). As companies expand, products and supply chains become more complex, and CM controls not only products, but also entire processes. When this happens it becomes increasingly difficult to recognise the effects of the application of CM and to draw conclusions about the benefits of CM. This means CM influences not only all departments of a specific company, but it also has influence on the whole supply chain and all the customers along the entire product lifecycle. Both the input and output capabilities of CM have an unmistakable diversity, as do the CM processes themselves within the black box (Burgess et al., 2003). Therefore, it is necessary to develop a framework to generate practicable application schemes in a variety of possibilities. Even changing a single input size can have a wide variety of effects on both processing and output. For example, an investment in a PLM system can impact suppliers, entire systems, reduce rework, improve data quality, and improve the physical product. The output from CM here is correct product data structures and the resulting as-built configuration list. In addition, profitability can also improve. The question is whether it is worth the effort, or if the benefits are lower than the costs.

There are various preliminary works on the topic of measuring the benefits of CM. Staats (2009) has defined KPIs in her work. (Boller, 2001); IPX (2018) has worked on how to define the current status. What has not yet been worked out, however, is the weighting of the various factors which influence the necessity of

the degree of application of CM. These factors include different company internal or external complexities, or different potentials for the investigated company. In addition, various parameters have been brought together that have not been connected so far. This means that the current applied weighted fields of CM of a specific company have been compared with the current weighted requirements for CM for complexity and potential. This is achieved by introducing the Quotient of the Degree of Implementation (QDI) by dividing the Degree of Implementation Actual (DIA) by the Degree of Implementation Target (DIT).

In order to decipher this problem and to define the correct procedure, experts in the field of aerospace were interviewed. To develop a usable framework from the interviews the corresponding requirements were identified and evaluated. In addition to CM experts, CM consultants, executive management in companies as well as government consulting aerospace experts and representatives of public authorities were interviewed. In the interviews, the corresponding requirements according to their expectations for measurements were identified and evaluated. A balanced composition of the interviews is particularly important in order to meet the needs of all stakeholders.

As a result of the interviews, an optimal solution in the form of a framework was developed. According to the experts, a particularly important starting point is the lack of an integrated overview of the CM of the company's strategy and corresponding product. In order to be able to use CM optimally, especially in the near future with ever faster product life cycles, it is important to strategically consider precisely what the products must be able to do with regard to Industry 4.0. The CM must be adapted in time to meet the resulting requirements. This fact was considered in the development of the framework by concentrating on the three core concepts of individualization, complexity and potential. The core concepts were identified from the analysis of the interviews as the most important factors with the highest influence on DIT. To keep the framework usable in the daily business the creation of the DIT is concentrated on complexity and potential.

The resulting framework has the basic requirement of being easy to understand and being able to show with a single number whether CM is used in the appropriate scope in the corresponding company. However, it is also possible to go deeper into the different survey levels and core concepts and to identify individual requirements. This basic requirement makes the framework interesting

for management decisions because, on the one hand, global statements are possible in a simple way and, on the other hand, detailed findings can be called up which can be used for fine adjustments in CM in the respective company. This is made possible by a continuous weighting system, which is used both for the determination of the already used CM as well as for the possible requirements. The development of the weighting system is to be regarded as the main contribution of this thesis. It is adaptable to the certain needs of a company and can be easily tailored to any company in the aerospace industry regardless on which level in the supply chain the company is. Thus, this framework is adjustable to any kind of company in the aerospace industry and this makes it unique and delivers a contribution to the knowledge in this area.

1.4 Research Questions

From the research aims and objectives, the following research questions have been developed to find answers regarding the theoretical use of CM with a practical implication.

1. What are the specific qualitative and quantitative measurable benefits of configuration management in the aerospace industry?
2. What key performance indicators (KPIs) can be used to measure the value of the CM in the aerospace industry and determine their effectiveness?
3. How could performance indicators be used to establish a useful evaluation framework for configuration management in the aerospace industry from a management perspective?

1.5 Research Aim

The aim of this academic work is to optimise the application of CM according to the individual needs of different specific companies in the aerospace industry. For this purpose, it is necessary to be able to measure the current application of CM in an individualised way in all the companies to be investigated. In addition, the optimal individual degree of application of CM needs to be determined for the specific company. The final goal of the study is thus to be able to optimise CM individually to the needs of the company by measuring the benefits of CM.

1.6 Thesis Overview

This section provides a brief overview of each remaining Chapter of this thesis.

Chapter Two provides an overview and discussion of the relevant literature in the research area of CM. In the beginning the rationality of the systematic literature review is explained and how it informs the developed theoretical argument. The literature review then focuses on the barriers to the introduction of configuration management. The vast majority of barriers to the performance-optimal implementation of CM systems are based on a lack of understanding of senior management. (Ali & Kidd, 2013).

This is due to the fact that so far there have been no suitable general measurement tools that consider the various complex interrelationships that the use of CM causes in the individual business areas. Existing measurement systems for the benefits of CM, such as that of Guess (2013), are limited to measuring the decrease in physical rework on the product. In addition, especially in recent years, there have been more advanced methods to measure the effectiveness of the CM process and its value to the organization such as the white paper CMII-840B (ICM, 2016), and Staats (2009). However, the gaps in the existing systems apply to a specific company. In this context, Staats (2009) points out in the limitations of their work that their system can only be used for a specific company. There are also highly advanced systems for measuring the current application status of CM, such as IPX (2018), but these are also tailored for use in a specific company.

The Chapter concludes by highlighting that it is necessary to eliminate the existing barriers responsible for the introduction of suitable CM systems. This is to be achieved by developing a framework for measuring the benefits of CM that is generally valid for different companies in the aerospace industry. The aim is to provide the management with a suitable tool to control the optimized use of CM.

Chapter Three provides a justification of the adopted methodological approach. With respect to their suitability for the topic of this study, different research paradigms and approaches have been considered. This study's research philosophy follows a constructivist rationale within an interpretivist paradigm. Due

to its universal applicability to qualitative data, its usability for cross-disciplinary research questions and its flexibility, a thematic approach is followed (Robson, 2016). Selection criteria and a selection technique for the interviews of this study are included in this Chapter. The design of the interview questions is described. The purpose, role and outcome from the pilot study is set out as to how it informs the main interviewing activity. The interview guide revisions made after the pilot study are presented as well as its influence on the interview technique, approach, and data analysis.

Chapter Four analyses all interviews following a thematic approach. For this purpose, all interviews are examined according to the defined themes. The themes are grouped into individual segments according to the defined coding and then analysed and interpreted. The defined themes consist of two main themes and three supporting themes. The main themes are defined as complexity and potential opportunities, and the three supporting themes are identified as individuality, costs and industry 4.0. By using the data generated from the analysis and interpretation of these themes, it is possible to develop the desired framework in Chapter five, the discussion.

Chapter Five critically discusses in a derivative way how the framework was created. First the measuring process is discussed theoretically, and the scales are described. In the next step the quotient of the degree of implementation (QDI) is defined. This is the most important parameter resulting from the application of the framework generated in this study. Then the fundamental structure of the framework is presented as the measuring systems in the CM-sector of different order. The Chapter derives the formulas or data bases for the DIA and the DIT. The most important contribution of this framework is the introduction of weighting factors and their application. In deriving the DIT, a distinction is made between external complexity, internal complexity and potential opportunities. The verification of the framework is carried out by two experts who reviewed the results in an interpretative way. Finally, the problem of prediction and the technical aspect of the predictability of the future are discussed.

Chapter Six brings the literature and the empirical findings together into a coherent and structured discussion by revisiting the research questions and the evaluation of to what degree they have been addressed. This shows how the fundamental structure of the framework has been theoretically developed and derived from research. Finally, the application of the developed framework in other areas and the academic perspective are presented.

1.7 Chapter Summary

The aerospace industry is characterised by enormous complexity, which will continue to increase strongly with further technical development. The aerospace industry also has to meet the highest safety standards, which must be mastered. Senior management needs information and a comprehensive understanding across all company divisions in order to be able to use the CM instrument in an optimised way. In addition, there is a great need to properly evaluate and optimise CM across the entire supply chain and operational life of the product. The existing measurement methods do not come close to meeting this requirement and this gap has to be closed in this thesis.

Chapter Two: SYSTEMATIC LITERATURE REVIEW

2.1 Introduction

This Chapter will provide an overview and discussion of the relevant literature in the research area of CM. By comparing the different literature sources, central topics related to CM in the aerospace industry are identified. The Chapter will critically present and critique both qualitative and quantitative related literature with the aim of setting out the current understanding of CM in the aerospace industry. The theoretical and practical CM literature has focused on the measurement of performance, the usage of KPI, barriers, complexity, potential and depth of CM and its application. This Chapter provides an overview of existing research related to this discipline, even if the research is still in its infancy. Since CM is a key function in the company, as it controls not only technical changes, but also, process changes when applied intensively, it should arguably include all company departments, not only technical, but also economic and management departments. Therefore these aspects have been included in the literature search.

2.2 Central purpose of the literature review

The purpose of this literature review is to compare this extensive commercial project with existing knowledge. The main purpose of the process is to capture and evaluate the current academic area, which is commonly considered to be one of the major purposes of literature reviews (Saunders, Lewis, & Thornhill, 2012; Tranfield, Denyer, & Smart, 2003). From this, an understanding of the current state of knowledge can be derived, including disputes, opinions and trends. The literature review ensures that any gap in current knowledge is addressed, by checking all sources identified as applicable and by investigating that the research questions have not yet been solved. The literature review also helps to concretise and, if necessary, to adapt the research questions. Furthermore, it is examined whether there are additional research opportunities. The literature review also further supports the following research steps by collecting supporting data for the topic in the area of CM and related disciplines. This knowledge, for example in the area of Industry 4.0, which is not possible

without the intensive application of CM, can be seen as a by-product supporting data of the literature review. The supporting data can be seen as an abstract list of information that helps in the development of questions for the interviews, in order to get information on how the benefits of CM can be universally measured in different companies of the aerospace industry. In this approach, the literature on the competency needs of CM is considered in the model development process. According to Rodriguez, Patel, Bright, Gregory, and Gowing (2002) a comprehensive literature review is the start of competency model development.

2.3 Narrative Reviews

Narrative reviews are the classic procedure for literature reviews that do not typically describe the review methodology (Bettany-Saltikov, 2012). They are primarily founded on the expertise and subjectivity of the author, who is often specialised in the subject area. Nevertheless, they are commonly used by scientists today and, if done correctly, can deliver a critical analysis of the latest publications and current knowledge on a particular issue (Cipriani & Geddes, 2003). Usually narrative reviews are extensive because they address a broad spectrum of topics. However, they frequently give no indication of how the sources included have been incorporated in terms of validity and relevance (Collins & Fauser, 2005). Narrative reviews are intuitive summaries of particular research results (Johnson, 1989) and, compared to systematic reviews, have the benefit that they can cover much broader questions. More flexibility and space allow the researcher to question the statements and sources as well as his ideas and the underlying presumptions in more detail. This is achieved through a targeted selection of key documents and concentration on specific issues in an area of investigation. Recent innovations, present conditions and arguments are discussed in narrative reviews in the focused fields of investigation. This makes it possible to design theoretical frameworks and provide new views with the aim of correcting gaps, omissions or identified weaknesses in the chosen key documents (Rumrill & Fitzgerald, 2001). Especially for practitioners who want to carry out a literature review, the narrative review is a good choice because it is less time-consuming than the systematic review (Leff & Conley, 2006).

The crucial weakness of narrative reviews, however, is that the reviewers may have different views on what are the most important authors and key texts for a

subject area and how they have been selected (Dijkers, 2009; Ladhani & Williams, 1998).

2.4 Systematic reviews and reviews in management research

Systematic reviews, unlike narrative reviews, provide an overview and summary of sources, which also allows conclusions to be drawn about methods applied, materials used and the objectives (Boland, Cherry, & Dickson, 2017). The systematic review represents a synoptic - comparative connection between the works according to a defined methodical procedure. In order to identify relevant publications, systematic reviews use established and proven procedures that select the literature using targeted thematic criteria. Specific criteria are applied to avoid subjective colouring of the literature review by the reviewer. Relevant unambiguous methods that are comprehensible, verifiable and understandable are used. Due to the advantages mentioned above, systematic literature reviews are regarded as high-quality sources of evidence (Tranfield, Denyer, & Smart, 2003).

Especially in scientific research, where the results are used by the management for important decisions in the company, the systematic review as a working basis is of decisive advantage, because transparency and reliability are necessary in decision-making processes. This is confirmed by Dixon-Woods, Agarwal, Jones, Young, and Sutton (2005), Tranfield et al. (2003). The limitation to one type of evidence could have the inappropriate consequences that any inconsistencies or discrepancies within the available literature remain undetected. The limitation to one type of evidence could have the inappropriate consequences that any inconsistencies or discrepancies within the available literature remain undetected (Dixon-Woods et al., 2005). Tranfield et al. (2003) also see the need to apply systematic reviews to the management field because this context-oriented research makes it possible to generate a sustainable knowledge base. The aim of knowledge accumulation is usually to provide solutions for particular management problems or proven and grounded technological rules (Aken, 2004). While a systematic literature review (SLR) was developed and is generally used to compare quantitative information, Noblit and Hare (1988) developed a systematic approach allowing a qualitative study using the SLR methodology. In methodologically weighing the different strengths of narrative and systematic literature reviews, Dijkers (2008) argues that the most effective

way to use them depends on the purpose of the research. Applied to the present study, this means: to generate the intended framework, it is necessary to generate statements of value and substance as well as structural connections, which is why, firstly, clearly defined and transparent methods for locating and evaluating the literature are required and, secondly, which fulfil the academic requirement of objectivity and reproducibility (Collins & Fauser, 2005). Since systematic literature reviews meet this requirement profile to a high degree, they are widely valued in literature work as evidence of high quality research (Tranfield, Denyer, & Smart, 2003).

Since the framework to be developed is intended to serve as a tool for senior management decision-makers, and needs to access evidence-based information for this purpose, the recommendation of Tranfield et al. (2003) to take advantage of a systematic literature review for this purpose should be followed. It provides the tools to provide a reliable and high-performing knowledge base for the target group of decision-makers in the course of the research.

The literature examined in this Chapter is divided into the fields of configuration management, value measurement and Product Lifecycle Management.

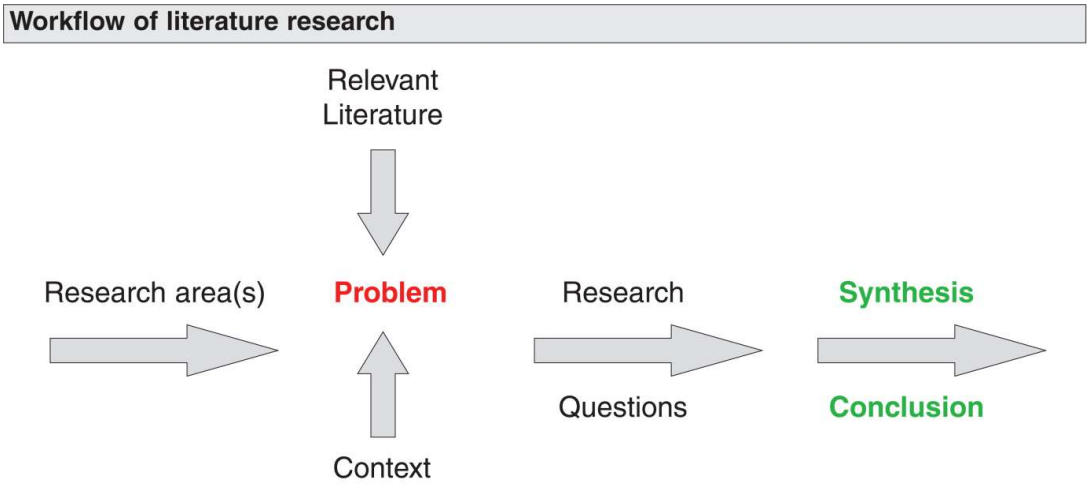

Figure 2-1: Workflow of the Literature Research

2.5 Literature Search Strategy

The systematic literature review in this thesis is conducted following the recommendations of Hart (2011).

Hart defines the literature review as:

> "The selection of available documents (both published and unpublished) on the topic, which contain information, ideas, data and evidence written from a particular standpoint to fulfil certain aims or express certain views on the nature of the topic and how it is to be investigated, and the effective evaluation of these documents in relation to the research being proposed" (Hart, 2011, p. 13).

The thorough review and synthesis of the literature has been undertaken using the methods described in Chapter Three. Furthermore, literature in the German language has been considered. Conceptual linking between different theories has been included. For example, one important aspect of value measuring is to validate the reduction of rework. Therefore, the theory of rework measuring has been added to the literature review process. In addition to the summative evaluation, a formative (structured) evaluation has also been performed on all the literature (Hart, 2011).

The aim of the literature review was to answer the following questions:

- What are the key sources?
- What are the major issues and debates about the topic?
- What are the political standpoints?
- What are the origins and definitions of the topic?
- How is knowledge on the topic structured and organised?
- What are the main questions and problems that have been addressed to date?
- What are the epistemological and ontological grounds for the discipline?
- What are the key theories, concepts and ideas?

Selective Criteria for this systematic review: The critical arguments of the quality of literature, the completeness and new ideas for my work.

2.5.1 Key Words

The following key words have been used for the search process of the literature review:

1. Accommodate change
2. Configuration management
3. Consistent conformance
4. Requirements management
5. Continuous improvement
6. Business process infrastructure
7. Clear, concise and valid
8. Corrective action
9. Closed-loop change process
10. Intervention resources
11. Fast-track changes
12. PLM software tools

2.5.2 Search Engines

For this research, the main search engines used were Discovery, Emerald and Google Scholar, because they are the most used and also provide the most and best search results and are therefore the most recognised.

2.5.3 Literature Comparison

Table 2-1 compares the most important literature using the following attributes to produce an overview for the reader. The attributes have been selected to sort the literature into a specific relevance for the research topic. The selected attributes include the type of publication, characterisation of publication, questions / objective, object of investigation, data base, method, theoretical approach / central concepts or model, important results / answer to the research question, strengths of the publication and weaknesses of the publication.

Among the key authors in the area of configuration management (CM) is Guess (2006), who has published a book which focused on CM standards. Guess (2006) showed that CM goes far beyond the original approach and is most suitable for the management throughout the entire process structure contending that CM becomes increasingly important when the projects are complex. While

the perspective of Guess (2006) is informative, the approach advocated to measure the rework of physical products has significant gaps in the area of how service providers can effectively measure their CM success. Lindkvist, Stasis, and Whyte (2013) agree with Guess (2006) noting that CM is increasingly important due to the amount of data which organisations need to deal with which has led to increased complexity. In reaching this conclusion, Lindkvist et al. (2013), in their comparative study into airline companies and other related industries, argue that for CM to be successful there needs to be accurate data integrity, as key a feature of CM. While the study provided a rich insight into the airline sector, the study neglected as how to effectively measure the value of CM. The value of CM can vary greatly in different companies and cannot always be measured directly in monetary terms. Staats (2009) earlier focused on how to measure the efficiency and effectiveness of CM. Here Staats (2009) contended that measurement tends to be relatively unproblematic in companies that produce physical products. However, due to the complex interfaces of service orientated companies, this can make defining and identify success problematic. Mirroring Guess (2006), Ali and Kidd (2013), Staats (2009) does recognise that there is a necessity to measure the outcomes of CM, and to ensure these results are visible. The rationale for Staats (2009) perspective is based on the insight that CM and its functions are too little known in many companies, especially in management.

This perspective is interesting particularly when considering that a common issue is that management has difficulty in quantifying the benefits of CM, as the concept, unlike production outcome, is often intangible. The study of Staats (2009) shows the importance and benefits of CM through the usage of metrics developed to measure efficiency and effectiveness. These measurements tend to be based on KPIs which provide a very clearly defined schema created specifically for a company or project. The KPIs are selected according to the specific needs of the company, and therefore this creates a predefined framework which cannot be used as a general valid template (Guess, 2006).

Studying CM in the European aerospace industry perspective, T. Burgess, D. McKee, and C. Kidd (2005) using a mixed method found that the sector perceived KPIs and CM as providing limited benefit. The study of T. Burgess et

al. (2005) found that only 25% of companies relied on their metrics to measure CM performance. Of the indicators used, the study argued that the sector tends to see CM as being a passive management activity which was often poorly managed, bringing limited benefits to the company. There are big differences in the use of CM between first tier companies and second tier companies. First tier companies have greater benefits from CM and therefore apply CM more. This is because the products and the effort behind them are more complex for the first tier companies because, among other things, a more extensive supply chain has to be managed. T. Burgess et al. (2005) found that there was limited management support for CM, which Ali and Kidd (2013) argued could be attributed to a lack of management support for the configuration manager. T. Burgess et al. (2005) noted that CM could provide benefits to companies both in a project context and potentially beyond in the operational environment, which included the area of social and environmental responsibility, but often CM effectiveness is impacted by various obstacles. Ali and Kidd (2013), in examining potential obstacles to the successful application of CM in both in the aerospace and defence industries, found aerospace companies have ranked CM barriers higher than any other industry, which means that CM topics have additional importance. This is reflected in the fact that aerospace industry professionals perceive these barriers as being more important in the implementation of CM than those of the defence industry. This means that the aerospace industry would need special attention in planning actions and avoiding these barriers in order to improve its CM practices. Of particular importance for this study is the finding that most barriers to the introduction of effective CM are directly or indirectly due to a lack of management support. There is a lack of academic knowledge to measure the degree of effectiveness, and consequently the benefits for different companies in a generally valid way. Due to this gap, the benefits of CM are currently neither sufficiently recognisable nor sustainably communicable for decision-makers.

Reisenweber, Vorspel-Rüter, and Regelmann (2009) examined the influence of short product lifecycles, branched supply processes and increasing customer requirements on the cost structure of a company. The study found that increased complexity can affect the quality of products and cost companies a lot of time and money if this complexity is not managed in an advanced way through the

application of CM. In two out of five companies in the German-speaking countries the application of CM is rated as insufficient. The effects of these deficits on costs, time and quality are mostly described as high. The study thus uncovers considerable potentials that have not been sufficiently exploited to date. Especially important for this study is the realisation that CM is becoming more and more important due to the increasing complexity of processes. Even though the potential of CM is now generally considered high in industry, the experience from numerous projects in research and consulting practice shows that often the benefits that arise for the individual company from the establishment of a functioning CM are hardly known (Burgess et al., 2003).

Drawing on the Guess (2006) study, the article identified that where numerous changes occur, the outcome can result in unplanned error corrections occurring which can lead to unnecessary costs being incurred. The size of an organisation, especially the number of suppliers, has a particular influence on the complexity to be managed. Since an increasing number of companies are introducing guidelines and minimum standards for their suppliers' CM, it should be seen by suppliers as a competitive advantage to introduce CM in sufficient quantities. 50% of the total existing improvement potential in companies is related to CM. It is astonishing in this context that 40% of the participants feel that the application of CM in their company is not sufficient and do not employ their own CM employees. This is due to the fact that the benefits of CM are not sufficiently understood in the management team because there are no sufficiently generally applicable and understandable measurement systems (Burgess et al., 2003).

Ali and Kidd (2013) and Reisenweber et al. (2009) independently found that only a small number of companies felt that management support in the CM process was not sufficiently understood or supported. Part of this finding was due to the gap between what was intended desire and reality of what is delivered. This is because the benefits of CM do not arise in a single department, but have positive effects across the whole company, indeed across the entire supply chain, as well as over the lifetime of the product. For this reason, the value of CM is very difficult to quantify.

ICM (2016) examines how the effectiveness of the CM process is related to the financial performance of the whole organisation. This is especially interesting when CM is not only active in the department but has a company-wide meaning. It is important that CM not only manages design documentation but also the entire documentation of the company. The white paper clearly points out that with increasing efficiency of CM, the efficiency in other company processes also increases. Based on the findings of Guess (2006) this white paper formulates 20 criteria from the CM2 model to measure the effectiveness of the CM process. IPX (2018) on the other hand, also based on Guess (2006), formulates a model to measure the status of CM within an organisation. For this purpose, eight topics were defined and seven questions were assigned to each topic. This model is important for this study and is therefore included in the appendix.
Both models complement each other, but have the weakness that they are not generally applicable, because they do not consider the individual needs of each company and can therefore only serve as a basis for this study, on which to build. As noted by Burgess et al. (2003), the damage to a company if CM is not applied is variable. This means that the cost of CM should ideally be different for different firms. This refutes IPX's measurement system, which assumes that the full application of CM2 provides the optimal benefit for every company.

	Guess 2006	**Whyte, Stasis, Lindkvist 2013**
Type of publication	Book	Journal Article
Characterisation of publication	Work which is setting standards	Case study
Questions/Objective	To improve existing processes to be more competitive	Managing change in the delivery of complex projects
Object of investigation	Configuration Management	Analysing change management practices in the three separate organizations as cases
Data base	MIL-STD-973	N/A
Method	Empirical, analytical, reductive, normative	Empirical basis
Theoretical approach / Central concepts or model	For the practical use adapted models	Comparative Orientation
Important results / Answer to the research question	Measuring the reduction of rework	Complexity and potential is important
Strengths of the publication	General practical useable	CM is presened in context of big data
Weaknesses of the publication	Limited generation of theoretical knowledge	N/A
Comparison with…	P156 Upper management support is necessary	N/A

	Burgess, McKee, & Kidd, 2005	**Ali & Kidd, 2013**
Type of publication	Journal Article	Journal Article
Characterisation of publication	N/A	N/A
Questions/Objective	How is the discipline of Configuration Management (CM) practised in the European Aerospace industry	What are the barriers of implementation of CM
Object of investigation	Configuration Management (CM) practised in the European Aerospace industry	Project Management
Data base	N/A	N/A
Method	Mixed method approach with a questionnaire survey followed by in-depth interviews.	Mixed method approach
Theoretical approach / Central concepts or model	N/A	N/A
Important results / Answer to the research question	CM discipline relies on fragmented and diverse processes and its organisational role and contribution are undervalued. Remedying present piecemeal deployment of information technology holds out substantial opportunity for improvement.	CM implementation success is dependent from top management support
Strengths of the publication	N/A	N/A
Weaknesses of the publication	N/A	N/A
Comparison with…	N/A	Cw Guess 2006: Lack of userfriendly software tools Cw Guess 2006: **Lack of management support** Cw Guess 2006: Lack of effective CM tools

Table 2-1: Sources comparison of key contributors of important CM literature for this research

	Staats 2009	Reisenweber 2009
Type of publication	Book	Book
Characterisation of publication	Definition of metrics to measure the efficiency and effectivity of Configuration Management	Cost saving potentials through the us of CM
Questions/Objective	Improvement of measuring systems	Presents the possibilities of using CM for reducing costs
Object of investigation	Configuration Management and Quality Managemer	Configuration Management in aerospace industry
Data base	N/A	N/A
Method	Empirical, analytical, reductive, normative	Questionnaire, interviews
Theoretical approach / Central concepts or mode	For the practical use adapted models	N/A
Important results / Answer to the research questi	Introduction of an advanced measuring framework	High potential of cost reduction
Strengths of the publication	Definition of precise formulas	All industry overview
Weaknesses of the publication	Comparability with other companies is not given	Limited to German speaking companies
Comparison with…	N/A	N/A

	IPX 2018	ICM 2016
Type of publication	Course Materials	White Paper
Characterisation of publication	Determination of the applied current status of CM	Determination of the current effectiveness status of CM
Questions/Objective	How can the current status of CM application be determined	To assess the effectiveness of the CM process and promote its use throughout a company
Object of investigation	Configuration Management (CM) practised in the international aerospace industry	Configuration Management (CM) practised in the international aerospace industry
Data base	N/A	N/A
Method	N/A	N/A
Theoretical approach / Central concepts or mode	N/A	N/A
Important results / Answer to the research questi	An easy to use measuring system for the current application status was developed	An easy to use measuring system for the current effectiveness of the CM status was developed
Strengths of the publication	Valuable for determining level of CM in a company	Valuable for determining the effectiveness of the CM process in a company
Weaknesses of the publication	The importance of the individual disciplines for the companies is neglected	The importance of the individual disciplines for the companies is neglected
Comparison with…	N/A	N/A

2.6 Configuration Management (CM)

Sorrentino (2009) defines Configuration Management as the one and only process which guarantees that manufactured goods retain the identical design, materials, structure and manufacturing processes that were initially defined as well as a consistent supply to the customer over the complete life cycle. Consistency in CM is achieved through serial number-related management of structures, i.e., the product structure for each individual product can be retrieved throughout the entire product life cycle. Product structure means not only a physical connection of the installed parts, but also their mapping in the form of a link to all relevant documents related to the product. CM is a core process of the whole Product Data Management (PDM) with the aim to manage the changes during the whole life cycle. This means from the design of future products to the modification of existing machines (Kuttig, Scholz, & Richters, 2007).
However, Guess (2013) writes in his further development of CM towards CM2 that the life cycle begins and ends not simply with the tangible object, but with the completion of product records. In addition to traditional CM, where the first aim is the preparation of prototype hardware, in CM2 the first aim is the preparation of product records. The verification in traditional CM is revealed by a prototype which shows the design functions, while in CM2 the prototype shows that the product records are correct. CM2 is a further development of the CM process which has embedded continuous improvement possibilities.
CM is the procedure of controlling process facilities and products by the organisation of the correlated information. CM delivers the data basis for project management and product lifecycle management. Data are therefore not only product structures and documents, but also all information concerning the process itself. CM thus ensures that the currently valid verified data are available for a corresponding individual product. This means that goal-oriented project management and product lifecycle management are generally not possible without CM, because CM delivers the valid data that the other processes and disciplines need. This includes all changes and CM ensures that changes are performed in the way they were expected. The International Standard ISO 10007 is the regulation which assists in the application of CM (Narváez, 2009).

According to the study by Reisenweber et al. (2009) the management discipline CM ensures the orderly and controlled evolution of a product throughout its

entire life cycle. This includes product structuring, the documentation of product requirements and changes, but also ensuring that the real product complies with this documentation throughout its entire life cycle.
The term ‘product’ is relatively broadly defined, and can refer to tangible products (hardware) such as aircraft, but also to software or services, for example in the insurance sector.

For Ali and Kidd (2013) CM is not a collection of new ideas, but it is a method for project managers to handle the complexity and the changes of a product throughout the product life cycle. CM is a management activity which handles the initial product definition and changing processes throughout the whole product life cycle.
The National Consensus Standard for CM (ANSI/EIA-649, 1998) defines CM as:

> “A management process for establishing and maintaining consistency of a product’s performance, functional and physical attributes with its requirements, design and operational information throughout its life”.

The actual definition, what constitutes CM will be introduced in the introduction Chapter 2, Section 2.7.

CM is defined in the MIL-STD (DoD, 1992) as follows:

a. As applied to configuration items, a discipline applying technical and administrative direction and surveillance over the life cycle of items to:
    1. Identify and document the functional and physical characteristics of configuration items.
    2. Control changes to configuration items and their related documentation.
    3. Record and report information needed to manage configuration items effectively, including the status of proposed changes and implementation status of approved changes.
    4. Audit configuration items to verify conformance to specifications, drawings, interface control documents, and other contract requirements.

b. As applied to digital data files (see MIL-HDBK-59), the application of selected configuration identification and configuration status accounting principles to:
    1. Uniquely identify the digital data files, including versions of the files and their status (e.g., working, released, submitted, approved).
    2. Record and report information needed to manage the data files effectively, including the status of updated versions of files.

The definition of a system or a product is controlled by CM throughout its whole lifecycle, which means from concept to disposal. The proper application of CM requires that all changes to a system or a product are carefully identified, controlled and recorded as this guarantees the product fulfils its defined physical and functional requirements (Samaras, 1988).

For Lyon (2000), CM is simply the process of managing change which means product data is captured and controlled by CM. There are two types of people in a company, those who want to have an overview of processes and be able to control all involved departments, and those who believe they save money and time if they do not make use of CM. All disciplines of CM such as Identification, Change Control, Status Accounting and Audits are directly connected with all processes of a company. It is necessary to find compromises between the control of the design and costs, as well as to what extent the product correlates to the design requirements.

Communication is one of the most important tasks of CM. The process has to be documented, measured and communicated. CM could be seen as a communication bridge between the design engineer and the rest of the world. The traffic which is passing over this bridge has to be associated with the measurements (Watts, 2009).

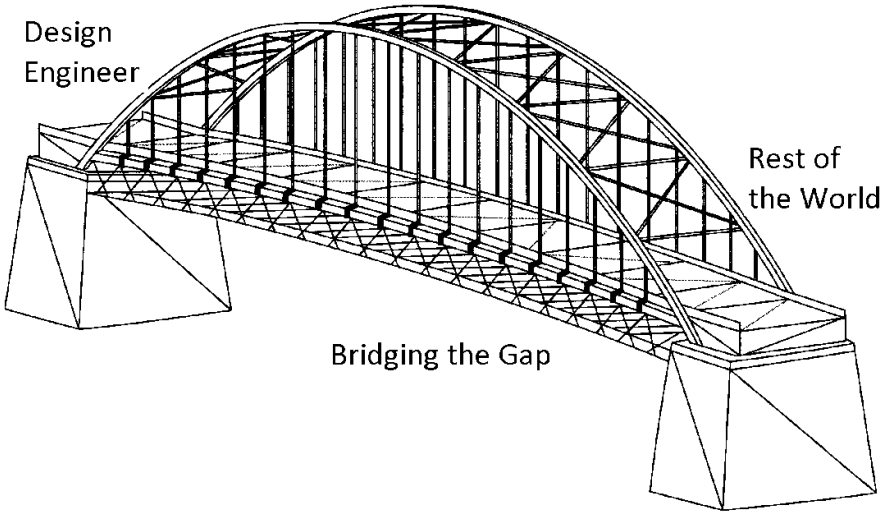

Figure 2-2: CM, a Bridge for Communications (Watts, 2009)

For this study CM is understood to be a management discipline that ensures that the customer receives a product with individually compiled properties and that this can be used over the entire product life cycle, as all the necessary individual product data can be accessed at any time and is always kept up to date (Guess, 2013). The term CM2 entails a global sense of CM, to adequately incorporate and understand how it functions or can function in entire industries or sectors, and to make CM possible in the real world, with a high diversity of large companies and complex supply chains.

2.7 History of CM

CM was first used in industrial management. The term has been used since the mid-60's, however Henry Ford had already used the concept of CM when organising the production of the first automobile (Bazelmans, 1985).
At the start of the 1950's, the US military carried out experiments with different missiles. Missile systems with different configurations were tested. From about 1000 missiles, just a few reached the target and exploded. Many exploded during launch or in flight. Because of insufficient documentation, it was not possible to draw conclusions on how the best missile was put together. The smallest undocumented changes often had the largest consequences. Results were not replicated. Subsequently military products could only be changed if change documentation had been recorded in a controlled manner (Gruber, 2015).

In the 1960s the first CM standards which can be seen as the official inauguration of CM were established by the US Military. These standards were designated MIL-STD-480, MIL-STD-481 and MIL-STD-483. In 1991, these “480 series” were combined to produce MIL-STD-973. The MIL-STD-973 was replaced by MIL-HDBK-61 in 1997. The most established and disseminated standard of CM, the ANSI/EIA-649 ‘National Consensus Standard for Configuration Management’, was created in 1998. The standard EIA 649 was created in collaboration with the Department of Defence (DoD) Configuration Management Advisory Group (CMAG). The EIA Engineering Standards and Publications were established to assist industry by reducing misapprehension between producers and buyers, enabling interchangeability, easier upgrading of goods and supporting the buyer to obtain the product at the time and in the condition he requires (ANSI/EIA-649, 1998).

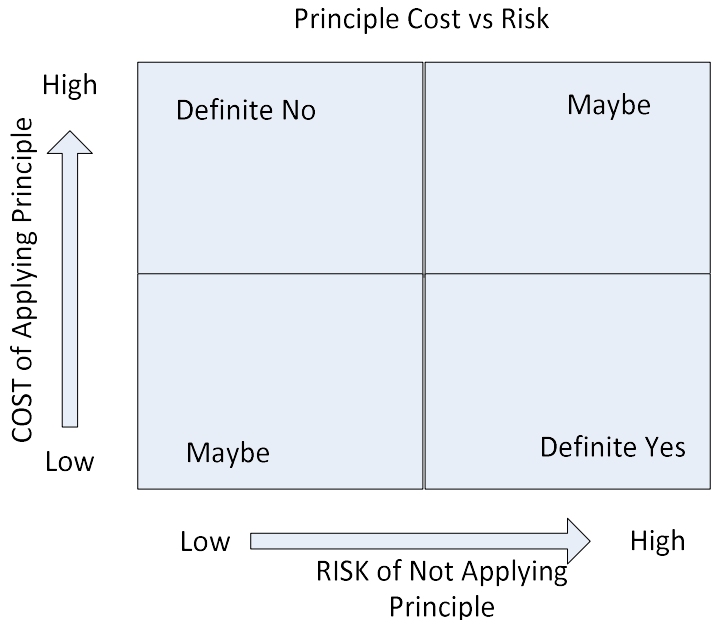

Figure 2-3: Overview of a Simplified Research Process (adapted from Gill and Johnson (2010)

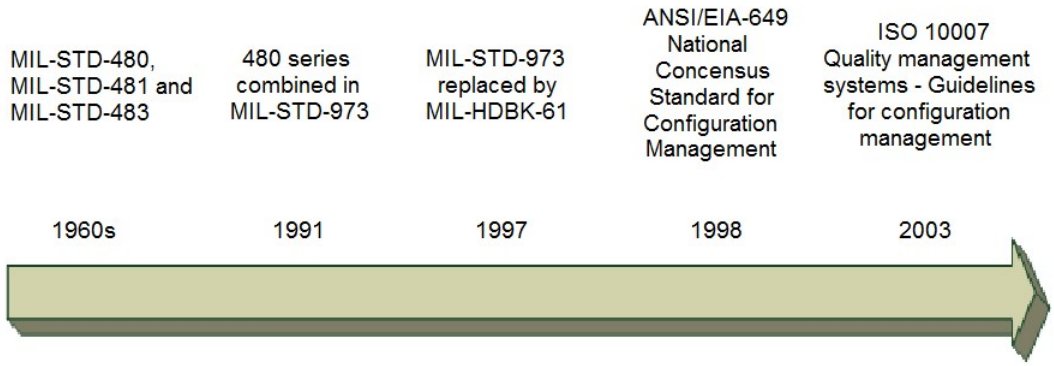

Figure 2-4: Timescale of the Configuration Norms

From the timescale of the different standards, it is shown that military standards have been the basis for all subsequent civil standards. The military positioned CM on a wide foundation to solve the challenges in an extensive way. Because of the historical situation at that time, the budget for the military enabled the creation of these sophisticated standards which are still valid today. Fundamental structures for management processes have been developed which are mutatis mutandis available for different applications. The main expertise and the main principles of DoD (1992) have been used in the ANSI/EIA-649 (1998) Standard as well as in the ISO10007 (1996) Standard. The principles of CM have been taken from DoD (1992) and are now presented in a new more easily useable ANSI/EIA-649 (1998). The typical Configuration Management Activities are represented in the ANSI/EIA-649 (1998) in this new format.

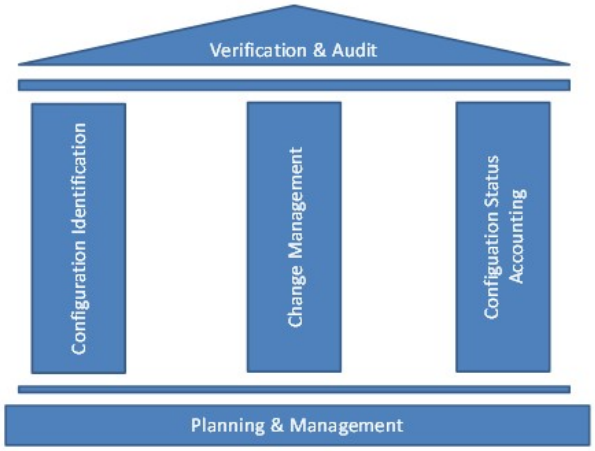

Figure 2-5: Main Disciplines (functions) of CM Presented in the form of a Temple

The main disciplines or general principles of CM presented in Figure 2-5 have existed since the official inauguration of CM. There has been little change since

that time. The main principles as defined in the different defence standards are continue to be valid today. The more recent literature about CM uses the main disciplines or principles to further develop and arrange CM in the context of new technical development and/or new management styles. The principles of CM are generally the same, but in different businesses and industries the depth and procedures of implementation are various. The following is the current status of how the most important literature defines the disciplines and principles of Configuration Management.

MIL-STD-973 (DoD) (1992) and MIL-HDBK-61 DoD (2001) defines the elements of Configuration Management as:

- Configuration identification
- Configuration control
- Configuration status accounting
- Configuration audits

ANSI/EIA-649 (1998) defines the elements of CM as:

- CM planning and management
- Configuration identification
- Configuration change management
- Configuration status accounting
- Configuration verification & audit

ISO10007 (1996) defines the elements of CM as:

- Configuration Management planning
- Configuration identification
- Change control
- Configuration status accounting
- Configuration audit

In contrast Guess (2013) defines the elements of CM as:

- Requirements management
- Change management
- Release management
- Data management
- Records management
- Document and library control
- Enabling software tools

The activities behind these elements do not work independently as there are important dependencies. The elements are interwoven in a sophisticated manner as can be seen in the following figure showing the relationships and dependencies. The top-level CM was created to use as an orientation for the preparation and application of the most important CM functionalities for the entire live cycle of the programme. The relationships are defined with inputs (left), outputs (right), enabling tools/methods (bottom up) and constraints (top down) (GEIA-HB-649, 2016).

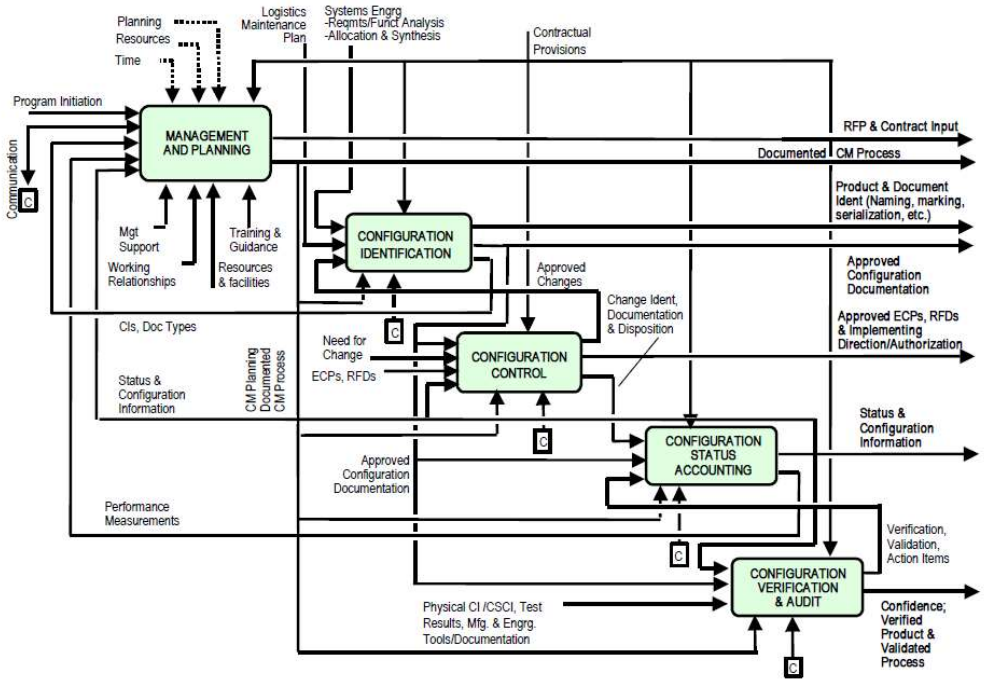

Figure 2-6: Top Level Configuration Management Activity Model MIL-HDBK-61 DoD (2001)

New digital possibilities from new technologies have a large influence on project management through new rational forms of organisation. The vast amount of data which is generated has to be managed in a professional way. From these facts, CM becomes more and more important for managing complex projects with large amounts of data involved (Lindkvist et al., 2013).

In 2005 the article “Configuration Management in the Aerospace Industry” was written by Burgess, McKee, & Kidd (2005). The main research question of this article is: ‘How is the discipline of Configuration Management practised in the European Aerospace Industry?’ Consequently, this article has a special significance for this thesis, as the subject matter of the article, and supports the need for this research highlighting the gap to be filled by a scientific study. The authors present an ambitious set of questions, where the depth of the subject matter is difficult to deal with completely in their limited technical article. An example of a broad and important question is: “How do companies value the CM process?”

> How do companies value the CM process?
> The above-mentioned comments about responsibilities provide evidence for low value ascribed to CM within companies. Other indicators were available. The respondents demonstrated their companies’ low reliance (25 percent) on metrics to measure the performance of the CM activities and the low incidence of risk assessment. Together these indicators suggest that CM is seen as a passive, compliance activity rather than an area that, if managed properly, could deliver benefit. The CM processes within these companies were claimed to be flexible and supportive of customer and project requirements, and not paper based. External auditing was undertaken against required standards by both tiers; however, first tier companies were open to more external scrutiny (T. Burgess et al., 2005, p. 296).

The most relevant statement in this article is that there is very little reliance on metrics to measure the performance of CM activities. This statement confirms the general desideratum which should be solved within this thesis. The article is very important in that it identifies the question of the research gap in the quality of measurement of CM activities. Naturally the trio of authors cannot deliver a satisfactory answer to this challenging question with the limited scope of their publication. Burgess et al. (2005) task was to determine the status quo of CM in the aviation industry and not to find a solution to the problems discovered in this study. Moreover, the following statement of the citation above, ‘CM is seen as a passive compliance activity rather an activity which generates benefit,’ and has innovative power for this thesis. The reason is that with many companies CM is

not performed to a suitable extent in the company or it is an isolated discipline. This critical fact is worthy to be researched in a deeper way.

The authors point out as an important finding that the contribution of CM is undervalued. In one paragraph Burgess, McKee, and Kidd (2005) tried to find an answer to the following question.

> Does CM add any value to the business?
> This question was mainly addressed by looking for views on the level of knowledge that CM personnel had and how CM data contributed to business activities. The positive responses indicated CM did add value to the business, with the CM personnel being seen as making a valuable contribution. CM activities were not seen as restricted to those individual functions with clear CM responsibilities within the organisation and CM personnel fulfilled a valuable role in advising on the requirements for projects that need to be undertaken (T. Burgess et al., 2005, p. 298).

To solve the question "Does CM add any value to the business?" the authors concentrated on how the knowledge of the CM personnel as well as the CM related data had an influence on the business. Through the analysis of the positive answers of questionnaires and interviews Burgess, McKee, and Kidd (2005) derived a result of what CM adds to the value of the business. The authors describe in detail the methods they used in their research. They explain the questions they asked the respondents and also how they evaluated their responses. Unfortunately, evidence to this critical question as to whether CM adds any value to the business, with important evidence supporting the result is missing. The author's answer is that CM adds value to the business, but the value being considered was not stated - the definition of the value is missing. Further, the question of the measurability of CM is not discussed in the study by (T. Burgess et al., 2005).

In the production of complex products there are different levels of manufacturing. A first-tier company is the manufacturer of a complete product. A second-tier company is the supplier of major components to the first-tier company. Of the first-tier suppliers, just 50 % have an 'end-to-end' process. The end-to-end process is the entire product life cycle and is not limited to actions such as the design. The second tier suppliers are in a different situation, because they are only involved with a limited portion of the entire product life cycle, and therefore the end-to-end process is not so important for them. Moreover, the trio of authors critically add that the end-to-end process of CM is now more a theoretical idea rather than the reality in many companies. In daily business, the CM function has

up until now not received the recognition it deserves. The authors explain this with the following facts. Often CM is not recognised at a senior level in the business organisation structure; very often, the configuration manager is not in the hierarchical position to have enough power to steer the CM in the correct way (Burgess et al., 2005).

From the literature review results, and also by comparing the official CM standards for both, military and civil, it has been found the CM2 standard is not a totally new development, but it is primarily a further development of CM which renders a user-friendly integration of CM possible. Noted, however, there is limited research to support this assertion. Where there are references these have been added. The integration may be shown through a graphical representation of the CM standards and easily understandable language, as well as the help of examples from the daily business life of real companies.
As shown in Figure 2-7, Guess (2012) developed a simple description for the practitioner. The original standard the ISO 9001 was much more abstract and difficult to use in small practical businesses. In addition Guess (2012) shows the limitations of traditional CM and explains which actions would be necessary to increase its scope. All companies are steered by requirements. The right use of Configuration Management guarantees that the services and products correspond according to their requirements. Each company has customers and services/products with the aim to serve the requests of the customers. To achieve every applicable phase of the lifecycle for those services/products there has to be a delivery system. As the market is changing rapidly there has to be a constant development of services and products to be able to compete in the market. The customer needs could be, for example hauling, systems. The products which serve these needs include trucks, tractors, wagons, their components, fuel, oil, maintenance. The delivery systems are organisational policies, value-added processes, rules and standards used to run the business. ISO9001 (2015) requests all requirements have to be documented: ‘The quality management system documentation includes documents, such as records to ensure the effective planning, operation and control of its processes.’ The rule is formulated by (Guess, 2012) ‘document what you do; do what you document’, or in CM2 ‘a requirement is not a requirement unless it is documented, validated and released.’ The traceability of requirements is only guaranteed if they are in

released documents. The storage and publication of released documents have to be done in baselines and repositories. Services and products have to be compliant with the relevant documents. Requirements have been met if the services and products conform to the documents.

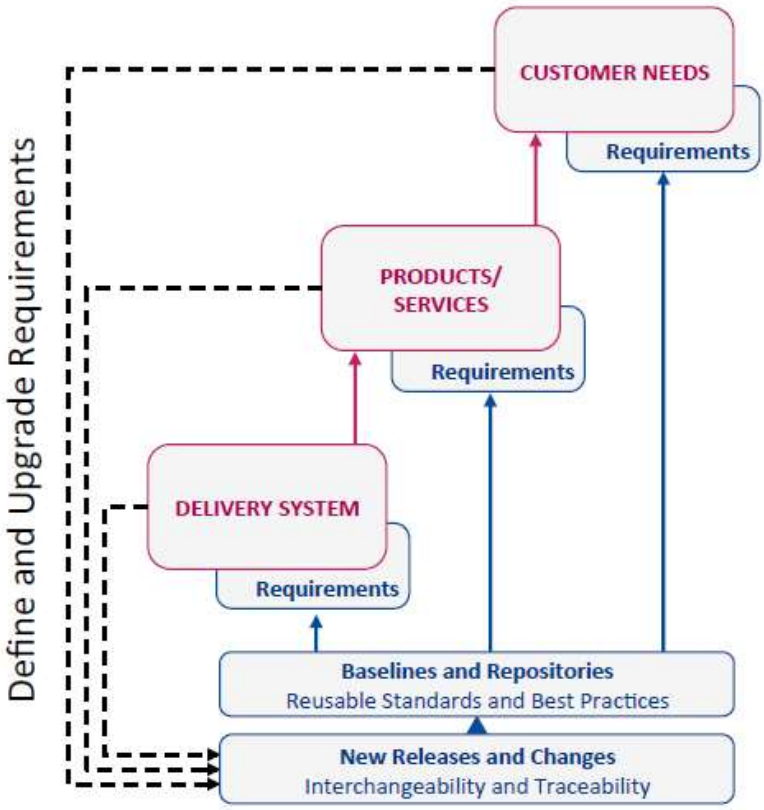

Figure 2-7: CM is Requirements Management (Guess, 2012)

Figure 2-8 depicts how the communication should be performed. It is crucial that the communication process is understood and properly managed. Otherwise the communication will not be clear, concise and valid. The communication of requirements with the help of documents requires that the release and change of documents must be efficient and absolutely reliable (Guess, 2012).

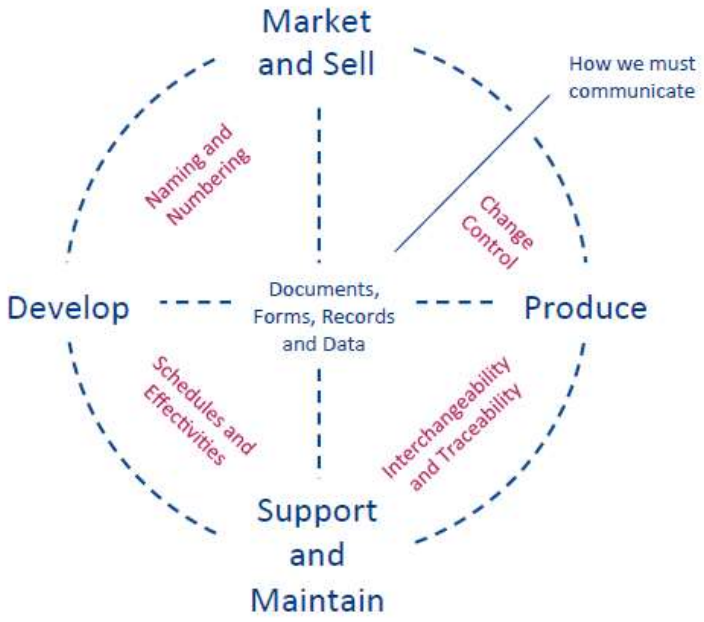

Figure 2-8: Development of CM2 (Guess, 2012)

As seen in Figure 2-9, all three sets of documented requirements are in a continuous change process. For this reason, all changes have to be done frequently and synchronisation has to be provided so that all requirements are clear, concise and valid. If this is done, consistent conformance is realised and a reduction of corrective action is measurable (Guess, 2012).

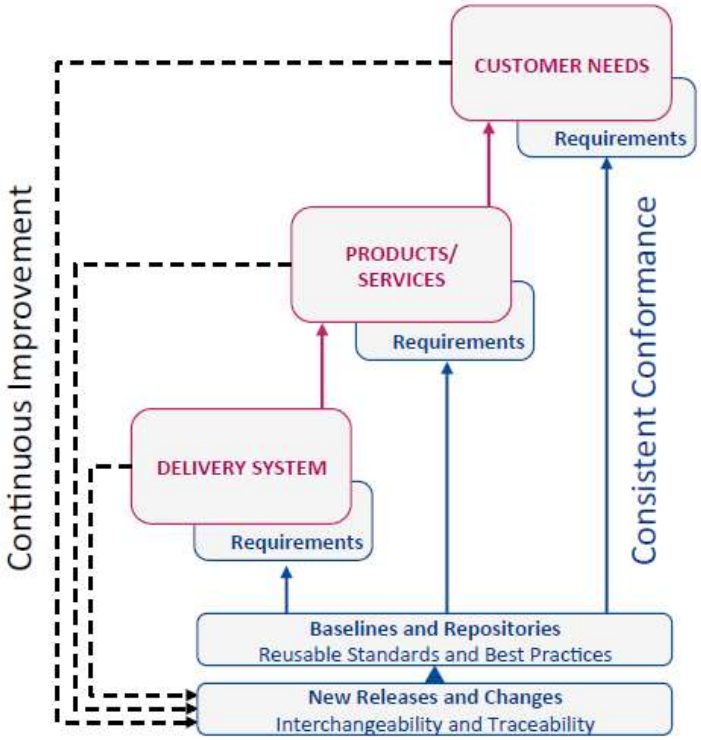

Figure 2-9: Updates Must be Quick and Synchronized (Guess, 2012)

The main principles may be enriched in future development through additional components and methods. An example of additional future development is that the selection methodology will have to be named.
In this methodology a selection criterion for the CM user has been worked out to make it easier for the user to decide to use the application criteria.
In a measurement framework for the value measurement of CM, it is useful to incorporate the most relevant procedures of CM. CM2 was developed mainly for medium to large sized companies where CM is not a core part of their management. Large companies, especially aircraft manufacturing companies, have created their own applicable standard (Jörn, 2015). For example, Airbus is not directly using CM2. CM is a core part of management for Airbus and therefore they have developed their own specific configuration standards, which are tailored exactly to their needs with training material being specifically tailored to the company (Jörn, 2015). The main advantage is that their CM is totally designed for the products of the company and so the maximum efficiency of the CM can be generated.

One of the main statements of CM2 is:

> Configuration management is essentially requirements management. (Guess, 2012, p. 4 Chapter A)

According to Ali and Kidd (2013) CM provides project managers with a formalised methodology to be able to control and steer changes while keeping an overview of projects.

The authors have identified nineteen barriers to effective CM which are further structured into the three groups, managerial and organisational barriers, planning and process barriers, and implementation barriers which are presented in a graphic on page 512 of their article (Ali & Kidd, 2013).

The most important barrier for this work is the lack of recognition and underestimating the importance of CM at every level of the company.

> It is obvious to see lack of recognition and underestimating the importance of CM within organizations in the presence of lack of management support, lack of centralized CM function, and lack of authority to implement CM. It is believed that CM is just tolerated but not embraced since top management doesn't understand its role while others believe that they can manage their products without its assistance. CM is only seen a necessary evil and has no importance within facilities until something really goes wrong (Ali & Kidd, 2013, p. 515).

This statement is so important for this thesis because it reflects the necessity to measure the value of CM exactly. The value of CM is not the same in every company and therefore a measurement framework which is adaptable to all types of companies is necessary. It is only possible to convince company management in the long term if exact and precise data is available which fits the specific requirements of different companies.

2.8 Barriers of Configuration Management Implementation

According to Ali and Kidd (2013), the lack of top management support is one of the most frequently highlighted barriers to the application of effective configuration management. It is also seen as a cause of many other barriers. The authors explain the root cause of the problem is that management is not familiar with the role of the CM process. There is no approach for a solution to this problem in this article. The framework to be generated in this thesis is an

ideal help for senior management to understand the importance of CM in relationship to the type of company they are in.
The lack of a centralised body for the governance of CM is caused through decentralisation of the CM process. This means CM loses power because the CM process is separated from and insufficiently interwoven into other core management processes. Especially in the project management environment, this problem becomes obvious when different companies work together. The authors emphasize the importance of a functionally centric view of CM because the practices across projects will then be strengthened. The lack of centralised body for the governance is linked to the lack of management support.
The lack of CM knowledge across organisations is linked to the lack of training in all departments within a company (Ali & Kidd, 2013).

> Research on cost versus benefit analysis – one of the weak areas in the limited CM literature – may answer many concerns including 'implementation costs outweigh CM benefits' (Ali & Kidd, 2013, p. 515).

Directly connected to this thesis is the common idea that implementation costs outweigh CM benefits. Ali and Kidd (2013) mention that this thematic is a poorly researched one in the CM literature. From this statement the authors detected a gap in the literature regarding cost benefit-analysis, which justifies the aim of this thesis to contribute to gain new knowledge in measuring CM benefits. The authors do not suggest a solution in their article for closing this gap, however they put the low valuation of the practical use of CM within a company in a causal correlation with the limited theoretical insight of the functionality and the effectivity of CM.

It is difficult to implement a totally defined CM process if the benefits of CM are not widely accepted. The lacking points causing barriers are identified and illustrated in Figure 2-10 "Lack of Top Management Support, the Most Central Barrier" in Chapter Two, Section 2.8. It is seen that the lacking points are connected. The connections are not only inside the three blocks, managerial and organisational barriers, planning and process barriers and implementation barriers but connections also appear between the three blocks. The central

reference point in this connected system is the lack of management support in the block of managerial and organisation barriers. Ali and Kidd (2013) identified this gap as the central critical point because the value of configuration management is not understood and identified. All managerial and organisational barriers are related to the lack of top management support. Through the lack of top management support, the discipline of CM is not valued sufficiently. This leads to a lack of career progression for CM professionals and this means that the CM professionals do not have the power they require to manage the CM processes properly. For the creation of a centralised body for the governance of CM the full support of top management is necessary. The top management is normally not able to value CM sufficiently and therefore it is not possible to decide if the implementation costs outweigh CM benefits (Ali & Kidd, 2013). Lacking the CM evaluation skills, the upper management is not able to communicate the importance of CM at every level of their organisation. To guarantee a working CM across an organisation, an appropriate training programme is necessary (IPX, 2018). This training programme has to be organised by the upper management. The lack of CM training across an organisation, the lack of recognition and underestimation of the importance of CM at every level of the organisation are connected in both directions. The lack of authority to implement CM principles and policies is created through the fact that the upper management do not empower the configuration manager with enough authority (T. Burgess et al., 2005).

The lack of authority to implement CM principles and policies leads to an outdated CM process, a lack of flexibility in the CM process, a lack of CM process across the product lifecycle as well as to a lack of current CM plans in the block of planning and process barriers. The lack of current CM plans and the lack of a centralised body for the governance of CM, leads further to a lack of maintaining consistency in CM practices across projects. According to Ali and Kidd (2013), who are seen as seminal direct influence on and causes poorly defined CM requirements and processes indicated in the planning and process barriers block as well as the lack of resources indicated in the implementation barriers block.

The uncertainty that implementation costs outweigh CM benefits leads to a minimized budget for IT tools, consequently the IT industry does not develop

effective CM tools. The lack of CM training across organisations leads to a lack of support from stakeholders and little CM awareness in the customer world as well as a lack of effective communication. Under implementation barriers, Figure 2-10 shows the extreme project pressures. This lack has no direct connections with other lacking items. The complex correlations between the gaps of the three blocks are obvious to see. Ali and Kidd (2013) delivered a systematic discussion and listing of the barriers of implementation of CM. The two authors described the lack of top management support as the most important barrier which gave occasion to present the similarities in the Figure 2-10. This research creates a framework to measure the value of CM in a precise manner and in correlation with the special needs of different companies. This enables the top management to understand the value of CM and this leads to the elimination of the barrier of top management support. As is visible in Figure 2-10, the elimination of the lack of top management support leads to the elimination of a lot of other barriers. All factors displayed in Figure 2-10 are coming from Ali and Kidd (2013).

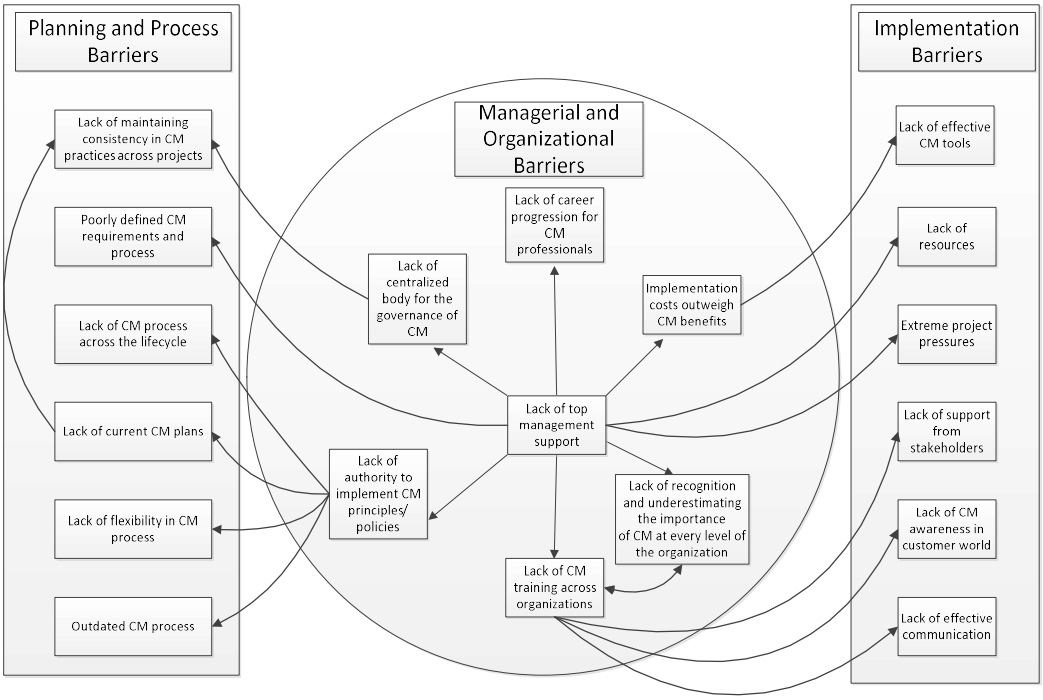

Figure 2-10: Lack of Senior Management Support, the Most Central Barrier

2.9 The value of Configuration Management

CM which works is not noticed by anyone. However, if the CM does not work, everyone notices it immediately. One important reason is that CM manages the basic data of the configuration items with which all other departments work because CM manages all CIs (Sorrentino, 2009).
After the emergency landing on the Hudson River in 2009, the aircraft manufacturer realised that some improvements on the structure improves the security (NTSB, 2010). These new improvements are not just applicable for new aircraft they also upgrade existing aircraft. For managing such an upgrade, a total overview is necessary. The beginning is the management of the engineering work. The engineering company responsible has to be identified and coordinated. All the operating airlines have to be identified and the upgrades must be managed with the airlines or the responsible maintenance companies (Lyon, 2011).

Requirements of all involved parties have to be steered along the whole product life cycle. The involved parties are for example the technology companies the customers or the authorities. Therefore, CM is the backbone of the whole PLM. This topic is dealt with in an exemplary manner by Kuttig et al. (2007), which is why his statements will be given a closer look at this point. Working CM is based on a sophisticated PDM system. For Kuttig et al. (2007) the main tasks of CM are the reduction of product recalls, unproductive work, and rework as a result of incorrect implementation of changes. Kuttig et al. (2007) believes there is a saving potential of 40 - 60 percent of company costs through reworking costs. This appraisal seems to be very high. A verification for these dimensions are not given by Kuttig et al. (2007) on this point. In the significant reduction of these costs, he identifies a main target of CM. Thus with this high announced saving potential in mind, he discusses the question of the extent to which CM is relevant for a company. Kuttig et al. (2007) evaluates the answer to this question as “very easy”. For Kuttig et al. (2007) the criteria resides with whether there are information deficits in the cooperation of the involved partners which can lead to financial charges. This could be seen generally as correct however this statement needs a substantial differentiation concretisation. The author for example says that the problem could occur ‘somewhere’ in the company. This answer is not precise enough. To give the decision makers a powerful organon it

is necessary to provide a precise localisation of the problem inside the structure of the company. In addition, Kuttig et al. (2007) is talking from a critical point which leads to irreversible damage of the company. On the one hand the question arises as to how this critical point could be theoretically defined and practically identified, and on the other hand, the question as to whether the introduction of CM is really 'latest then' necessary if this critical point is reached. It could be guessed that this emphasis is not satisfactory enough for the potential of CM. An evaluation of such relevance criteria of CM is one task of this thesis. Kuttig et al. (2007) recommend the CM2 standard from the Institute of Configuration Management, whose application works according to the guideline as much as necessary and as little as possible. This motto has been evaluated by Kuttig et al. (2007) as 'good guidelines and basis to integrate the CM in the whole business process'. However, a quantitative clarification of the 'as little as and as much as' does not occur. Kuttig et al. (2007) recommend in line with the CM2 standards the three core elements:

- All activities are requirements driven
- The structuring and linking of information are optimally designed
- A formal change process allows performing non-bureaucratic changes

Kuttig et al. (2007) further emphasise that CM has to be understood and performed as a consistent process. To guarantee this the right classification in the structure of a company is crucial. According to Kuttig et al. (2007), CM has to be located directly on top of the company management to avoid inconsistence in the application of CM. The question arises how this demand for a 100% implementation is compatible with the before referenced moderate motto 'as little as'. It is possible that Kuttig et al. (2007) intends a company specific adaptation. This means for different companies the CM2 process should not generally be applied because it would not generate the expected value, even though this is not mentioned in the article explicitly. Furthermore, the report of Kuttig et al. (2007) is based upon a survey on the current status of CM implementation for German suppliers, mainly from the aerospace industry. According to this report 28% of the companiescompanies' state that CM is already implemented as a gapless process. 78% of the participants however state that CM is only partially or not implemented. (In these two points a differentiated quantification would

have been desirable). Nevertheless, Kuttig et al. (2007) justifiably announced the high potential in the further development of CM in many companies.
Each company has to meet the requirements of CM in one or another way. The crucial point is according to Kuttig et al. (2007) in which quality and with which success the implementation takes place. Therefore Kuttig et al. (2007) expresses the demand for a precise measuring system with a need for KPIs and precise measuring values. KPI examples are provided here:

- Processing times of changes
- Numbers of changes
- Time of the release cycle

These examples are for sure just a small excerpt of the field of possible KPIs. The search and justification of a set of reliable KPIs will be one of the main goals of this thesis. Kuttig et al. (2007) states the delta measuring between the different stages for example ‘as designed’ and ‘as built’ are just possible because of a CM system that works well. To enable such delta calculations is one of the main values of CM. The value of CM is rising in the surroundings of a diversification of product varieties, more complex product structures and a global development and production. Through this the future importance of CM is clearly expressed by the authors. For Watts (2009) the most important function of CM is to manage communication. Especially essential for the whole product lifecycle are communications about documentation and processes. According to Watts (2009) the process measurement is a part of CM. To the process measurement belongs the design of the control processes the documentation as well as the communication. CM is setting the stage for innovation. Watts (2009) explains in simple words that people, tools and design documents are necessary to produce products. According to Schultheiss (2017) CM is the key for new business models in industry

2.10 Practical CM Literature

This literature is created by CM experts, who have been working for a long time in this field and have rich practical experience. No adequate theoretical models have been formed, presented and developed in practical literature (Sorrentino, 2009). For this thesis practical information is used, including theoretical literature

as a data base, which is supplemented by additional new data and information from interviews to produce a theoretical framework.

CM is inconsistently defined in the literature. The literature explains CM from the different viewpoints of multiple usages.

CM is principally necessary even for simple tasks. For example, if you renovate the floor of a room, the craftsman mentally considers or records in simple notes what he needs to carry out the job including materials, documents and plans for coordination with other craftspeople. Many people have experience with this situation and know that even then things can easily go wrong. For example, the colours do not match your requirements as the plan was not kept by the craftsman. Examples of extremely complex tasks are part of the international space industry where without using agreed and approved methods and processes fatal errors may occur. Without using CM methods, such things as the material quantities, time flow coordination, work flow coordination, the work process coordination and the information flow between different companies across continents would not be possible.

In industries which are not part of the aerospace business, CM is becoming more and more important (T. Burgess et al., 2005). Today, the research literature in the area of CM is limited and mostly concentrates on change management, and not the broader spectrum of configuration management and the obstructions preventing a favourable CM outcome (Ali & Kidd, 2013). This brings into question whether CM is worth using in an organisation? This was one core question of Ali and Kidd (2012). For Ali and Kidd (2012), CM was still undervalued by the senior management and therefore is not given the importance it deserves. The authors draw the comparison with the quality control organisation where it was the same situation in the past. Nowadays the quality organisation is recognised as important. Therefore the research questions in this thesis, are today considered very relevant and of great value.

For Guess (2013) the most important measurement criteria to value the effectiveness of CM is to measure the data integrity. Employee effectiveness and data integrity are the measuring variables for him. The following curve shows how important the data average integrity level is. With a data integrity level of 92 % there is an employee effectiveness of only 50 %. The mathematical function which describes this correlation is exponential.

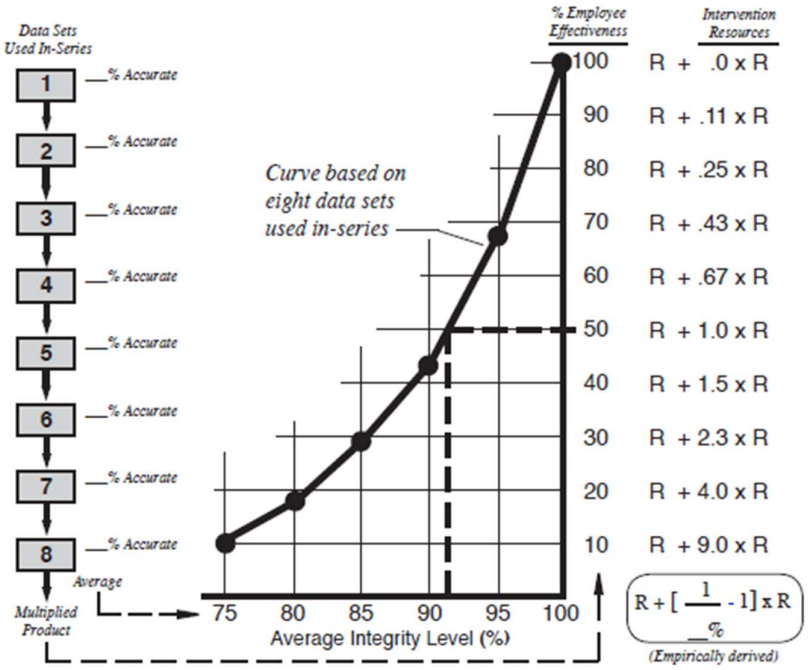

Figure 2-11: Resource Effectiveness as a Function of Data Integrity (Guess, 2006)

2.11 Performance Measuring

Performance Measurement has to be connected with the strategy of an organisation to deliver beneficial data as a basis for successful decision making (Tsang, Jardine, & Kolodny, 1999).

Rework is an omnipresent issue in the engineering sector. There are many investigations which deal with rework and cost overruns but little research exists on rework and schedule performance. Rework is a main factor which influences schedule performance. The most common causes which lead to negative schedule performance are changes in the design combined with insufficient coordination and deficient site management (Hwang & Yang, 2014).

When establishing performance metrics it is important to consider the specific requirements for each stage of the product life cycle (Bond, 1999).

Important knowledge can be gained from the article of Gries and Restrepo (2011).

The value of this article is that the authors introduce advanced measurement procedures in the engineering and design sector. They have performed a case study to investigate the measurement process and have proven that the best measurement is similar to the project management discipline. According to the axiom ‘what cannot be measured cannot be improved’, the aim of the article is to

develop an interactive KPI Management Dashboard. For this thesis the following statements about KPIs are essential:

1. ‘Heterogeneous application and data landscapes’: The data is gained from different unconnected systems. In addition, the analysis of the data is often unsynchronized.
2. ‘KPI inflation’: Many companies measure too much data which is not really important for them. Not every KPI has the same importance for every company. Gries and Restrepo (2011) find fault with the fact that many companies measure what they are able to measure and not what they should measure.
3. ‘Pseudo-accuracy’: Due to the first two points the data accuracy is often illusionary and can lead to wrong management decisions because of the missing connection to reality. The pure quantity of data has no clear relationship to its value.

Without measurements it is not possible to make real improvements. This principle is especially important in the PDCA (plan-do-check-act) methodology. In the phase ‘check’ for example, the effectiveness of a newly implemented process has to be measured. Only measuring financial performance such as earned value added (EVA), turnover, working capital (WC) or net profit (NP) is not sufficient because other important facts are lost. Staats (2009) therefore developed an advanced KPI based measurement system. An advantage is the launch of strategic performance measurement tools such as the Balanced Scorecard (BSC) (Gries & Restrepo, 2011). With the help of this tool the undervaluation of measuring reports has been observed by many company employees as well as by the management. Even the CM manager, the engineering manager and operations manager have the capacity to understand all processes and problems of the company by means of their intuition. There are investigations in which several managers have been asked what the source of a specific problem is. Every manager gave a different answer, but the precise source was not identified. This means in companies often reports with different solutions from several creators exist in the form of flow diagrams or block diagrams, however the results do not fit together. If there is not a precise measurement, it is not possible to evaluate the process improvements. It is

necessary to measure objectively all the steps of a process in a detailed way and not to rely on intuition or subjective judgment (Watts, 2009).
The Institute of Configuration Management recently carried out research on measuring the effectiveness of the CM process. The deeper motivation according the practical and economic circumstances for this research was to convince decision-makers about the advantages of CM2. The main question of this research was: ‘How does the effectiveness of your CM process correlate with your organization's overall financial performance?’ Therefore it is important that CM is not seen as a single discipline inside the engineering department. It must be seen as a discipline with enterprise wide importance. As design definition is less than one/fifth of all documentation, it is essential that CM covers all the product documentation. CM2 is seen as an enterprise wide activity which means that the CM process improvement has a positive influence on the whole company (ICM, 2016).

The rating of the effectiveness of the CM process has been discussed more frequently in the last few years. The measuring procedure described by ICM (2016) concentrates on identifying the grade of implementation of CM2 inside a company. For this thesis, this measuring procedure is helpful, but it is by far not sufficient to create the required framework. CM2 recommends for every company to remove CM from the engineering department to give it an enterprise-wide perspective. This recommendation is useful but the level of application of CM which is useful for the individual needs of a company is missing. According to ICM (2016) it is absolutely correct to give CM an enterprise wide perspective, which means that CM is used for all departments including engineering, marketing and customer relations. In ICM (2016) one dimension is disregarded. The introduced procedure measures the grade of implementation of CM2 and not the benefits for the individual company, which means that the probable benefits which a company can gain from CM has to be defined. The title of the article ‘Measuring the Effectiveness of Your CM Process and its Value to Your Organization’ is confusing because ICM (2016) uncritically sees the 100% implementation of CM2 as the maximum reachable value for every company. In this thesis this assumption will be critically investigated.
The literature which deals with controlling has identified, according to (Staats, 2009) the following KPIs for measuring the efficiency and effectiveness of

Configuration Management. Staats (2009) places particular emphasis on the distinction between efficiency and effectiveness in the definition of her terminology. Efficient performance is required of companies in every industry. Accordingly, both the overall company level and the individual divisions are to align their activities with efficiency and effectiveness targets. The interaction of the two is decisive here. Because as long as there is no evaluation of the market, it is by no means certain whether the internal services, which may have been created with high efficiency, really have a benefit in terms of the company's goals. Therefore, efficient execution is still a waste. This means that a process fulfils the criterion of effectiveness, provided that it serves to achieve the objectives. However, it is only efficient if it is done with the least amount of resources. Efficiency attempts to answer the question of whether action is or has been taken effectively.

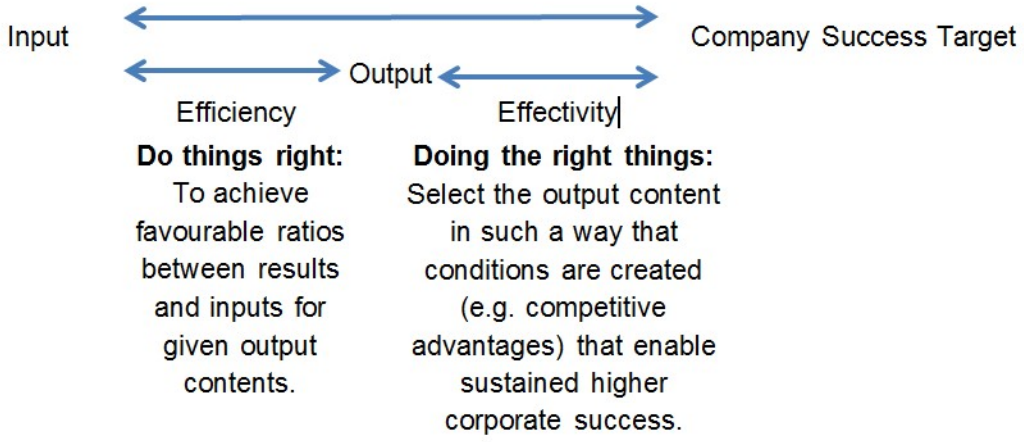

Figure 2-12: Efficiency and Effectivity (Gladen, 2013)

Efficiency is achieved if the objective, a defined output, is achieved with the least amount of resources. In terms of resource-oriented effectiveness, it refers to economic efficiency and productivity in the context of the provision of performance. The economic efficiency is based on values (Gladen, 2013). It refers to monetary output-input ratios such as the return on assets. Productivity, on the other hand, describes quantitatively expressed input-output relations such as painted products per hour of labour. An efficient work process results in a product that has been developed at relatively low cost in a relatively short time with the aid of appropriate resources and optimal use of development capacity,

and therefore presents a relatively acceptable risk. It has a high transfer potential with regard to current and/or future development projects and uses synergy effects (Gauglitz-Lüter, 1998). Reducing development costs and avoiding waste of scarce operational resources are therefore an important starting point for increasing efficiency, and this is achieved through the correct use of configuration management.

The effectiveness related to performance utilisation describes the targeted use of scarce entrepreneurial resources. To measure effectiveness, the goals manifested in the strategy and the innovator's expectations are compared with the actual results of product development. As a result, target-actual comparisons point out deviations in costs, time and performance and allow conclusions to be drawn about the degree of satisfaction (Gauglitz-Lüter, 1998). Effectiveness thus describes the general suitability of a measure to fulfil a specific purpose or objective. In terms of effectiveness, competitiveness is considered and output is determined in such a way that good profits can be achieved in the long term. Effectiveness can also address internal performance and answer the question of whether internal services created by divisions have a positive influence on goals at the company level (e.g. the profit) or are related to the company goals in a purpose-means relationship or cause-effect relationship (Gladen, 2013).

During the literature review, a comprehensive model for determining the application of CM was identified. This is the CM2 model for determining the application status of CM within an organisation. What is interesting about this model is that not only CM itself is examined, but also all relevant connected areas such as requirements management and enabling software tools. With regard to the research questions on which the work is based, the question now arises whether this system, despite its undoubted strengths, is already sufficiently finely differentiated to be applied in a meaningful and target-oriented way in different companies in the aerospace industry. In this respect, this is a promising starting point for further research. The model of CM2 is listed in the appendix for an initial overview (IPX, 2018).

2.12 Description of the gaps identified in the literature

A review of the available literature reveals an explicable wealth of specialist literature of varying academic depth. Different metric approaches by various authors are discussed. ICM (2016), with the title “Measuring the Effectiveness of Your CM Process and its Value to Your Organization” which are concentrated on the reduction of costs and bringing the company out of the corrective action mode. The extensive literature review has shown that many definitory and functional statements are made, but the advantages are rarely thematised (Xu, Malisetty, and Round (2013). To address this gap in research the first research question is to determine:

What are the specific qualitative and quantitative measurable benefits of configuration management in the aerospace industry?

Xu et al. (2013) describe the benefits of Configuration Management are in the paragraph ‘Challenges of CM in Aerospace and Defence industries’. In it, Xu et al. (2013) explain the fact that a high degree of complexity, which is particularly important in the aerospace industry, can be managed through configuration management. In addition, they draw attention to the high documentation requirements, especially by the authorities but also by the customers.
Finally, it can be said that several authors have worked out the benefits of configuration management, but that the necessary depth for solving the research problem to be solved in this study is missing.

In the literature, it has been possible to identify several measurement methods based on KPIs. Established measurement methods are, for example, as mentioned by Guess (2013), the reduction of rework that is avoided by the use of CM. Reisenweber et al. (2009) have also contributed to the measurement of the cost saving potential of CM by developing a questionnaire to solve the problem of suitable KPIs. The Institute for Process Excellency has developed a CM2 measurement baseline for the current application of CM. To clarify if these KPIs can generally be used in the aerospace industry to measure the value of CM the study will address the second gap by addressing the following research question:

What key performance indicators (KPIs) can be used to measure the value of the CM in the aerospace industry and determine their effectiveness?

In the literature, it was possible to identify in particular an authoritative work that explicitly and extensively deals with the question of the required KPIs - the work of (Staats, 2009). As previously reported, Staats (2009) presents a lot of KPIs and discusses them critically. The limitations of this excellent work lie in the fact that the linking of the KPIs and the resulting allocation and applicability to different companies are no longer the subject of this study. Staats (2009, p. 180) is also aware of these open questions and expresses this in her work, as has already been explained in this Chapter. These limitations provide a research gap in existing knowledge which is addressed with the third research question.

How could performance indicators be used to establish a useful evaluation framework for configuration management in the aerospace industry from a management perspective?

The mere discovery, naming and justification of various KPIs has been carried out to varying degrees in the literature reviewed. What is decisive, however – and this is the aim of the third question – is that the different KPIs are not isolated in the theory building like erratic blocks, but rather systematically shown how they are formed into coherent structures.
As previously stated in the literature discussion, Staats (2009) must again be referred to regarding this problem. She too, is primarily dedicated to finding KPIs; she delves deeply when she critically notes towards the end of her investigation:

> “Nevertheless, there are limits for each metric that are based on the limits of each individual key figure. For example, no key figure has a claim to universal meaningfulness – but this can be strengthened by combining it with other key figures.”

This means that a single key figure is limited if not of a disappearingly small significance if it is not strengthened and expanded in its meaningfulness by the combination with other key figures. How this demanded combination should take place can be read from the empiric reality, but in such a way that these combinations cannot be purely accidental, i.e. completely unpredictable. Rather, it is important to create a set of rules on the basis of which such effective

combinations can be classified and applied to the various applications. Only then will the rightly demanded combinations not be a conglomeration, but a systematically founded framework. The fact that the compilation of key figure combinations, which takes place de facto in selective selection and synthetic combination, must first reflect their respective compatibility, is also expressed by Staats (2009), at least in a convincing way, when she thematises their 'comparability': 'A limit of key figures lies in their comparability. The metrics of one company cannot easily be compared with those of other companies.' In other words, key figures can only be combined to form an application set if they have a similar relationship to a particular type of company. What applies to a company in this respect does not have to apply *a priori* to another company. Only comparable companies can be measured and evaluated using comparable key figures and, in particular, comparable sets of the same. For this comparability an ordinal matrix must be created. This task is targeted by the third research question.

2.13 Literature research framework

To represent the findings of the literature review, a framework was devised to visualize the emerging themes and existing gaps in the literature in connection with the research questions. The literature framework shows that there are a number of gaps which includes the specific qualitative and quantitative measurable benefits of configuration management in the aerospace industry. Key to addressing this gap is to understand of the benefits of CM in management, as to date this theme has not been sufficiently investigated. The second gap identified in the literature review relates to whether there are any key performance indicators (KPI) that can generally be used to measure the value of CM in the aerospace industry. The literature has highlighted that CM needs to be measurable and also transparent. The existing literature indicates that some KPIs have provided a critical insight, however, there remains evidence that some KPIs are not generally applicable, as they are perceived to be not suitable for the aerospace industry as they are too generalised. Leading from this gap, what remains unanswered is whether a generalised approach can be created to represent the aerospace industry. This gap is confirmed by Staats (2009) who states that this theme needs to be further researched. The third gap identified is how performance indicators could be used to establish a useful evaluation

framework for configuration management in the aerospace industry from a management perspective. In addressing this gap, the research would enable the research project to extend the existing CM framework to represent the aerospace industry.

The first gap identified is based on the premise that CM potentially does not deliver performance as it is often not correctly understood by management and therefore does not receive the necessary resources. To address this gap, this study intends to develop a framework that will make it possible for management to better understand the benefits of CM. In achieving, and drawing on the existing literature review, this CM tool will permit the organisation to evaluate the benefits. The second identified gap based on searching the literature related to the existing measurement systems based on KPIs, has highlighted that there is a commonly accepted premise that KPIs cannot be generally applied to the aerospace industry. This is highlighted by Staats (2009) who identified a gap in the existing knowledge in CM which needs to be addressed. To address this gap, the study conducted a series of interviews with experts in the field to better understand whether KPIs can be used, to determine whether generalised KPIs can be effectively used. The third gap is based on the literature review's acknowledgement that there is still a need for a framework to be developed. In developing this framework, the secondary data analysis has highlighted the need to investigate which specific KPIs can be used in the evaluating of CM when applied to the aerospace industry.

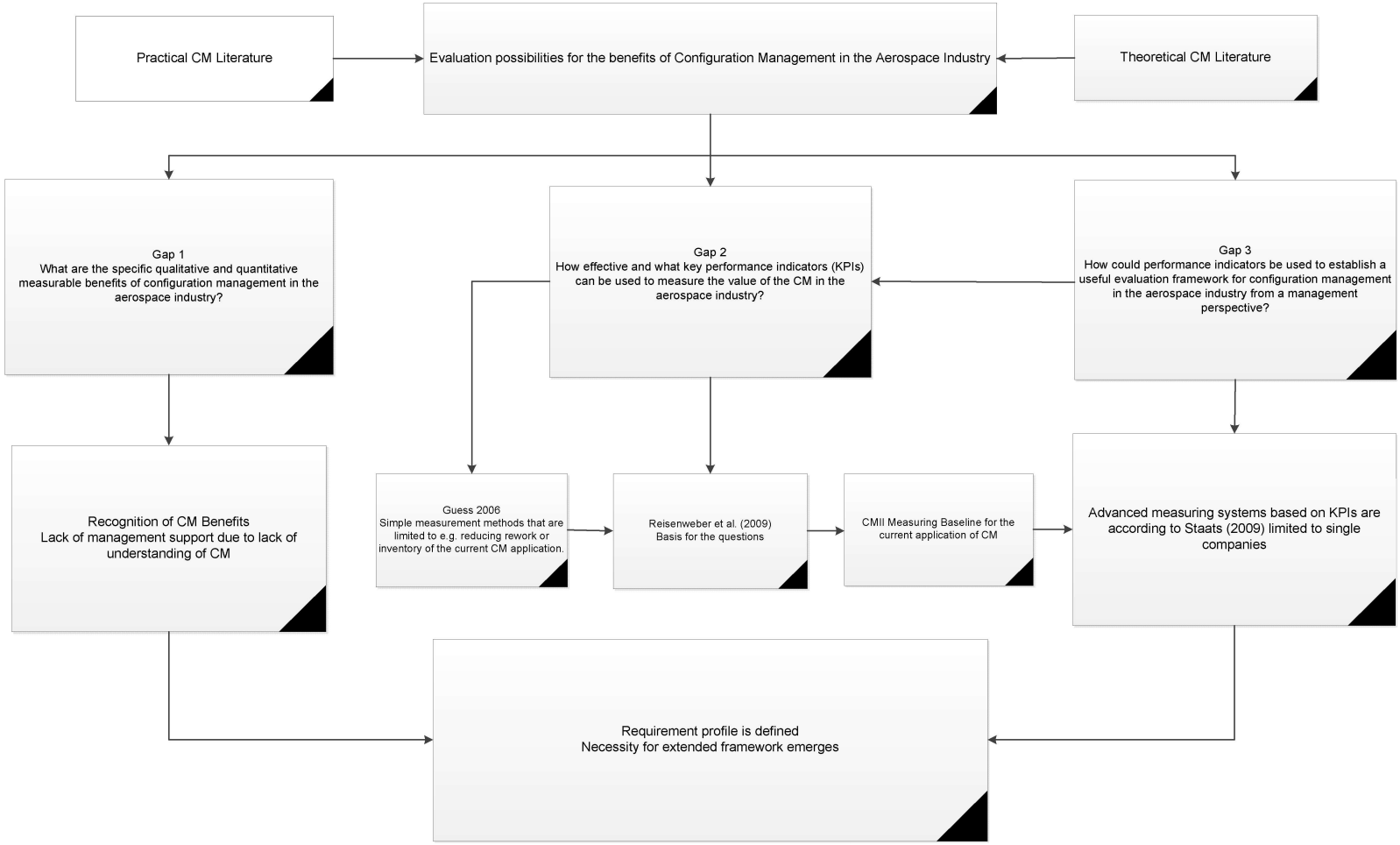

Figure 2-13: Literature Framework

2.14 Chapter Summary

This Chapter has considered a wide range of research from various authors in the CM sector. Of special importance for this research are Staats (2009), Ali and Kidd (2013), Reisenweber et al. (2009) and Guess (2013). Their work shows that there is a necessity for advanced measuring systems in the CM area in the aerospace industry. Guess (2013) developed simple to use CM measuring methods which are very common in the production sector of the aerospace industry, while (Ali & Kidd, 2013) criticising that the existing measuring methods are not sufficient to convince the management of the importance and the possibilities of CM. Staats (2009) has developed a more advanced measurement system which, as she says, cannot easily be compared with other companies performance measurement systems. Due to the lack of comparability, this system is difficult to use in different companies in the aerospace industry. In critiquing the existing measuring systems, the literature review has identified a common theme - the existing measuring frameworks in CM are not generally usable for the needs of different companies. For authors such as Staats (2009) this is an important problem which is important to be solved.

For other sectors of industry the thematic of performance measuring is deeply discussed in the literature (Cedergren, Wall, & Norström, 2010; Driva, Pawar, & Menon, 2000; Pawar & Driva, 1999). The phenomenon of rework is discussed intensively in the construction industry (Hwang & Yang, 2014). One of the main aims of CM is the maximum possible avoidance of rework (Guess, 2013). Therefore, it is innovative to transform the knowledge of other industries about performance measurement and the reduction of rework to the aerospace industry.

The two main literature bases are applied literature and academic literature. The academic literature is limited but has increased in recent years. This reflects the future importance of CM (Narváez, 2009). Without management support the application of CM throughout the whole company is not possible (Ali & Kidd, 2013). The importance of the measurement process of CM is clearly stated thus not enough researched and documented. The social component of CM research is not sufficiently considered. It is important because there is a large interaction between different individuals in all departments of the company and on all levels of hierarchy. It is not just inside the company it is along the whole global value

chain. CM supports the intercultural management on a social component. (IPX, 2018)

The critical examination of the literature finally raises the question: *What* is measured *for what purpose*? After a short consideration of the relevant publications, it is obvious that CM measuring systems – with great variability in type and scope – have been developed. These measuring systems do not have to be in an exclusive competitive relationship with each other, but can be understood, or at least partially as complementary supplements or alternatives to each other. And this is where the real metatheoretical problem becomes apparent: How can this variability occur and how can it be mastered in practice? As already mentioned on several occasions, the meaningfulness of existence of measured values – even if they are quite valid in individual cases – is only very limited. At a higher level, it is not the production of individual or several measured values within a measurement system that is to be problematized, but rather in advance the classification and evaluation of entire measurement systems as such in relation to different types of company.

Based on the study by Staats (2009), which comes from the field of controlling, it becomes clear towards the end of the study that key figures based on KPIs must be critically questioned with regard to their informative value. Staats (2009) intends that no key figure is entitled to universal significance, but this can be strengthened by combining it with other key figures. This means that not only the mere *existence* of conception, implementation, interpretation and corrective-regulatory application of measurements is decisive at the level of argumentation claimed here. Rather, the decisive question is a) at what *structural level* will be measured and b) for what *purpose*. If, as we have just seen, Staats (2009) requires a *combination* of key figures, this requires reliable *regulations*. It is therefore inadequate to limit the measurement with available tools to the actual efficiency of CM in a real economic situation. In addition, a metric scheme is required to ensure the normative applicability of different measurement systems for different company forms.
Staats (2009) continues in an evaluative control reflection: ‘One of the limits of the key figures lies in their comparability. This means that a company's metrics cannot easily be compared with the KPI systems [sic!] of other companies.’ From

this overarching perspective, it is therefore not the superficial production of key figures, but rather the extraction, typing and application schematisation of key figure *systems*. A system is not unstructured! A system is constitutively given by an ordered, continuous connection within a sense-bound unit. In individual cases, this evokes the question: What is the system-forming force? This will finally prove to be the classification of company structures within a modern, global market in the further progress of the present study. Only from this can the constitutively corresponding combination and selection *rules* be derived for the required combinations, which lead to an adequate measurement system with an associated setup of measurement observables. Only categorically comparable companies can apply comparable systems of key figures. Of course, a controlled, reasonable and optimized use of CM cannot succeed without a multitude of empirical key figures. These are always present and relevant as a subset of the CM framework. But their measurement can only make sense if it is preceded by *another* type of measurement which has a *normative* function for the former. Of course, only the given can be measured: in this case, structural characteristics of corporate forms. And yet the required normativity can be derived directly from this factuality. This higher-level form of factuality also has normativity for the measurement systems to be used to determine the key figures. In other words, the measurement of the second order serves as a reference framework, which normatively determines how the measurement of the first order has to take place in order to provide meaningful, realistic results. (However, it is not the task of the present study to add another one to the set of the manifold measuring systems of the first order.) This is therefore the elaboration of a metrically stored instruction manual for an essentially existing set of instruments. In this way, the framework to be developed at a later stage processes roughly the desideratum that Staats (2009, p. 183) formulates indirectly with the words:

> "Despite the careful selection of key figures, there are always limits within the framework of the use of key figures and metrics that limit their usefulness. Due to their limited informative value, they should not be used as the sole decision criterion but rather as a supplement to or guideline for strategic measures."

The decision criteria mentioned at the strategic level are naturally subject to a ‘soft’ measurement at nominal scale level, which classifies the companies concerned qualitatively, due to the second order systemic generality. This does not argue against a mathemateability, since different scaling dignities come into play depending on the order under consideration.

As a final résumé one can conclude that the scientific CM literature is still limited as Ali and Kidd (2013) emphasized in their publication. It is foreseeable, as (Narváez, 2009) says, that the volume of CM literature will grow in the future. A peculiarity of the literature currently available is that the authors focus on individual topics in monograph form, but only marginally cultivate academic discourse among themselves. An in-depth scientific discussion among the CM experts can therefore currently be regarded as a desideratum to be redeemed.

Chapter Three: RESEARCH METHODOLOGY AND METHODS

3.1 Introduction

In this thesis the interpretivist paradigm in combination with an thematic approach was chosen. For reasoning see Section 3.2.1.2 and 3.2.2.3.

As with any academic study, the question that must be asked at the beginning of the research project is what is the fundamental relationship between the *object* or *subject* being researched and how is the knowledge to be acquired? To achieve this clarification of the ontological and epistemological position of the study therefore needs to be determined. By determining this, and then selecting the appropriate methodological approach to collect and evaluate the data, a robust and suitable research strategy needs to be devised, from which a subsequent theory can be either tested, new theories created or a contribution to knowledge generated. Gill and Johnson (2002, p. 491) state:

> …the choice and adequacy of a method embodies a variety of assumptions regarding the nature of knowledge and the methods through which that knowledge can be obtained, as well as a set of assumptions about the nature of the phenomena to be examined.

Reflecting the requirements of Gill and Johnson (2002), this Chapter sets out the research strategy adopted, in which an interpretivist methodology with a thematic approach was adopted. In following this strategy, the philosophical standpoint will be presented together with the practical methods which underlie the empirical implementation of the study. Inevitably this will include a critical justification of the research approach and strategy, but also an awareness of the potential inherent limits of the study.

Researchers need to face the challenge of generating a research methodology, and therefore need to fully understand the central purpose of the study (Blaikie, 2007; Halkier, 2010; Silverman, 2013). The relationship between the specific research subject and the general worldview of the researcher needs to be reflected from the outset of the study. The ideological background of the researcher has a direct influence on the assumptions, approach and values

associated with the underlying topic. Blaikie (2007, p. 16) states that this reality is constituted by ‘representations created by individual minds’ and resides in the existence of subject-independent facts (Silverman, 2013).

Reflecting this, the methodological approach adopted for this study follows the Blaikie (2007, p. 8) call for a ‘bottom-up’ approach to be followed using an inductive strategy, where the concepts of social science and the realities of life can be gathered from the everyday experiences and understandings of social actors. This approach can also enable the experiences and perspectives of the participants gained through the use of interviews, whereby the data generated is dependable and authentic (Jebreen, 2012).

3.1.1 Ontology and epistemology

Ontology is that branch of philosophy which deals with the nature of the existing Crotty (1998). In addition, it is to be said that it asks for the common ground of all of that which exists. Moreover, ontology pursues the question of ‘how you choose to define what is real’. In constrast epistemology seeks to answer the question, ‘how you form knowledge and establish criteria for evaluating it’ (Hatch & Cunliffe, 2006, p. 12). The theory offered on ontological attitudes to the nature of the reality of life is often divided into two dichotomous categories, namely positivist or anti-positivist and objectivist or subjectivist. In contrast to the hard positivist positions, which claim that knowledge lies exclusively in the objective measurement and classification of an independent external reality, the chosen epistemological model takes into account that economics is a man-made, lived and at least partially controlled process. It is taken into account to the extent that ‘something exists only when you experience it and give it meaning’ (Hatch & Cunliffe, 2006, p. 12). This is important for the present research topic, as economic processes are decisively shaped by human decisions.

As noted above, epistemology is the theory that describes how individuals gain knowledge about the surrounding world, and includes what a person knows (Blaikie, 2007; Silverman, 2013). Epistemology provides a philosophical basis for deciding and establishing what types of knowledge exist, what is known for certain, and what the criteria are for deciding how knowledge is judged to be both appropriate and legitimate (Crotty, 1998, p. 8). Crotty (1998, pp. 8-9) states

that epistemology ‘is the theory of knowledge embedded in the theoretical perspective and thereby in the knowledge’. From this quote it can be deduced that the epistemological position describes the way a researcher perceives the world. As proponents of the interpretivist approach, the interviews are designed to gain knowledge in the awareness that reliable knowledge can only be gained from the perspective of the individual who experiences the phenomenon under investigation first-hand. This is achieved by the selection of interview partners who, although in different ways, are in any case closely related to the CM topic professionally.

3.2 Research strategy

According to Blaikie (2007), there are two main considerations in the choice of research method(s) which should be used and applied. The decision is based on either on the decision made from a pragmatic reason, as in matching ‘a strategy to the nature of a particular research project’ and the kind of research questions which have been selected for consideration, or alternatively on the basis of the researcher’s ideological position with regard to the gain in knowledge about human interactions (Blaikie, 2007, p. 15). For this study, the perspective adopted by Blaikie (2007) is of crucial importance because it determines the research strategy, the choice of which implies ‘the adoption of a certain set of ontological and epistemological assumptions’ (Blaikie, 2007, p. 6). Both Easterby-Smith, Thorpe, and Jackson (2012) and Alvesson and Deetz (2000, p. 6) point out that the distinction between quantitative and qualitative paradigms is important, but not necessarily of primary importance. Instead Easterby-Smith et al. (2012), argue that mistakes in inadequately addressing the ontological, epistemological and axiological position of the study are essential and this has potential implications for the outcome of the research, leading to fatal errors and flawed outcomes.

3.2.1 Possible research methods

In the sense of the methodological requirements described above, the central principles of the research methodology are set out in relation to this study. According to Blaikie (2007), the choice of a particular methodology from a possible portfolio reflects the value system that determines the researcher's

worldview. Bryman (2016) adds that both the quantitative and qualitative research approaches have similar intentions and characteristics but contrasting features. These characteristics reflect epistemological beliefs about what constitutes acceptable knowledge. In deciding which research strategy is appropriate for a given subject, authors such as Silverman (2013), Bryman (2016) and Veal (2017) claim that there are two main paradigms: positivism and interpretivism.

3.2.1.1 The positivism paradigm

A postivist paradigm is closely assocated with a quantitative research approach, whose thinking can be seen as residing and being closely associated with natural sciences. One of the key characteristics of positivism is that of a reductionist, which means that a hypothesis is set out and then either verified or disproved by means of a hypothetical-deductive approach (Guba & Lincoln, 1998). Positivism represents an objectivist conception of social reality based on the collection of numerical facts, then uses a deductive and predictive approach to comprehend the correlation between research and theory.

Blumer (1956, p. 685), in examining the characteristics of positivist studies, found that this paradigm tends to neglect ‘the process of interpretations or definition that goes on in human group’, otherwise the validity of this paradigm is weakened, particularly if the role of the researcher involved. The postivist contends that the perception of the individual is an everyday event, and needs to be considered in isolation with the subjective outcomes ignored. Schutz (1962) agrees adding that a quantitative or positivist approach does not take into account the distinction between individuals and social institutions, or the differences between ‘the world or nature’ or ‘social world’. For Guba and Lincoln (1994), positivism can only generate insights that exist independently of any form of theoretical framework and can therefore only produce useless results when investigating real-world issues such as beliefs, attitudes and perceptions (Guba & Lincoln, 1994). Guba and Lincoln (1998) earlier concluded that positivist distancing and freedom from values means that the subject under investigation is excluded or faded out of his or her social world. This circumstance has led writers such as Sarantakos (1998, 2012) to contend that the study of social reality must be located in reality, without the human part being lost and

appearing synthetic. In examining the characteristics of positivism, Bryman (2016) also emphasized the objective and value-free nature of this concept, which implies that the researcher must be detached from the research. The positivist approach is not used in this thesis because it does not do justice to the complex contexts, including the social requirements.

Therefore, this study focuses on the experience and input of the actors involved in the whole process of configuration management, including operational managers, configuration managers and consultants so that the perceptions, experiences, and knowledge can be investigated. As can be seen from the previous characterisation of positivism, the positivist method is not appropriate for this study.

3.2.1.2 The interpretivist paradigm

Unlike positivism, the interpretivist paradigm is typically associated with a qualitative approach. Interpretivism implies that social research is generated through interaction. In achieving this, there are two key methods, that of researching objects among themselves or between the researcher and object. This characteristic of interaction also means that interpretive research seeks to address subjective meaning as opposed to objective meaning of social action. Through this inductive approach, the research process takes into account the interdependence of the researcher and subject (Easterby-Smith et al., 2012). This assertion by Easterby-Smith et al. (2012) implies that the researcher cannot remain detached as a representative of positivism or be eliminated from research, but deals with the subject in a subjective context, which is reflective of this study.

3.2.2 Potential research approaches

For Rogers (2011) and Guba (1990) there is a single approach to the decision-making process as to which research approach should be chosen. Although clear differences between the approaches can be identified, Sale, Lohfeld, and Brazil (2002, p. 43) claim that they are qualitatively and quantitatively incompatible since ‘the two paradigms do not study the same phenomena,

therefore qualitative and quantitative methods cannot be combined.' Other authors including May (2011), Bryman (2006, 2016), Creswell (2014) and Robson (2016) highlight that the individual approaches are not independent of each other and that the identified differences appear to collapse during the examination. Due to the small number of potential interviewees that were identified for this study, there was an insufficient sample size for a quantitative approach such as a questionaire to be used. Instead, a qualitative approach was adopted, providing the added benefit of being able to focus on the specific and unique experiences of the interviewees, thus gaining a rich insight into these participants' viewpoints.

3.2.2.1 Quantitative approach

The quantitative approach is related to the mindset of positivism and the way of thinking, originating and residing in the scientific paradigm. It is based on the notion that there is an unambiguous reality of truth that can only be explained by the application of fixed laws, and that a value-free deductive method is needed to ensure that the results are valid (Bryman, 2016; Bryman & Bell, 2015). This approach requires a method that leads to mathematically or valuable results to satisfy the understanding of validity. In practice, this usually leads to a desire to identify recurring patterns in the data that make it possible to predict and verify future events, provided that the underlying research variables are controllable (Guba & Lincoln, 1998; Huberman, 1994). A quantitative approach was rejected as this study intended to take an inductive approach whereby the study can generate a new insight as opposed to proving a hyphothesis or assumption.

3.2.2.2 Qualitative approach

If the quantitative approach is linked to positivism, then a qualitative approach has a close natural affinity with the interpretative paradigm. The qualitative approach is centred on the assumption that the living world is not a natural fact, but is based on the perception of a human construct. To investigate this, research and investigation can only be adequately understood from the participant perspective of social interaction (Bryman, 2016; Bryman & Bell, 2015). The qualitative approach is inductive in nature and therefore is not primarily based on generating facts, but provides an insight and understanding of

how and why a phenomenon exists. The effort to understand reach into a deep layer, which opens up the context of origin of the given. Finally, this approach provides meaning to social reality, if relevant, and leads to the creation of richness of data (Bryman, 2016; Bryman & Bell, 2015), which is reflective of this study.

3.2.2.3 Thematic approach

According to Braun and Clarke (2006, p. 11), thematic analysis 'provide(s) a rich thematic description of the entire data set, so that the reader gets a sense of them [sic] predominant or important themes.' Clarke, Braun, and Hayfield (2015) describe a thematical approach as a method of high flexibility to collect patterns of meaning within and between a set of qualitative data. The aim is not only to summarise the existing data content in condensed form, but also to identify and interpret it. It is not necessarily essential to collect all the characteristics, but the most important ones; in this respect the procedure is selective. This method is particularly suitable for experience-oriented research, in which the behaviour and practices of the participants should also be considered. It is applicable to data sets of different sizes. It can be used variably, for both inductive and deductive analyses and for capturing explicit and latent meanings.

Braun and Clark (2006) further identified that the thematic approach is especially useful for research into under-researched or otherwise obscure topics. This corresponds to the present study, which, as described in the literature review, has not yet been adequately investigated and researched, regarding the general applicability of measuring CM for use in different companies.

3.2.3 Research design

To conduct a research project, the most suitable method must be found and selected. It is important that the operational framework for conducting the research is appropriate. To develop a sufficiently rigorous analysis process, it is necessary to consider carefully how the necessary data should be collected and how this should be evaluated. For the data collected from the interviews, which were from three different professional groups, thematic coding analysis was

identified as the most advantageous. Robson (2016) contends the approach is flexible and can be used for almost all qualitative studies. Furthermore, the results of the analysis can be easily shared with practitioners or management, which facilitates collaboration with these groups. Furthermore, thematic coding allows to filter out the most important topics from a large amount of qualitative data. Finally, thematic coding analysis is not limited to a certain level of interpretation but can also be used in complex cross-disciplinary projects. Topics are to be compared with codes or are constructed from groups of codes, and a topic is defined as a category that has been identified by the analyst through the data by being related to the research questions (Bryman, 2016). These topics are built on codes identified in the transcripts, and this allows the researcher to understand the data theoretically in relation to the research focus. Thematic analysis is described as 'a way of seeing', specifying a method of coding and analysing data and using the result to form theories (Boyatzis, 1998, p. 77). A theme can be many things, but is essentially a category identified by an expert interviewee related to his or her research or field of expertise, and there are several possible methods for identifying themes, most importantly repetition, i.e., ’topics that recur again and again’ (Bryman, 2016, p. 580). However, not everything that is repeated is a viable theme (Bryman, 2016). In other words, it is not just a matter of quantity but of the significance of a particular term. Instead, a second step is required, which is the reflection of the researcher on what has been said that repeats, and the identification of continuities and linkages within these repetitions. The thematic approach involves two different patterns of analysis, inductive or deductive (Braun & Clarke, 2006). The analysis employed in this thesis utilizes aspects of both approaches. This is because some themes were already evident in the literature analysis, and some themes only became evident from the interviews themselves. This is in keeping with Braun and Clarke (2006, p. 97), who note the ‘method (should be) driven by both (the) research questions and (the) broader theoretical assumptions’. Reflecting this, an inductive approach was employed in order to confirm the importance for the interviewees of the major themes identified in the literature review. Furthermore, the inductive approach was used to discover and flesh out thematic aspects that were not evident or previously described in the literature.

Phase	Description of Process
1. Familiarising of the data	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
2. Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each theme.
4. Reviewing themes	Checking that the themes work in relation to the coded extracts (level 1) and the entire data set (level 2), generating a thematic 'map' of the analysis.
5. Defining and naming themes	On-going analysis to refine the specifics of each theme and the overall story that the analysis tells; generating clear definitions and names for each theme.
6. Producing the report	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating the analysis to the research question and literature, producing a scholarly report of the analysis.

Table 3-1: Phases of Thematic Analysis; Source: Braun and Clarke (2006, p. 87)

3.3 The reliability and authenticity of the study

The robustness of the research design was carefully considered when setting up the evaluation of the benefits of configuration management and the investigation of measurability. For this reason, the four criteria of Guba and Lincoln (1994) were considered, namely creditability, transferability, dependability or bias, and confirmability.

3.3.1 Credibility

Credibility in research is created by results that are reliable and trustworthy. It is particularly important that research results are presented in a way that is understandable to the academic reader, which fosters credibility. In order to achieve a high level of credibility, a constant review and verification by the researcher is necessary, which involves continuous observation and a reorientation towards those areas that are particularly important for the study. Guba and Lincoln (1994) and Lincoln, Lynham, and Guba (2011) also advise that the selection of interview partners should be authentic. In this study the interviewees were configuration managers, executives and consultants from various companies and institutions in the aerospace industry, which followed a purposive sampling strategy, see Section 3.5.4. The pilot study was conducted before the main study confirmed that interviews with the right participants are the right instrument to obtain the necessary information to create a credible framework to evaluate the benefits of CM in the aerospace industry. It was important to select the participants for the main study in such a way that the most meaningful functions were chosen from the most suitable companies and institutions in the industry. Consideration was given to the research results and to its presentation a certain degree of authenticity while minimizing possible disturbing influences.

In order to further increase credibility, the researcher should, as Guba and Lincoln (1994) suggest, always return to certain themes. A thematic approach was used to code the data in this study, using several themes as interview guidelines. To further enhance authenticity, the interviewees were also given the opportunity to check the transcripts.

3.3.2 Transferability

For the qualitative researcher, according to Baxter and Eyles (1997), transferability is less important than credibility. By accessing the results and the approach chosen, transferability enables future researchers to advance the research subject.

3.3.3 Dependability

Dependability ensures that trust in the research and integrity in the narrative of this study is established. For this reason, dependability is essential for qualitative research. Dependability should also guarantee that the research results are applicable for other times or, similarly to transferability, and should ensure that the data and research results are also available for other analyses. The interviews in this study were recorded with the consent of the interviewees, so that the analysis was not only dependent on notes, but could be accessed at any time using the spoken word.

3.3.4 Confirmability

Confirmability refers to the degree to which the results are determined by the interviewees and are not influenced by the researcher's bias. Researchers should therefore provide an explanation of the extent to which their motivation and interests have influenced their interpretation. Authenticity, truthfulness and honesty are essential for rigorous, qualitative research (Huberman, 1994). Authenticity, is ensuring that there is a truthful or genuine honesty to oneself, and is supported by being able to convince a reader that the narrative is coherent and presented with sufficient context. According to Huberman, the reporting process becomes plausible by making the research resonate throughout the duration of the study. The interviewees were not only asked to review the transcribed narrative, which confirmed the results, but in addition a validation was performed at the end of the study. An executive expert was selected who could particularly benefit from the results of the study. For this validation, the questions for the interview were designed and divided into two parts. The first set of questions asked the expert to check the interpretation of the interview results and whether they lead to the right conclusions for the development of the

framework. The second part is the review of the framework. The following questions were designed for this purpose. Is the framework sufficient to evaluate the benefits of CM in the aerospace industry? Are the questions appropriate from the depth? Are there unnecessary questions or should additional questions be asked? In your position, would the framework help you to further develop CM? These questions are evaluated in Chapter Four and should contribute to the confirmability of this study.

3.4 The main research instrument

The interview could have been conducted following three types of formats: a structured focused, an unstructured format or a blend of the two, known as semi-structured. A semi-structured interview enables the generation of interview information by giving the participant being interviewed a chance to 'recount their story', whilst also providing the researcher with some form of structure to the interview. According to Schütze (1977) semi-structured interviews can provide the means to generate a narrative enabling the participants to tell a coherent story comprising all relevant occurrences from the beginning to the end. For this reason, this strategy was followed in the present study.

3.4.1 Formal construction of the interview on CM

The interviews undertaken in this study were conducted using semi-structured interviews, and followed the following phases:

a) **Introductory phase**: the following information was presented to the participant about

   - The aim of the study
   - The content of the interview
   - How the interview was to be conducted and the right of the interviewee to refuse to answer or to end the interview.

   The key purpose here was to create a neutral and safe atmosphere, as well as assurance of confidentiality and adherence to the ethical regulations of the University.

b) **Telling phase**: Was aligned to the research aim and the question was set out in Chapter one. It sets out the main part of the interview which commenced with the existing interview questions acting as a prompt.

c) **Verifying phase**: The rationale was that the research questions were verified was set out in Chapter one. This phase was centred on the use of immanent questions to elucidate clarification of emerging themes and ensure correct understanding.

d) **Accounting phase**: Was set out to address the research aim as set out in Chapter one. This phase included, the meaning of the narrative discussed by the participants.

3.4.2 Organizational preparations

From the outset a logical planned approach was adopted for the interviews which included an evaluation of the person to be interviewed, which involved a time scale for interviews and selection of the location. The selection of interviewees and information about the background of the study was sent to the participants in advance to provide them with a clear understanding of the purpose of the study.

3.4.3 Recording of the interviews

With the consent of the interviewees, the interviews were recorded by video and audio, or at least by audio, which had the advantage that the analysis is not exclusively based on notes. Instead, the actual words of the interviewee could be listened to and individually analysed, which has the advantage that, for example, the tone of voice or response time is also available for evaluation (Saunders, Lewis, & Thornhill, 2012). Thus, it is possible to judge not only what was said, but also how it was said. Since a recording makes the analysis much easier it was important to convince the participant to consent to the recording. Permission for the recording was obtained in written form from the interviewee. For business reasons not all interviewees agreed to the recording, so some interviews were only recorded in written form. Written permission was also obtained from the Interviewee for this. Four interviews were recorded both by video and audio. Six interviews were recorded by audio only. Unfortunately, three interviews were

only allowed to be recalled through written notes. The duality between recording and note-taking reinforced the content of most interviewee's report, which also made it possible to verify the analysis, which further increased the reliability of the study.

Question Types			
Open	**Closed**	**alternative**	**suggestive**
How + Why-Questions	Binary response option: Can only be answered with yes or no.	Either ◄► Or	The answer is inherent in the question
= Informative Point of view Opinions Expectations Personal position	= low gain of information Primarily suitable for short answers or to complete a topic	= to the interest adjustment To the reconcilement of another procedure or to split-up the further interview according logical standpoints	= non-scientific No gain of information
What are your expectations? On what do you attach particular importance? How did it come to this? Which experience do you have?	Is the application of CM standard you have described standard in all divisions? Yes Is the branch in London already opened? No	Described in paragraph 4.7	Do you also have the opinion that the incorporation of CM increases the efficiency of the production?

Table 3-2: Formal-logical Question Typology (Buchholz, 2017)

3.5 Conduction of the interviews

In order to set the framework for the interviews, the interview questions must be defined and selection criteria for the interviewees must be defined. Before starting the main study, a pilot study was conducted. To present accurately the pilot and the main study this section will logically and systematically present each stage independently.

3.5.1 Pilot study

Before the main study was carried out, it is advisable to conduct a pilot study to ensure that the methodological strategy and procedure is trialled (Connelly, 2008). This involves the testing of the main interview strategy, but on a smaller scale and includes the trialling of the interview questions to ensure that the central themes to be covered are both dependable and credible. The pilot provides the interviewer with the opportunity to review various skills and techniques, including interview questioning, listening, and documenting skills, then how the data will be analysed. The pilot study revealed overall that the basic assumptions made during the literature review were suitable for the main study.

The importance of a pilot study is confirmed by Van Teijlingen and Hundley (2001), who reiterate that such a study allows the research instruments to be developed and the adequacy of the approach to be tested. The feasibility of a full-scale study can be assessed and the research protocol can be reviewed and if necessary redesigned if it is realistic and workable through conducting a pilot interview. Logistical challenges and problems can be identified which might occur using the proposed methods and it is possible to determine the resources as necessary. Another important advantage of conducting a pilot interview is that the approach can uncover potential problems and develop the research question and research plan. Finally, a pilot study can enable the researcher to develop their research skills.

The first interview in this study was seen and used as the pilot interview. The pilot provided the means to test the research protocol as being realistic and workable and helped to identify any potential logistical problems. The interview

skills of the researcher were tested and evaluated to see if the answers to the questions were dependable and reliable. The pilot interview confirmed that the general approach of the study was suitable. In terms of the research questions, the outcome of the review of the pilot interview showed that although slight changes to the wording of the questions to become more open-end were necessary, the essence was generally usable. The participant in the pilot interview was a Configuration Manager. Following intended interview protocol, the questions included 'How is Configuration Management valued in your company' which needed to be changed to focus on the consultants as to 'How is Configuration Management valued in the companies in which you are doing consultancy work.' Following the research protocol, there were a number of question changes which includes the rationale was that the questions were not clear of sufficiently succinct. The details of the changes are explained in Section 3.5.3.

3.5.1.1 Preparation of the pilot study

After a strong baseline had been created through personal as well as methodical preparation, a pilot study was also carried out in this phase. As already mentioned, the focus was on the semi-structured interview, as the guidelines were to be used as a backbone for the interviews. The aim of the pilot study in this context is to check both whether the interview guide generates the required information and, if further questions, themes or other changes have to be included in order to conduct the interviews in the empirical research phase in an optimal way. Bryman and Bell (2015) suggested using the pilot interview to question the original version of the guidelines and to create a final version for further use based on the generated results.

The selection of the expert is very important for the semi-structured pilot interview, therefore a senior expert from Configuration Management was selected. The interviewee for the pilot study was chosen, not only because he has a lot of experience in CM, but also because he has management experience and the necessary theoretical knowledge required for scientific work. He is responsible for all areas of CM in the entire organization, such as configuration management planning, configuration management identification, configuration management change management, configuration management verification,

configuration management audit and accounting, and therefore has the necessary overview. The author of this study has known the Interviewee for many years because he organises conferences for the exchange of experiences in the field of CM and there is great mutual trust, which further enriches the process of the pilot study. The points mentioned made it possible to conduct the interview in a relaxed atmosphere, which also helped to receive open and critical feedback. Furthermore, the guidelines were questioned and important advice for further interviews and investigations was provided.

As the participant of the pilot study was known, all interviewees were contacted directly and explained what the topic was, the reasons and aims for the study and how the further research procedure was planned. In accordance with the defined ethical guidelines, the participants were informed from the first contact that all information received would be treated as strictly confidential and that all personal data would be made anonymous. Furthermore, each interviewee was informed that they could stop the interview or the further research process in which is the participant was involved in at any time without giving reasons. After the candidate had agreed and signed the consent letter, the interview guide was made available to the candidate in order to prepare for the interview and to elaborate possible questions.

After the pilot interview was conducted, analysis and any necessary changes were shared with the interviewee. This was intended to verify the decision to conduct semi-structured interviews or, if necessary, to develop alternative options (Easterby-Smith et al., 2012). Following the interview, the transcription and additional interview notes were presented to the interviewee. This gave the interviewee the opportunity to make corrections and possible adjustments, even additions and deletions would have been possible (Saunders et al., 2012). This method was also used in the following interviews.

Based on the results of the pilot interview, the influence on the guidelines was discussed. The pilot study also aimed to confirm the research approach and methodology, which is why the results of the pilot project were also used to answer the research questions in order to contribute to the fulfilment of the research objectives.

3.5.1.2 Pilot interview

The pilot interview to test the research questions and the research approach took place on 19.09.2014 in Switzerland with the process responsible CM for several divisions of the company. The interview had a duration of approximately 60 minutes. The divisions the interviewee is responsible for are military and civil development, and production and maintenance of complex aerospace products. These products are, for example, complete weapon systems such as jet fighters including all systems. In his role the interviewee has deeper insights into the complex CM processes within the company as well as across companies in complex international projects and this with professional experience of over 20 years.

The pilot interview was divided into eight areas in order to follow the interview guidelines to be tested. The areas were in the following order and included introduction and welcome, briefing: topic content, reasons for the selection of interview partners, ethics and confidentiality explanation, interview process of asking questions, clarification of ambiguities through in-depth questions.

At the beginning of the interview process, the interviewee was provided with the prepared questions with the request to review them and to give feedback on which research questions were important and meaningful (Saunders et al., 2012). These questions were developed based on the gap identified in the literature review, that the existing measuring models are generally KPI-based and cannot generally be applied in different companies (Guess, 2013; Staats, 2009).

The prepared questions are as follows:

1. Do you make use of CM in your company?

   This general question was asked to determine whether to continue the interview.

2. To what degree of intensity do you apply CM?

   This question was asked to gauge the extent of CM use, as well as to help guide the interviewer to understand how detailed further questions could be.

3. Do you evaluate the effects or benefits of CM?

   This question was asked to determine whether interviewees have knowledge and experience of measuring CM.

4. How do you quantify these effects and benefits of CM?

   This question was asked to determine if the company already employs a scale for measuring CM and if prior knowledge of this exists.

5. What are the results of this quantification in your company?

   This question was asked to determine if the measuring process had already provided benefits to the company and what optimisation might be possible.

6. In which way do you make use of your results?

   This question is related to the previous one and was asked to better understand the process of measuring and optimisation of CM.

7. Do you compare your figures and what is the basis for your comparisons?

   This question was asked to determine whether and how a company compared data to measure improvement.

8. How did you come to your special approach, especially your way of quantification?

   This question was asked to gain further knowledge of how methods and models were developed and quantified, where applicable.

Furthermore, it was asked how many questions from the perspective of the pilot interviewee were necessary to answer the research questions and how the results should be evaluated and quantified. During the course of the interview it was recognised that the field of application of this research can extend far beyond the aerospace industry and can also be of great importance for other industrial sectors.

3.5.1.3 Interview revisions after the pilot study

The interview questions were divided into the two areas of undervaluation of Configuration Management by the senior management, and the measuring process. Furthermore, based on the advice of the pilot interviewee, all questions were reworked so that no closed questions were asked. All questions had to be sufficiently differentiated, with regard to the depth of the questions and focussed on the highly diagnostic process indicators. It was advised to ask a maximum of 12 questions and a number of about 10 interviews was considered sufficient. In general, it was advised that the framework should be designed to compare different percentages and not to benchmark monetary aggregates. Finally, the pilot interviewee pointed out that general questions and machine evaluation did not make sense for this topic, rather an individual interpretation of the interview results is necessary.

The main change in the interview guidelines was to change the order of the different interview points. The pilot interview showed that, in order to build up trust and rapport, it made sense to include the point on ethics and confidentiality explanation immediately after the introduction and welcome. Both interview guidelines, before the pilot study and after the pilot study are presented in the appendix Section 7.6.

3.5.2 Main study

For the main study, the interviews were conducted on a one-to-one basis using semi-structured interviews, which had clear advantages, including being to react to the participant on an individual basis. It was decided from the outset and confirmed during the pilot stage that telephone interviews should not be used, or used only as a last resort if the participant was unable to be interviewed in person. With the interview questions revised and formulated as open-ended, it was therefore possible that knowledge and the background of the interviewees could be gained more easily. Another important outcome of the pilot was to confirm whether the interviewee was motivated to support the study. The pilot study found that the participant could see the benefits of participating the study and would therefore be willing if needed to find other potential interviewees to contribute. Further, the participant also expressed that the study and its

relevance was also an incentive to provide a critical insight and richness of data essential for a qualitative study.

3.5.3 Interview questions

Questions to the undervaluation of configuration management by the senior management.

- How is Configuration Management valued by the senior management in your company?
- What significance has Configuration Management within your company?

These questions were modified and adapted from the pilot study questions, with the goal of better understanding the role that senior management plays in the employment (or lack of employment) of CM within a company. This was designed to gauge how important senior management's interest and investment in CM is for the utilisation of CM in a company.

Questions about the measuring process.

- Do you measure the value of Configuration Management?
- Why do you measure the value of Configuration Management?
- Why don`t you measure the value of Configuration Management?
- How do you perform the measurement?
- Which key performance indicators are important for you?
- What do you do with the measurement results?
- How important are the results for the management?

These questions were modified and adapted from the pilot study questions to be more open-ended so as to better obtain an overall understanding of how CM is employed and measured in each company.

3.5.4 Selection criteria for interviewee

In this section the selection criteria for the interviewees is presented. Purposive sampling was employed. Prior to the selection of the interviewees, several key areas of competence were identified as being essential for the study. Since the intended outcome of the thesis was to develop a framework which could

represent the advantages of using CM in the aerospace industry from a management level perspective together throughout the entire value chain across companies, competence areas in CM, consulting, management and aerospace were clearly defined. To achieve the most suitable candidates the study focused on ensuring that the participants had practical CM knowledge, theoretical CM knowledge and CM consulting knowledge, together with sufficient knowledge from all three areas. Practical CM knowledge included the users in a company who carry out the different disciplines and functions associated with CM, as set out in the literature review. By drawing on the practical experience of these specialists in the field of CM, it was the intention of the researcher to ensure that the data gathered contained an invaluable insight into CM, from which the framework would be created and developed.

In selecting the candidates, the study firstly conducted a pre-selection of possible interviewees who could participate. These candidates were selected through a network of contacts via professional organisations, the personal field of work or the academic environment. To ensure that all criteria were met a competence matrix of possible interviewees was created, which mapped their backgrounds, role, and availability. The first group of participants approached were configuration managers who possessed a high level of in-depth specialist knowledge and fitted the profile of specialist. The second group was made up of CM consultants who had an overview of several companies, and these represented the generalists. The Configuration Managers provided a deep expertise with detailed knowledge as to how project management flowed into the framework. Furthermore, the background of these individuals had strong a industry-specific overview of the entire industry. The final group represented senior management and decision-makers in the aviation sector. The senior managers had the insight and real-life experience for decision-making. The criteria and profile of the participants are shown in Table 3-3 page 101.

Competence areas	Practical CM Knowledge	Theoretical CM Knowledge	CM Consultation Knowledge	General Management Knowledge	Specialist Knowledge in the Aerospace Sector	Scientific Knowledge in the Aerospace Sector
Interviewees						
Participant A	X	X	X			X
Participant B	X	X	X		X	
Participant C (Telephone interview without recording)	X	X				
Participant D					X	X
Participant E	X	X	X			
Participant F	X	X				
Participant G	X	X	X			
Participant H	X	X				
Participant I	X	X	X			
Participant J	X					
Participant K (Interview without recording)	X	X				
Participant L				X	X	X
Participant M (Interview without recording)				X	X	X

Table 3-3: Competence Matrix of Interviewees

The competence grid, as shown in Table 3-3 page 101, reflected the selection process based on the three groups of people. Following this strategic selection process, which was enabled through a systematic typology performed during the pre-selection process, ensured that the skills and attributes matched the criteria and provided sufficient depth. To illustrate this, Figure 3-1, depicts the final overlapping of the profiles amongst the three groups.

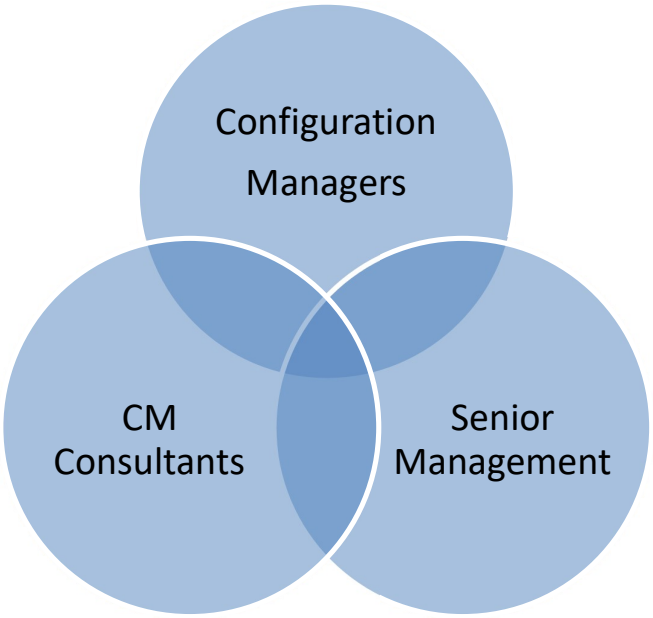

Figure 3-1: Overlap of the usable input from the individual groups of participants

3.5.5 Interviewees

Building on the previous section, the interviewees were chosen to ensure that expert knowledge and expertise would be gained. The criteria used ensured that there were the necessary appropriate participants who represented different areas of CM, and that the study followed a purposive sampling strategy. The largest group of interviewees were the configuration management experts. These individuals were chosen because of their configuration management experience. One participant categorised as a senior manager was also selected together with an interviewee who had authority in the process, and one person who was totally independent from CM.

Interviewee	Role	Location	Date
Participant A	CM Consultant	Hamburg	16.03.2016
Participant B	CM Consultant	Oberpfaffenhofen	10.02.2016
Participant C (Telephone interview without recording)	Configuration Manager	Munich	21.10.2014
Participant D	Authority representative	Munich	24.09.2014
Participant E	Configuration Manager	Hamburg	16.03.2016
Participant F	Configuration Manager	Emmen	18.03.2015
Participant G	Configuration Manager	Emmen	19.09.2014
Participant H	Configuration Manager	Emmen	18.03.2015
Participant I	CM Consultant	Stuttgart	23.10.2014
Participant J	Configuration Manager	Oberpfaffenhofen	18.09.2014
Participant K (Interview without recording)	Configuration Manager	Zürich	17.02.2015
Participant L	Aerospace Consultant	Lausanne	17.11.2015
Participant M (Interview without recording)	CEO	Oberpfaffenhofen	08.01.2016

Table 3-4: Interviewee Partners

A more detailed introduction of the participants can be found in the appendix 7.1.

3.5.6 Analysis and coding the interview data

The interviews were recorded if agreed by the interviewee, then transcribed and analysed and finally manually coded. The interviews were semi-structured interviews. The coding and analysis approach necessary for the evaluation of these interviews in this study was designed to solve the central research objective in the best possible way. It is a qualitative research approach in which the large amounts of text resulting from the interviews were coded first. The large amount of rich data was then analysed and interpreted. The analysis underlying this study was not only based on the framework of thematic analysis, but also took into account the latest developments in management and economic research on the organisation and analysis of text data. This approach to the coding method and data analysis is also recommended by Braun and Clarke (2006), and King (2004) because they emphasize that compared to other theories, such as grounded theory, there is greater flexibility for the researcher in coding the data. The flexibility of the coding structure of thematic analysis uses the use of priori themes as well as the initial structure to organize emerging themes (King, 2004). Due to the use of qualitative thematic analysis in this study, text data can be analysed flexibly (Cavanagh, 1997). The use of this approach has also enabled the classification of large amounts of text into an efficient number of categories representing similar meanings. This goes far beyond simply counting matching words or events to be classified. Downe-Wamboldt (1992, p. 314), underlines this with the statement 'provide[s] knowledge and understanding of the phenomenon under study' by giving the transcripts contextual related meaning.

3.5.6.1 Coding of the data

For the coding of the data, different coding approaches, including the grounded theory, were examined for their usefulness. Grounded theory requires both deductive and inductive thinking, since the theory is systematically generated from the data. According to Glaser and Strauss (1967), the hypotheses are not formulated in advance in this methodology because otherwise the data would have no influence on the preconceived hypothesis of a theory. Since grounded theory is not a descriptive method, according to Glaser and Strauss (1967) a different approach should be chosen if the goal of the researcher is already

known. For this reason, the grounded theory in its original form was considered inappropriate for this study.

In grounded theory, the researcher does not start the research process with reference to literature, but rather exact research steps are prescribed, which must be followed (Corbin & Strauss, 2008). In grounded theory, the significance is derived primarily from the subject or the setting. Qualitative thematic analysis, on the other hand, offers greater flexibility because the data is categorized into essential themes using a framework. In addition, the characteristics of the language used by the participants in the transcripts can emerge. In qualitative research with a thematic analysis, the data is presented and analysed in a similar way as in grounded theory.

The data is coded and categorized in the qualitative thematic analysis, which supports hierarchical categorisation and systematic classification in the analysis process. This approach is subject to constant revision as data collection progresses (Vaismoradi, Turunen, & Bondas, 2013). The revision process underlying this study included the analysis of interview transcripts and related notes, which led to changes in the themes within the hierarchy. This revision process also influenced the coding by introducing new codes or modifying existing ones (Vaismoradi, Jones, Turunen, & Snelgrove, 2016).

3.6 Ethics of the research

Doing research with human participants always confronts the scientist with a series of choices and challenges. This section outlines and discusses the ethical issues related to this study. This research was carried out within the Principles and Procedures framework of the University of Gloucestershire. The British Educational Research Association (BERA) and the British Sociological Association (BSA) established this framework. The researcher's responsibilities include ensuring that ‘the physical, social and psychological welfare of the research participants is not adversely affected by the research’ of the participant giving his/her free informed consent (Gloucestershire, 2020). There is the requirement for the researcher to provide the participants with information on the nature and objective(s) of the research, the reasons for carrying out the research and the way in which the results are to be communicated and distributed. The

anonymity of the participants must be guaranteed and they must be sure of the confidentiality of the data they provide.

There is a power relationship between the researcher and the participant. At the beginning of the interview there is no balance, because the interviewer is in possession of the study with all the information about it. The interviewee, on the other hand, does not know at the beginning which are the questions were asked. After the beginning of the interview, this relationship of power shifts more and more, because the interviewee has the necessary expertise to report (Tietel, 2000). In the further course of the interview this development can change into the opposite direction again, as the interviewer could ask questions that the interviewee cannot or does not want to answer. For this reason, the researcher needs to be sensitive so that the balance of power does not get out of control. As Bravo-Moreno (2003) points out, the researcher has to be aware of these shifts and has to offer an appropriate open communication, which makes it possible to criticize the applied method of research during the interview. The participant must also be given the opportunity and the right to refuse to answer questions at any time during the interview (Brinkmann & Kvale, 2005). Attention should also always be paid to the language of the interview so that the following interpretation of the interview data reflects the professional experience and position of the participant (Few & Bell-Scott, 2002). Few and Bell-Scott (2002) also point out that during the interview, especially when sensitive data is being asked, the participant should be reminded that he or she is free to answer the question or to stop the interview. These principles were followed in this study and written consent was obtained from all participants. It was important that the participants fully understood the nature and purpose of the study and their role in it in advance. This was achieved by providing the participants with a summary of the research purpose and structure in advance and by clarifying before the interview whether this summary was understood and whether they agreed.

The anonymity of the participants was ensured throughout the entire duration of the study. Assurances regarding confidentiality and anonymity were given in written form and repeated orally before the start of each interview. This is indispensable, especially to sensitive technical and economic data arising in the field of CM. The names of the interviewees were made anonymous in the

interviews and in their analysis. In addition, it was important to collect as little personal data as possible, which would allow conclusions to be drawn about the identity of the interviewees. Permission to record and transcribe the interviews was obtained on an individual basis. Not all interviewees agreed to a video or audio recording, which is why some interviews were recorded in written form. All recordings were handled carefully and kept in a safe place. As the interviewees were mainly very busy people, the most convenient location for them was chosen, usually their office. They were also reminded that they did not have to answer all the questions or could stop the interview at any time. In general, it was important that a pleasant environment was available for conducting the interview so that the comfort of the participants was guaranteed.

3.7 Methodological limitations

To ensure that a sufficiently rigorous approach to the topics identified in this study were chosen, supervisors and colleagues were asked for alternative views. To ensure that the settings, methods and materials of the study reflect the position of the research, special attention was paid to the reliability of the research. This is particularly important because human action is situated and depends to a large extent on contextual attributes and determinants, as Chamberlain (2008) and Schmuckler (2001) noted. Therefore, in this study, great importance has been attached to achieving a high degree of authenticity by ensuring that the interviews took place mainly in the natural working environment of the participants. When using an interpretative approach in qualitative research, one challenge is that this method provides a large amount of rich, interesting data for analysis. Another even greater challenge is the allocation of the data into themes. Easterby-Smith et al. (2012, p. 129) sees an inherent tension between ‘generating meaning and counting frequencies’. To meet this challenge, free coding for interesting categories of material were created in this study. This made it possible to check data that were not directly related to the central coding structure and ensured that the focus was maintained and the emerging theme retained its relevance.

3.8 Chapter Summary

The purpose of this Chapter has been to describe the research strategy and research design of this study, which was developed to appropriately fulfil the overall needs of this study. Different research paradigms and approaches were considered, and their positive and negative aspects were weighed in respect to their suitability for the topic of this study. It has explained the choice of research approach, namely the thematic approach, which was chosen, following Robson (2016), due to its universal applicability to qualitative data, its flexibility, and its applicability to cross-disciplinary research questions such as the ones identified in this study. The conduct of the study has been outlined, including the criteria involved in the choice of interviewees. Additionally, the design of the interview questions has been described. The pilot interview was explained in detail to identify how it shaped the form and conduct of the later interviews. The procedure to record, analyse and code the data was documented and details have been provided regarding issues of flexibility, validity, and reliability. An explanation of the findings of this study can be found in Chapter Four. Chapter Five presents the creation of the framework based on the analysis.

Chapter Four: ANALYSIS

4.1 Introduction

The interviews were evaluated using a thematic approach as set out Chapter Three. The interview design used a semi-structured approach with a narrative component to ensure, there was necessary flexibility and an appropriate degree of individualisation for each participant. The interviews contained a high degree of individuality and incorporated differing perspectives and ideas.

4.2 Determination of the analysis criteria

For the purpose of analysing the interviews, an initially broad field of themes emerged. In relation to the research questions, it was important to focus on an effective selection of core concepts, which was guided by the literature review. Staats (2009) argued that the lack of research and practical application of *individualizability* should be at the centre of interest. According to Guess (2013), *complexity* is a broad core but complex theme, which also contributes significantly to the understanding of softer attributes and characteristics. Since the application of CM, especially from a management perspective, is always oriented towards the future, it must also include the key concept of *potentiality* in the categorical core portfolio, which has an important function for interview evaluation. Further terms from the periphery are added for an extended understanding.

For this reason, the following terms were defined and color-coded for analysis; the main themes degree of Complexity of CM is coded in yellow, the degree of Potential of CM is coded in green and the supporting themes degree of Individualisation of CM is coded in red while Measurement and KPIs are coded in aqua-blue.

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4.3 General rating of the interviews

The interviews had differing themes and characteristics dependent on the interviewee and their background. In the main, the management consultants, who have a broad overview of the most diverse companies, were able to provide

more useful information to solve the research questions. The configuration managers in the individual companies were very much focused on the internal problems. The purpose of this analysis is to combine all the results of the interviewed configuration managers, consultants and other interviewed persons in a solution-oriented way.

4.4 Thematic analysis involving all interviews

A thematic approach was chosen for the analysis of the interviews. The interviews were analysed several times and examined for recurring, consistent themes relevant for addressing the central aim of the study. These themes were repeatedly identified independently by the interviewees, which meant that the theme was relevant and dependable, and provided key attributes for qualitative research. The interviews were then colour-coded according to the identified themes. In the following analysis, the themes were logically sorted and interpreted in relation to the context.

As identified in the literature review, the work of Staats (2009), found that the real problem is not really available simply through looking at KPIs. The problem is related to its applicability and cannot be systematically tailored to different companies and their specific needs. In other words, not every company produces the same product using the same criteria.

Based on the interviews, two main themes emerged together with three supporting themes. The two main themes are *complexity* and *potential opportunities*. Complexity refers to either the internal complexity within a company or external complexity, which can refer to the needs and demands of different stakeholders including in the supply chain and governmental affairs, for example. Potential opportunities describe what the company and the CM is able to make possible, for example to establish different business models and save costs. The three supporting themes were identified as *individuality*, *costs* and *Industry 4.0*. These three sub-themes make it possible to develop the two main themes in more detail, as will be shown below. For example, it can be argued that the more individual a product or service is the more complex it becomes. Furthermore, management is generally very cost-sensitive and the Industry 4.0 is not possible without the usage of CM.

The use of these themes and sub-themes make it possible to provide a critical insight into the relevance and usage of CM as explained in the introduction to this thesis. The themes and sub-themes also helped form the basis of the framework as presented in Chapter Five. By analysing and interpreting these themes and supporting themes it is possible to construct the desired framework and thereby addressing the central aim of the study. The themes make it possible to identify the relevance of necessary aspects to the effective usage of CM in the aerospace sector.

4.4.1 Individuality

There are different forms of individuality, which were addressed by the interviewees. These include: product Individualisation, company individualisation, KPI individuality and individualisation of measurements.

4.4.1.1 KPI Individuality

The theme KPI individualisation was identified as being critically important to two of the interviewees (Participant A and Participant B) who possessed extensive consulting knowledge in different companies. These interviewees came to the same conclusion that there are no KPIs that are generally applicable for different companies. For the participants, there were no distinct differences between suppliers as to the usage of the scorecards. The interviews further revealed that there was a high range of diversity amongst the different suppliers, and therefore for this study it was not possible to highlight general applicable KPIs.

Participant A for example wanted to express the fact that there are no KPIs universally applicable to all companies in the aviation industry.

> “What I just wanted to point out is, we have just introduced these score cards for the important suppliers. As you can see, there are no most important KPIs in this sense. These are the things we're recording right now. Of course, these are not mathematical KPIs. There are of course Score Cards (A-F), behind which of course the individual information stands” (Participant A).

For Participant A, there is a clear emphasis that it is not sufficient for the framework developed in this study to be limited to simple KPIs, since the KPIs must also be weighted to determine how important each is for a specific company. Participant B is equally of the opinion that there are no generally applicable KPIs for measuring CM for various companies in the aviation industry.

Participant B is equally of the opinion that there are no generally applicable KPIs for measuring CM for various companies in the aviation industry.

> “It's therefore difficult to say they are the standard KPIs, there's a standard procedure as we find the customer specific KPIs, that's there, but CM is so enormously broad the data integration that it's most difficult to say there is this table” (Participant B).

Several interviewees (Participants A, B, J, H and M), pointed out that it is difficult to identify CM as the source of deviations, as there are many different ways of causing them. Depending on the type and nature of the deviations, they can have consequences of varying intensity and extent. For example, Participant M stated:

> “However, I do not know the exact cause of any deviation. I don't know if the deviation is CM relevant” (Participant M).

Furthermore, it is also necessary to consider the effects of errors in the documentation, as Participant A puts it in the following statement.

> “If there was a typo correction, then of course it's something different than if the design was really nonsensical” (Participant A).

This perspective of Participant A, was supported by Participant M, who concluded that every difference must be checked to see whether it was caused by the CM or whether it could have been prevented by the CM.

> “However, I do not know the exact cause of any deviation. I don't know if the deviation is CM relevant” (Participant M).

The comment of Participant M mirrors Participant A in that rework can have many causes. Often, it has nothing to do with CM. There are many different individual root causes that vary from product to company. For this reason, the root causes of reworking must be considered individually for each application and company, as seen with Participant A.

> “This can be used to determine how many percentage points were caused by the config. For example, this could be a maximum of 20 percent CM” (Participant A).

Since it is the role of CM to enable the detection of errors, e.g. when providing delta comparisons between design status and production status, a differentiation must be made as to whether the error has already been detected internally or whether this was only done by the customer, which Participant M identified.

> “A clear distinction must be made between whether these complaints were discovered by the customer or whether they were established internally” (Participant M).

Participant M pointed out in his interview that the extensive KPIs he applied were not sufficient to draw adequate conclusions about CM. An important positive effect was the increase in customer satisfaction. Due to the complexity and interplay of the individual KPIs, it is not possible to draw direct conclusions about CM. This can be seen with Participant A, who provided an impetus for the idea that individual KPIs are not sufficient to evaluate the benefits of CM in the aerospace industry satisfactorily.

> “Thus, the part of the configuration process that directly affects the customer, is essentially the change process, the customisation process and for all that there are surveys. This is a large number of KPIs that report status. One can't say there is a KPI where you can now say that CM was good or bad” (Participant A).

Participant G also clearly points out in his interview that there are no generally valid KPIs, but that the results depend on several influences.

> “It depends what you want. Do you want a big variety of process indicators and figures or do you want to have two or three informative and highly diagnostic process indicators, whose data you can collect continuously and consistently” (Participant G)?

From the interviews, it is clear that measuring standardised KPIs alone is not sufficient to create a generally valid measurement system for CM in different companies in the aviation industry.

4.4.1.2 Company individualisation

Every company in the aerospace industry has to perform CM with a different individual intensity and depth across its disciplines presented in the literature review Chapter. Aerospace products are reliant on individual products that involve a very large supply chain. The degree of individuality normally decreases along the supply chain. It is therefore important that the individual suppliers carry out the correct amount and depth of CM. Most important is the compatibility of the CM system between the individual suppliers and the OEM. As participant A says, suppliers who produce products with a low degree of individuality often lack understanding. This understanding of the individual necessary CM application can be achieved by using the framework developed in this thesis. However, for complex supply chains to work, certain standards must be maintained. This is not understood by many, which is supported by Participant A's statement.

> “Especially at the beginning there is a lot of discussion between Airbus and the Suppliers. They say it's not in my contract to do CM. That will have to be renegotiated first. I can remember the story about the manufacturer of slides who made a very simple window slide, and who was hard to educate about why he had to stay up to date. The supplier of a super simple product thought he could make ends meet without CM and didn't realise that he was classifying himself as a complex product. That is why the OEM, in this case Airbus, demanded a certain configuration standard” (Participant A).

The statement of Participant B does not support necessity of an elementary standardization either, but he points out intensively in his answer that different individual intensities of CM are necessary in different companies and industries. Or, as he says,

> “That doesn't mean every industry needs the same thing” (Participant B).

Participant G points out in this context that there are several aspects to consider when choosing an individual CM system.

> “That's the reason why I would first ask about the legal standards or normative requirements companies have to cope with” (Participant G).

The size of a company also plays an important role in the individual application of CM. In general, it can be said that CM is becoming increasingly important.

> “It always depends on how big the company is and what they are dealing with. I am convinced, I think CM is more and more important” (Participant H).

In this context, Participant M pointed out in his interview that the increasing importance of CM in many companies is not sufficiently considered and individually adapted: “A few years ago, I noticed an imbalance between the factual necessity and the internal significance that CM had de facto assumed. Therefore, the imbalance between the necessary application of CM and the actual application is increasing noticeably".

All this indicates that different companies in the aerospace industry therefore would benefit from introducing a uniform compatible CM standard at a lower level. The depth and intensity of the required CM differs significantly between different companies. This circumstance must be sufficiently considered in the measurement framework to be developed.

4.4.1.3 Product individuality

The individualisation of the products and their long-term use make special requirements on the CM necessary. It has to be considered very carefully how an optimal CM has to appear and by which means it can be achieved.

> “So we really go on, we stay with a product from requirement to phase out, go through these configurations and try to analyse what the customer has already using in these configurations, what he needs, what he doesn't need” (Participant B).

The measuring systems used also depend on the individuality of the products and the resulting complexity of the products, so there is a direct connection between individuality and complexity. This statement makes it clear that a standardised CM system with individual levels of depth is required. There is a direct proposition of the complexity of the product to the necessary depth of CM. The more individual a product is, i.e. the more customer options there are, the more important is a profound CM system. This connection is confirmed by Participant D, Participant H and Participant A.

> “Most [companies] have systems that are different in nature. Of course, this depends on the size of the company as well as on the products they produce. The individual methods often differ considerably in scope but also in terms of content and the way in which they are carried out. Of course, the scope also depends on the complexity of the product or products, but not only with complicated products, some companies have relatively simple systems others very well elaborated systems, which produce essential results” (Participant D).

Participant D points out that the complexity does not only depend on the product but that the size of the company also matters. He also explains that the CM systems have to be designed differently so that the reached benefit is optimised.

> “I have, for example, the comparison of CM in space flight to CM in aviation. It's certainly two pairs of shoes. So, basically the topics are the same everywhere, but for example, I notice the CM we now do, we are not an OEM. We do maintenance with plus or minus a few modifications to it. However, now for example with the Ariane carrier rockets which we have manufactured ourselves the traceability is naturally important up to the last rivet” (Participant H).

Participant H uses the example of the production of components for the Ariane launcher to explain that in the very complex field of space flight, particularly high demands are placed on the CM, which must be met without exception. These high CM requirements are due, among other things, to the extremely high values of the payloads that are transported into space.

> “The more complicated the part or product that the suppliers we support become, the more they have to move towards full CM. The dependence is there absolutely. For those who deliver a very simple product ("Built to Print", we design the finished product), this is reduced to a few important points” (Participant A).

Very clearly, Participant A states that the degree of application of CM depends on the complexity of the product to be manufactured. It is also interesting that participant A points out that the dependency on CM is absolute when complexity is high. On the other hand, CM can be reduced to a few important points if it is a very simple product.

However, Participant A also points out that in special, very individual applications, for example in shipbuilding, where there is no series production, the importance of CM can decrease with individuality. This is because CM is not limited to change management in any serial production.

> “They do very little reuse in shell construction and interior finishing, because they plan individually and are architecturally designed so

> that it is simply not worth doing. What they do however, is change management and that is to the point, because they have fixed-price contracts with their customers then tighten the specification and say, I am now delivering the ship. If the customer still has change requests, then he must pay extra for these" (Participant A).

Participant A's perspective includes an example of shipbuilding to illustrate this special case. In aircraft manufacturing, this phenomenon is normally limited to the complex, one-time interior design of private jets. On the other hand, series production predominates, such as in spacecraft. Nevertheless, this example is interesting because it indicates that there are special cases and a higher individuality does not always lead to more extensive CM. This study also found that individual product structures play a significant role. In aviation the ICAO structure with its chapters is used. In these ATA chapters, the various systems in the aircraft are structured hierarchically, with the fuselage, for example, having chapter 53. Other industries use other structures which are not necessarily compatible. In general, however, systems should be structured. Ideally, CM helps to make the single individual structures compatible.

> "In aviation, for example, the ICAO structure is organized in chapters; in the rail sector, there are ISO standards, where there is a functional structure for trains. We have made projects in the field of ships and submarines, where there are also structures. In tank construction it is the so-called Gatel structure, i.e. also a standardized functional structure. This means that very many companies have functional structures from within their industries where they can structure the systems" (Participant B).

CM also enables new business models by offering products individually to customers for use, as can be seen with the comment of Participant B:

> "There are new business models. We may now be able to sell a blood diagnostic machine or an entire laboratory facility to customers who would not have been able to afford it before, because they had this one-time financial contribution but if I now

> charge via Services that is a completely new business model and that is another story. It is therefore also about presenting in the form of KPIs, there are new EBIT opportunities. New processes where I can generate an additional EBIT" (Participant B).

The examples mentioned by Participant B are also transferable to aerospace. For example, Pilatus not only offers its training aircraft for sale, but also sells rights of use. This individual business model is not possible without the intensive use of CM.

4.4.1.4 Individualisation of measurement

The measuring process itself depends on several individual interrelated factors. For example, it is important to take learning curves into account or to carry out the measurement outside of such learning curves.

> "To measure the weighting, that is exactly the difficulty. You have the numbers. You already know how many open changes there are. Then you can compare with different MSNs (aircraft). The first 50 are difficult, then it gets better and better. There are fewer concessions, the curve goes down" (Participant A).

Furthermore, Participant G stated that it would make more sense to measure in percentages rather than in absolute terms, because this maintains comparability between individual measurement results.

> "You only achieve comparability among different projects by thinking in percentage terms. 100% for example means 'conditions are compiled' 110% means 10% over fulfilled, 90% means 10% below your expectations or 10% over your budget" (Participant G)

4.4.1.5 Summary of individuality

In analysing the interview data, it became clear from the statements of the interviewees, that there was a general consensus that a framework cannot only

be based on KPIs as it is insufficient to identify the benefits of CM. Firstly it needs to be recognised whether a problem is either caused by or fails to be prevented by CM. Secondly, every company has its own set of needs, and considering every company as the same obscures this fact. Following on from this, it is clear that different methods are required to measure the value and amount of CM for each company.

As can be seen, a wide range of influencing factors must be considered. These include the size of the company, the kind of product, and the risks that accompany the product, where it might be necessary to have a much higher traceability, how complicated the supply chain is, or the customer or government requirements involved. It may also be important to consider when a measurement is made, for example whether a measurement is made at the beginning of a learning curve, or near the end. This is reflected in the three different categories of individualisation which this study has identified: individualisation of the KPI, of the company and of the product.

4.4.2 Complexity

4.4.2.1 Introduction to complexity

From the main study, the interviews revealed two main themes, which included complexity. The study was able to contextualise the key characteristics associated with complexity, as being either internal or external. *Internal* complexity refers to levels of complexity that exist within a specific company. For example, a large company might have a very large process landscape which must be dealt with skilfully. *External* complexity refers to all the aspects outside a given company, having to do with all their business partners or customers along the whole product life cycle. For example, this would include an extremely complicated and long worldwide supply chain with different companies in different regions worldwide, which would have different corporate cultures and mentalities.

Within this fundamental division of complexity which become apparent early on the study, this study was able to identify specific sub-groups associated with complexity. To assist in identifying these, the interviews also provided additional

resource. Participant E was presented with a questionnaire from Reisenweber et al. (2009) which was based on the complexities and the potentials associated with complexities of configuration management and associated cost savings. The questionnaire provided additional context to the main study, including the usage of a combination of qualities associated with complexities, which included additional 7 sub-groups related to the internal complexity and a further 8 sub-groups of external complexity. Based on the questionnaire developed by Reisenweber et al. (2009), together with the interviews the first part of the findings is linked to internal complexity.

4.4.2.2 Internal complexity

4.4.2.2.1 Diversity of product range (IC1)

From the interviews, the diversity of the product range indicated that the concept does not only mean a certain number of independent products. Even a single complex product can be configured in different ways according to customer requirements. There are mandatory choices, such as the colour of the product. There are also additional options that can be freely selected. Accordingly, the configuration options can branch out in a variety of ways according to the laws of combinatorics. This means that many options for product design result in a very large number of different configurations, so that production requirements can easily reach the level of individual/special production.

In the aerospace industry, an additional antenna can be used for providing internet access to airplanes. This is not just the installation of an additional component as such. The additional optional element has a number of consequences: changes in design because additional holes weaken the structure; internal processes become more difficult; production planning becomes more complex as do logistics processing, warehousing and picking, and finally production coordination. All this requires a considerable amount of control and coordination, which must be managed by CM.

This was contextualized by Participant A who pointed out that the complexity resulting from an extensive range of products with a correspondingly high degree of variation is often underestimated by companies and that this results in related problems.

Participant B confirmed by stating:

> "Yes, and so there are still three results from a PLM Big Picture Workshop. One is this huge map where really starting from requirements management up to phase out, all configurations are displayed with all IT systems and all the related processes" (Participant B).

Participant J clearly pointed out that the wide range of variations in an extensive product range also considerably inflates the necessary documentation effort and thus requires corresponding CM instruments. This is particularly true for the safety-sensitive aviation industry.

> "Complexity of products of processes and procedures where you have to combine a lot. Especially for start-up companies, whose product becomes more complex, the importance of CM increases massively. For example, if they had only one product before, CM wasn't that important. If, for example, the number of products and the variety of variants increase, the control of the design documentation becomes massively more complex. From my point of view, complexity is the most important criterion. Other important questions are how many external interfaces there are and how often the product is changed" (Participant J).

CM is therefore essential for mastering complex customer options as indicated by Participant M who stated:

> "For example, in my function as Head of Production Control for Helicopter Production, there were many customer options for the product that had to be processed in close cooperation with CM" (Interviewee M).

In summary products can become very complex due to customer options, as the product structure and the associated documentation become comprehensive and individual. Mastering this complexity can be essential for companies with such products to survive. CM is the central instrument to manage this complexity.

4.4.2.2.2 Multidisciplinarity (IC2)

With the phenomenon of multi-disciplinarity, a form of complexity emerges, which results from the necessary, predominantly parallel working methods of different disciplines as a weak cooperation in terms of content of interdisciplinary work. Multidisciplinarity can be seen as a working style of different scientific fields in the field of development. It was not addressed centrally in the interviews. Also not directly addressed is the theme that is still relevant because it belongs to the theme of complexity. In the study by Reisenweber et al. (2009), the term interdisciplinarity is used instead of multidisciplinarity. In principle, the transitions from interdisciplinarity to multidisciplinarity or pluri-disciplinarity are fluid.

Interdisciplinary work is indispensable when the scientific level of basic research is high. In applied research and technological development tasks in the aviation industry, weaker forms of cooperation at the multidisciplinary level are usually sufficient, although these must then be appropriately coordinated and synthesized by CM. The space shuttle project described in the relevant interview, on the other hand, is classified by such extreme and exposed scientific requirements that interdisciplinary working methods also had to be applied there. In the industrial everyday life of the aviation industry the requirements are lower. As there is no voice of a participant, no citation is possible and a more detailed description with corresponding examples of the complexity of multi-disciplinarily can be found in Chapter Seven, Section 7.16.2.

4.4.2.2.3 Variety of applicable processes (IC 3)

Processes and the correct effective ones are essential for efficient working environments and internal company procedures. Often the more complex the production processes are, the more extensive and diverse the processes to be applied. In order to ensure that the complex and extensive process landscape is up to date and is also used correctly by the individual users, CM2 recommends the cross-departmental application of CM.

Large companies often have difficulty in managing and maintaining an overview of the entire complex interlinked processes. Participant B provided a CM-based

solution approach so that management can maintain a cross-process overview, even in the most complex processes.

> “Yes, and so there are still three results from a PLM Big Picture Workshop. One is this huge map where really starting from requirements management up to phase out, all configurations are displayed with all IT systems and all the related processes” (Participant B).

The complexity does not only result from the existence of a process landscape of standardised business processes. This is further increased by additional processes that are necessary for implementation of projects. For this to occur there needs to be a complete integration of the processes through the use of CM. The correct use of a complex process is not possible without controlling every aspect through adopting CM methodology. Even the complete traceability of the products is only possible if all processes are followed without gaps, as illustrated by Participant H:

> “Yes, it also depends on that there are several different perspectives of CM. There is the CM for the company and there is CM within a project and that is of course positioned totally differently. The CM for the enterprise focuses mainly on the company-specific processes, such as processes that are established, including HR processes, financial processes and everything under it. The project-specific ones are really specific to the project technically. These are then already two points of view and often one concentrates only on the technology. You won't get the approval to produce a product if you can't ensure the quality system or the CM system is guaranteed. Yes, product liability is certainly also an issue” (Participant H).

Many different departments are involved in the management of complex projects. For this reason, many different processes can run simultaneously. CM must not only ensure the basic technical requirements, but also the process and organisation specific ones. It must therefore be ensured that everyone in the

project always has access to the currently valid data, even if changes are frequent.

> “If a project goes through smoothly right from the beginning, of course there are always corresponding problems, but if these are of a technical nature, process-specific or organization-specific then CM definitely has a part to play in this occurrence. I don't think a project will go through smoothly if you don't have CM. I'm convinced of that” (Participant H).

Since a company only runs through valid and validated processes, this point is of particular importance. CM not only ensures that the technical data is valid, but can also ensure that the complex process landscape of a large multinational corporation runs according to the highly integrative requirement profiles.

4.4.2.2.4 Exchange of information between different business units (IC4)

The large manufacturers of aircraft and spacecraft are often multinational corporations located all over the world. New locations are often added through acquisitions and takeovers of other companies, which then form new business units within the existing company. Naturally it is difficult to harmonize the different systems. This is one of the reasons why there is a multitude of different systems that do not have fully automated interfaces. This increases the complexity in these large companies immensely. One task of CM is to reduce the necessary number of tools by standardizing the structures. Participant A highlighted this theme:

> “The will to have a unified tool landscape from Airbus, or shall we say to reduce the many tools” (Participant A).

In addition, the internal exchange of information between business units and departments can have a positive impact through adapting new business models. Participant B provided an interesting example that initially could lead to external complexity, but also has influences on the internal complexity. This is a new business model in which aircraft are no longer sold in their entirety, but instead the customer is billed for the

number of hours flown. All maintenance and administrative tasks remain with the manufacturer. This means that a large amount of data comes from the operator, which must be distributed and processed internally, between business units and departments.

> “Let's take Pilatus. It's relatively new, and for me it's amazing that for example the Kuwait Air Force don't buy their training aircraft anymore. They say we don't need training aircraft, we need flight performance and availability. That is, Pilatus had to offer you the entire operation, the total maintenance expenses and so on. Only now, of course, the problem is that I now need a lot of information about these flight diagnostic systems of these aircraft, because if the maintenance I have calculated is not correct, because the customer uses the aircraft incorrectly because, for example, the Kuwaiti army flies outside the flight envelope” (Participant B).

4.4.2.2.5 Period of product development (IC5)

The period of product development in the aerospace industry can be divided into two product groups: manufacturing and design. Manufacturing of complex single pieces and small series has happened in the past, mainly in the space industry.

> “[…] the Space Shuttle was a very complex machine and it was of course designed, built, and then tested by space specialists” (Participant L).

In the aviation industry, especially for commercial aircraft such as the Airbus A320 series or the Boeing 737, large volumes are often produced over the past two decades. These products have been adapted over the long production period to new technical developments, such as new engine technologies have had a huge impact on the aircraft. In addition, new customer options are added as a result of new demands. New legal requirements may also necessitate changes to an aircraft program, which must then be introduced from a certain aircraft onwards. An example are changes in the aircraft structure of the A320, which have become necessary due to identified weaknesses after the

emergency landing of an A320 on the Hudson River. These circumstances are explained by Participant D:

> “The main reason, of course, is always to make sure that an expensive system is worth the effort and where improvements can be introduced. In addition, there are of course still legal demands from different sides that one must prove somewhere that the introduced system fulfils certain conditions” (Participant D).

All of these changes are introduced through modifications in the CM process. The large numbers of modifications that have been made over the decades and have a wide variety of influences on the aircraft program are extremely complex. In order to master this complexity, the modifications must be administratively controlled by extensive CM processes, for example by product structures. Different modifications show different levels of complexity and have different influences on other systems. As Interviewee M stated these modifications must be introduced within the right time frame:

> “The time frame must be proportionate to the complexity of the change” (Participant M).

Particularly, in the long period of product development, complex changes can occur and therefore impact on the CM process. This complexity has also been increased in recent decades by the rapid development of new IT systems, due in part for the need integrated and the development of new systems.

4.4.2.2.6 Period of production (IC6)

As the aerospace products are very complex, and have an extremely large number of parts which need to be assembled by subassemblies involving many stages, the production of aircraft takes several weeks or months. Furthermore, the production of spacecraft can take several years and the construction of subassemblies must be precisely coordinated. This coordination is very complex, as many disruptive factors are involved, such as changes in the customer's delivery schedule. To control this complexity, precise CM processes are

necessary and have to be followed. Interviewee D described this complexity with the following words:

> “One of the most important things especially in the aviation industry or in the supply industry is of course on time delivery, as punctual delivery is extremely important because otherwise the entire manufacturing process at other companies or other company departments are disrupted, which can lead to major problems” (Participant D).

4.4.2.2.7 Parallelisation of development and production (IC7)

A further internal complexity arising from the study relates to the parallelisation of development and production. In the aerospace industry it is common practice to start prototype production in the development phase in order to keep project times within reasonable limits. The different design reviews and the parallel running production must be managed by CM processes and kept up to date. This is particularly challenging, since data changes very quickly in the design phase. Even after a design freeze has already been carried out, it is often necessary to make changes at short notice, as Participant H explained:

> “Not so long ago, we have defined KPIs (Key Performance Indicators) to measure our process. That's when we said we need to know how many corrections we have after a design freeze. That means when we look at the development process, we have a PDR (Preliminary Design Review), we then have a CDR (Critical Design Review) and then we have a Final Design Review before the prototype flies” (Participant H).

Good real-time data networking between development and production, controlled by the CM, is essential to ensure error-free parallelisation of development and production. Only in this way can the accurate integration of late changes be ensured.

4.4.2.3 External complexity

The different external complexities were extracted from the interview statements and the questionnaire used by Reisenweber et al. (2009). The first external complexity Suppliers Quality Fluctuations is due to the statements of increased rework costs regarding quality problems.

4.4.2.3.1 Suppliers quality fluctuations (EC1)

Suppliers quality fluctuations are deviations in the delivery quality of the suppliers. Such fluctuations can have many different causes. They can be caused or not prevented by CM. It is very complex to find out the causes for such fluctuations because, as Participant A stated:

> “Then try to evaluate, but when evaluating you are very quickly involved with the human component and feeling. It is difficult to say when it could be or may be a configuration problem” (Participant A).

The fluctuations in supplier quality can also lead to missing or incomplete requirements. If the customer is not provided with the most precise specification including the tolerances to be fulfilled, this leads to increased incalculable and therefore complex rework. This is particularly important with a large number of supplied parts from different suppliers, a quality fluctuation of the individual suppliers can have fatal consequences and question the financial success of the project. Participant B encapsulated this by stating:

> “In the end it was a black zero instead of an EBIT from the project, because we didn't have Requirements Management under control and then had to do so much rework. We really try to make a ROI consideration on the basis of these findings” (Participant B).

CM is of particular importance to ensuring the traceability of parts, which is caused by the fluctuations in quality caused by suppliers. With many thousands of supplied parts, it is important to keep track and to be able to identify the machines in which the parts in question were installed. This is particularly important for space products, as Participant H highlighted:

> "[…] when we still had Ariane 4 payload fairings, they were riveted together with thousands of rivets and at one stage the rivet supplier came and said: hey, for the rivets in that batch the surface protection and the grease coating on the rivet head is wrong, a production defect. Then you had to be able to see which payload fairings that were in production, those already standing somewhere in Kourou on the launch pad that have been produced with this rivet batch" (Participant H).

This necessary for the need for traceability was confirmed by Participant I.

> "Especially companies in the aviation sector with high complexity and the associated risks have an increased interest in CM to make these risks manageable. With a good CM you can make all traceable" (Participant I).

The different perspectives of the participants indicate there is some consensus and confirm the absolute necessity for the use of CM to control this external complexity. The greater the fluctuations in supplier quality and the more complex the end product, the more important is the application of CM. The economic effects of fluctuations in the quality of supplements can also be controlled by CM.

4.4.2.3.2 Fluctuation in customer demand (EC2)

The production period of products in the aerospace industry can have a long duration. For example, the Boeing 737 has been in production since the 1960s. During this long production period there are technical innovations or changes in customer demands. The manufacturers must therefore react accordingly and incorporate the changes by means of modifications. The period of use of commercial aircraft is also correspondingly long. Customer requirements therefore change even for products that are already in use and can be incorporated via later modifications. The management of changes and modifications during the manufacturing phase as well as for later modifications is regarded as complex and is normally managed by the CM. Another practical example would be the conversion of a passenger aircraft into a cargo aircraft

after a long period of use. Participant B points out this hybrid use by the customer with the following words.

> “This means that it must always be borne in mind in these issues that we are sometimes talking about very long product life cycles and, that the products are used as hybrid by the customer” (Participant B).

In the case of major technical innovations, the modification of the product is sometimes very demanding and very complex. The study revealed examples with new geared engines. On the Boeing 737, this modification was not easy to implement. The reason for this is that there is not enough space under the wing because the engine diameter has increased. This means that there is no longer enough ground clearance under the engine. For this reason, the engine had to be mounted further forward, because this allows a higher installation. However, this also changed the aircraft's centre of gravity and made it necessary to use software-based control due to the resulting aerodynamic instability. All these complex modification steps are coordinated by the CM in the different engineering departments. Unfortunately, the software-based control system proved to be not reliable enough and the entire Boeing 737 Max fleet had to be grounded for a long time after several accidents. The calculation of costs for complex modifications can also be supported and ensured by CM.

4.4.2.3.3 Customer specific adaptations (EC3)

In the aircraft sector, for example, it is possible to furnish the A320 in different ways, which involves different structures, for example the floor structure must be built differently. As discovery from the interviews, if there are, for example, 50 different customer options, then there will be a high number of different configuration possibilities. One company might order only 2 customisation options, and another order for many more, therefore the complexity increases since there are so many different combinations. Due to these different combination possibilities, it is absolutely necessary to create a product structure based on requirements for each individual product. This also helps to be able to charge the customer for subsequent changes, as Participant H points out below:

> “If you get involved from the beginning to establish an order baseline, and you can establish these are the requirements, the customer requirements, every time a fresh change comes from outside or inside, you can hold up your hand and say, hey these are customer requirements and if the customer comes with a new requirement, you can request money, you have to charge money, so you get feedback back from the project itself and actually also for new projects, that added value is there, as you are involved from the beginning” (Participant H).

Customer-specific adaptations also have a great influence on the entire production process. Without exact product structures, no exactly documented reallocations are possible, because no exact delta, which means difference of the data, can be determined. Reallocations are the subsequent allocation of component serial numbers to new machine serial numbers, as seen with the comments of Participant M.

> “For example, in my function as Head of Production Control for Helicopter Production, there were many customer options for the product that had to be processed in close cooperation with CM” (Participant M).

As Participant M says, a large number of customer options cannot be managed without intensive use of CM. The costs resulting from customer options can also be monitored by CM.

4.4.2.3.4 Rate of change of production requirements by customers (EC4)

The high number of possible configurations can lead to a large number of customer options. This can also increase the rate of change of production requirements by customers. For these reasons there could also be the need for technical innovations or changes in customer requirements, which is particularly challenging in late changes from the customer. In order to be able to correctly classify the complexity of these changes, as Participant A stated, the complexity factors of changes need to be accurately classified:

> “When it comes to late change, for example, the airlines have a factor from engineering that measures complexity with a kind of score number. The airlines often have very special wishes which they express very late” (Participant A).

As Participant B stated, the increase in the rate of change of production requirements by customers has a strong impact on the complexity of the products, since all product structures are affected throughout the entire product life cycle, as can be seen above with Participant A.

> “Many products are configurable, i.e. I have a customer order where I see what the customer actually wants. “As Should Be”, “As Planned” or “As Configured”, there are different terms. And then, of course, comes the “As Built”, which comes out of the supply chain, which is the generated hardware configured as to-be and then as-maintained with the lifecycle across the entire Operating and Maintenance” (Participant B).

The comparison of these different product structures, such as "as planned" and "as built", is a great challenge for CM due to the complexity of the data structure. Such a comparison is absolutely necessary in the aerospace sector because it is required by the applicable legal authority, for example, the FAA in the United States.

4.4.2.3.5 Rate of change of production requirements by authorities (EC5)

The technical innovations and changes needed in this sector has resulted in the need for greater analysis of accidents, which can lead to changed production requirements of the authorities. One example is the successful landing of an Airbus A320 on the Hudson River, where weaknesses in the floor structure were revealed. These weak points were eliminated by appropriate modifications. As Participant A and E independently stated, it is the core task of the CM to ensure that the company retains its approval from the authorities:

> “We have the customer, the end customer, the operator, the airline, we have the authorities; they are also a kind of customer.

> Or one has a strong connection, as we use CM also to satisfy the authorities to remain approved" (Participant A).
> "There are legal requirements that we have to meet with regard to an aircraft. We must provide documentation confirming that the aircraft has been built in accordance with the definition" (Participant E).

Since the verification process is very complex due to the large number of configuration options, the change of requirements by the authorities is a great challenge for CM. The fast fulfilment of authority requirements is especially important for the survival of companies in the aerospace industry so that a company is able to fulfil authority requirements quickly.

4.4.2.3.6 Fluctuations in delivery times of suppliers (EC6)

Due to the extremely large number of suppliers that deliver products in the aerospace sector, it is absolutely essential that guaranteed delivery times are adhered to, therefore scheduled production needs to run to plan. As the fluctuations in delivery times are often due to quality problems, it is important, as Participant E explains, to introduce appropriate quality gates between the individual partners in which the delivery times are also coordinated:

> "For the A350, we have agreed various quality gates. Quality Gates from our supplier to us and the Quality Gate from us to St. Nazaire where we deliver Section 13, 14 and a Quality Gate from us to the FAL" (Participant E).

Since it is often not possible to bring whole sections from the supplier to the final assembly line on time due to problems due to various reasons including delivery damage, quality problems and handling damage. Alternative sections that were originally intended for other machines must be relocated. The CM has to report the differences in modifications and inform the relevant departments about reworking or system-related changes. Participant E set out some of the problems that arise from clocked flow production with regard to delivery in the correct time frame:

> “We always measure the delivery reliability; we arrive on time and then there are still the quality indicators or the performance indicators that we show. We also measure how much work is left between the individual workstations. The remaining work can also be missing parts. The missing part situation is also measured. Since we have an industrial schedule and we have to clock, i.e. the components have to go from one building site to the next, you can't stop the running system somewhere” (Participant E).

For the aerospace industry, there exists complex and long supply chains, therefore timely delivery is crucial but cannot always be guaranteed for various reasons. Since CM knows the exact configuration of the products, it can mitigate problems caused by late deliveries through reallocations.

4.4.2.3.7 Exchange of information with the customer (EC7)

The exchange of information with the customer is becoming increasingly important as a result of the emergence of digitalisation and Industry 4.0. As a result it is important to reduce the complexity resulting from the application of different systems. This is particularly important because it reduces the interfaces with customers. For Participant A it was related to the need for unified tools:

> “The will to have a unified tool landscape from Airbus, or shall we say to reduce the many tools” (Participant A).

Moreover, the introduction of new advanced business models has increased the importance of data exchange with the customer. If a company can no longer sell the manufactured product, but instead offers usage time including all maintenance and servicing work, it is necessary for an even more intensive data exchange to take place between customer and supplier. This can be, for example, as Participant B says, a complete aircraft. All-important operational data of the aircraft are transmitted via data link to the manufacturer so that the manufacturer can plan the necessary maintenance work and provide the necessary spare parts and service staff.

> “Let's take Pilatus. It's relatively new, and for me it's amazing that for example the Kuwait Air Force didn't buy their training aircraft anymore. They say we don't need training aircraft; we need flight performance and availability. That is, Pilatus had to offer you the entire operation, the total maintenance expenses and so on. Only now, of course, the problem is that I now need a lot of information about these flight diagnostic systems of these aircraft, because if the maintenance I have calculated is not correct, because the customer uses the aircraft incorrectly because, for example, the Kuwaiti army flies outside the flight envelope” (Participant B).

However, due to the extensive amount of data available, there are many more possibilities in the area of cooperation with the customer. For example, Participant B stated it was possible to match tools directly with the existing CAD data, so that no manual adjustments to the tool are necessary.

> “Yes, now suddenly we have completely new possibilities. For example, we can directly store the production manufacturing information from CAD. When we have ten screws on one flange that need to be tightened where all have different torques. Now I can store this directly in the CAD and SAP knows I have a parts list item with quantity 10 (10 screws), but because I have now integrated it that way, I have actually stored the transformation matrix” (Participant B).

These identified new insights into complex data exchange with the customers could lead to the fact that without smooth data exchange, then business processes may not function as effectively. Since CM is responsible for the data and specifies the data, then arguably CM needs to become an essential tool in the aerospace sector.

4.4.2.3.8 Exchange of information with the supplier (EC8)

Data exchange is vital for any business whether it is do with dealing with suppliers or customers. The exchange of data is of increasing importance due to a number of reasons as identified in Section 4.4.2.3.7. Participant A stated that

suppliers are often involved in the development process. This comment of Participant A potentially means that there is also an increase in the exchange of complex engineering data. Therefore, it is possible to surmise that CM is particularly important because it coordinates the changes and thus also the data exchange.

> “If we look at the suppliers of A350, they are risk sharing partners who also help develop the design, we can say that we have developed score cards for these different suppliers” (Participant A).

Participant B pointed out that it is particularly important that the data structures defined by CM are adhered too. Without this, data exchange is not possible due to the high complexity of material data and documents and inevitably leads to incorrect configurations. In a complex supply chains, this problem is exacerbated, as seen with Participant A comments above.

> “The only thing that is clear is what I can really report and substantiate in structures, with all associative data, documents, article masters, structures, and everything that depends on them” (Participant B).

Due to the increase in data exchange combined with the complexity of data, it is becoming more important to standardize the appearance of product structures and information systems between the partners.

4.4.2.4 Summary of complexity

From the interviews it becomes evident that there are many different kinds of complexity based on different factors. CM is generally meant to make this complexity manageable. However, not all complexities can be handled by CM in the same way or to the same extent, in addition, they are not of equal importance to a given company. Based on this, it became evident that it is necessary to be able to implement a weighting for each of the different sub-groups of complexity. Independent from any specific category, how CM helps handle complexity

differs. It is all related, but has different intensity. As Participant A pointed out there is a weighting problem: ‘To measure the weighting, that is exactly the difficulty’. Therefore, it can be deduced that it is necessary from the point of view of CM to have a weighting performed by experts. The complexity of each product is different and complexities are different in each company. It is therefore necessary to weight each complexity individually, a task that can only be performed by an expert familiar with the specific company and/or product. Therefore, it can be deduced that it is necessary from the point of view of CM to have a weighting performed by experts. This will be developed further in Chapter Five.

There are often associated costs in handling this complexity. The fact that complexity has a great influence on costs and that these costs can be mastered by CM was stated by interviewees A, B, D,E,F,J and L. The greater the complexity identified through the interviews is associated with the greater the potential costs, and to the need to manage this complexity. As management is naturally cost-sensitive, the goal of the framework developed below is to concentrate considerations of complexity around the question of reducing costs.

4.4.3 Potential opportunities

CM offers a number of potential opportunities and could increase the future growth and delivery in companies, for example to create new customers. CM could also be used to develop a more competitive business model in high-wage countries and to compete, for example, through automatisation of production and identifying more cost- effective manufacturing-based countries. Based on the interviews, and drawing on the questionnaire used by Reisenweber et al. (2009), a number of different aspects that describe different future changes that a company can experience have been identified. The goal of this study is therefore to identify potentials, as possibilities to be used to the benefit of a company, which are only realisable with an individualised application of the different available CM methods.

4.4.3.1 Generation of new business models (POT1)

For CM to be effective, it needs to be successfully implemented as one of a number of business models. There are several reasons for this, which have

become more and more important, especially in recent times. At the same time, the authorities are becoming increasingly demanding, especially with regard to CM. Furthermore, new business models are often based on the ability to reliably manage huge amounts of data. The large amounts of data result from a wide variety of configuration options and from data exchange that is necessary due to new business models. These new models include new marketing opportunities that include all kinds of services, up to the offering of usage units instead of selling the product. However, for the aviation sector such marketing models are not only offered by equipment manufacturers for production, but also for entire aircraft systems. Participant B points out the changed business environment with the following words:

> “The topic of CM is therefore becoming increasingly important, not only because regulations are becoming increasingly stringent, but also because business models are turning around” (Participant B).

Participant I pointed out that CM is suitable for opening up completely new sources of income. Aviation is an international business, which sources its raw materials mostly from developing countries incurring high import duties which have to be paid. The finished product is often sold again to another third-party country outside the customs and economic area of the country of manufacture. If the aircraft manufacturer is now able to prove that the imported and duty paid raw material has been re-exported in the form of a finished product, the manufacturing company is entitled to recover the duty amount for this transaction. This represents a not insignificant reduction in the cost of the manufacturing operation. The documentation of the installed parts, which are decisive for the customs authorities, is subject to the CM. This means that this improvement of the business model, as described by Participant I as being potentially only possible through an advanced, integrated CM:

> “The main problem is that the material comes in, but is not exported in its raw condition, because it is used further. Here it must be proven exactly which titanium was used in which assembly, when it was purchased and where it was subsequently used” (Participant I).

The cases mentioned here are only examples that show how CM can contribute to the generation and improvement of business models. Due to the increasing digitalisation and the resulting networking of production and the entire use of products, the importance of CM will continue to increase. This is particularly the case in respect to the development of new business models. The evaluation of the possibility of generating new business models through CM is therefore of outstanding importance for the assessment of the potential of CM.

4.4.3.2 Cooperation between different locations of a company (POT2)

In the aerospace industry, there are often large companies that have locations all over the world. Especially large and with many international locations are the OEMs or their direct suppliers. These suppliers are known as Tier 1 suppliers. Aerospace products are usually very complex with many different configuration options, resulting in very complex product structures. In order to enable a perfectly coordinated production between the plants across continents, a highly developed CM system is required that provides each plant with the necessary product structure and guarantees the matching of the finished product. If such a highly developed CM is not sufficiently installed, this could result in extremely high reworking costs or even the scrapping of costs, and the delivery schedule may not be able to be kept. This can lead to further expensive contractual penalties. Participant D addressed the cost aspects of CM systems and stated that this strategy was justified as the production input can be coordinated internationally and thus any additional expenditure or costs can be minimised.

> “There are also internal financial demands or financial reasons why one runs such systems. Reasons of environmental protection, reasons to be able to work out the future company strategy where inputs from the current production are needed” (Participant D).

Drawing on the experience of Participant D, if, for example, a section is damaged in an American final assembly plant of Airbus, the CM must suggest a suitable replacement section or inform of the MOD differences and the resulting necessary conversion work. If this knowledge and the resulting coordination does not exist, production would cease and extreme costs would be incurred. If a company plans to establish an interlinked production over several locations

for strategic or cost reasons, the potential that the CM offers increases significantly.

4.4.3.3 Overview in a company (POT3)

Companies in the aerospace industry are increasingly dealing with and managing complex infrastructures. Not only is the company structure complex, but also the products to be manufactured and their achieved sales and customer service environment can be of complex nature. Accordingly, it is difficult to keep an overview in such companies. As Participant A stated, it is first necessary to define what the company wants to achieve through CM. CM can be used, for example, to check profitability throughout the company and to determine whether the company is developing according to plan.

> “Yes, it depends on many complexity factors. Firstly, it depends on what I want to achieve with my CM. Do I only want customer satisfaction, or the ability to deliver different characteristics of a product at a glance. Or do I also have government requirements that I must meet and do I also want to control my profitability via CM. I want to use CM through the traceability of my product data to understand whether I'm really on my target path, when I check my costs and my sales targets, etc. I want to be able to use CM to check whether I am really on my target path” (Participant A).

As Participant B stated below, consulting firms are increasingly focusing on developing tools that use configuration data to help companies improve their service and their understanding of customer needs. In addition, the tools help the managers to give an outlook in which direction the company is heading.

> “So, it is really the case that we are now trying to implement a so-called Enterprise Development Manager at the companies, which is actually based exactly on a Development Configuration, which Requirement actually says, where the company is heading” (Participant B).

In order to develop a company on a long-term and sustainable basis, it is essential to have a comprehensive overview of the company's activities and products. Since the complexity of companies is generally increasing and CM, as the participants agree, plays a key role through the data provided, CM has an increasingly large potential in this area for most companies in the aerospace industry, which must be determined individually, as can be seen with the comments of Participant B.

4.4.3.4 Reduction of rework (POT4)

The potential that CM can offer and which this study has also confirmed lies in the reduction of rework. Due to the increasing complexity caused by a large number of different configuration options, the risk of misconfigurations that lead to reworking, which can be very cost-intensive, increases. CM must therefore ensure, as Participant J stated, that the requirements are implemented as intended.

> "At the beginning I have requirements for my product to be developed. After production, for example, I notice that the requirement has not been met. This implies a lack of CM and unforeseen costs for reworking or re-development. I'm losing time because of this. That would have to be recognised and that would be the potential I could realise through my CM" (Participant J).

The potential based on the reduction of rework is so large because often extreme costs are caused by the rework. As Participant A stated, a price reduction must also be granted for many reworks. In addition, rework can also lead to schedule problems or damage to reputation.

> "The airline is paid for every concession. They consciously look for mistakes. There are also airlines that are short of cash. They look even more deliberately for mistakes to save money. That means the feedback is very direct. At the time of delivery, you are told that this and that are your mistakes, this and that you have to rework" (Participant A).

The reduction of rework is such an important potential of CM that it has already been investigated by organisations such as the Institute of Process Excellence, which conducted the CM2 training. Participant I, for example, speaks of a white paper from CM2 that is intensively concerned with the goal of reducing rework.

> “That is primarily the reduction of rework, which is the ultimate goal. You can measure that, there is a white paper from CM2. There are formulas where you can see how the rework goes back. In general, you can say that the number of errors must be reduced and the number of improvements must be increased” (Participant I).

A core task of the CM is therefore to specify the configuration through product structures in such a way that industrial engineering can create the work plans for the different machines without errors and therefore no reworking is necessary.

4.4.3.5 Finding new customers (POT5)

CM essentially contributes to adapting a product to the individual customer needs and requirements. The adaptations to the customer needs do not only refer to technical modifications, but CM can enable completely new marketing opportunities by managing the data over the entire product life cycle. Customers who were not financially able to buy cost-intensive products in the past can use these products by purchasing usage units. In the following statement, Participant B emphasizes the need to overview and manage the extensive data by stating that:

> “That means if we now want to use the product in a completely new way, we will stay with Pilatus, which no longer sells aircraft but only sells services. I have greater demands on the sensor technology, yes this must have been defined as requirements up front, because the sensor technology must be integrated into the product. Evaluation systems must be made available. Systems, where I now have to retrieve much more data, manage it and to

> evaluate it for these configurations, yes, someone has to create these software solutions" (Participant B).

In recent years it has become increasingly difficult to find new customers. One of the reasons for this is that the market environment is becoming increasingly transparent and customers have more and more specific wishes. Many manufacturers in the aviation sector are overstrained when it comes to complex products and are unable to adapt them to individual customer requirements. Part of the reason for this could be that the product structures are becoming very diverse and complex and must be managed throughout the entire product life cycle. This is further complicated and the whole spare parts business is becoming more complex as a result, which in turn has an impact on logistics. Without a well-adapted CM system, companies are not able to meet these requirements and it becomes more and more difficult to win new demanding customers.

4.4.3.6 Delivering services over the whole product life cycle (POT6)

As already mentioned for POT5, the manufacturer must be able to offer services over the entire product life cycle. For CM this means, among other things, several independent product structures must be maintained throughout the entire service life and that these must be communicated to the various stakeholders. For example, it is necessary to maintain electronic spare parts catalogues for various configurations so that the products remain easy to maintain for the customer during the operating phase. Participant A emphasised this necessity of ensuring that CM is used throughout the entire product lifecycle:

> "The customer has two ambitions. On the one hand he wants to have delivered a super quality and that speaks for CM, the customers know that too. On the other hand, he has the ambition in operation and in maintenance to be as simple as possible" (Participant A).

As the core products of the aerospace industry are used for two to three decades, advanced services over the entire product life cycle are essential to ensure continuity. Engine manufacturers, for example, already collect the live

operational data generated during the flight via a data interface with remote transmission and evaluate it in order to provide the necessary services in a timely manner. This method generates huge amounts of data that must be evaluated in a structured way. These cases already lead in the direction of Internet of Things and are not possible without intensive use of CM, both by the manufacturer and the operator.

4.4.3.7 Ensuring the individualisation of a product (POT7)

A very important theme to emerge from the study related to the application of CM is its linkage to the individualisation of products. This is particularly important in the current market environment, as the ability to individualise and make specifically tailored products allows companies in high-wage countries to be competitive with companies in best-cost countries that utilise mass production. CM makes a significant contribution to this, because it ensures that individualised products can be manufactured in a synchronised flow production. CM ensures that the interaction of the supplied parts works perfectly in production, because the industrial engineering department receives as a contracted product structure from CM for each individual machine, which makes it possible to keep a constant overview of production. Participant B emphasises this competitive advantage by stating:

> “Another problem is we have customers who say we are being blown away in Europe with our cost structures by Asia and Latin American competition. We can only survive if we become premium in our field and this of course includes certain benefits etc. Others say we need to change our processes to batch size one” (Participant B).

There are many thousands of different configuration options for frequently built commercial aircraft, and virtually every aircraft is individually configured. There is an exception in the case of a fleet purchased by identical customers, where the configuration for each aircraft is generally the same for each series. This individuality has an impact on the entire supply chain. Suppliers must therefore be supplied with data individually. Customer changes and changes in standards

therefore also affect many suppliers. In addition, there are also so-called concessions that must be documented individually for each machine. Smaller manufacturers of special aircraft, such as the Do228, must be able to implement the most diverse customer requirements, because their operators have very special demands on the aircraft due to specialized operations such as coastal surveillance. These can make it necessary to adapt the aircraft structure due to additional openings in the fuselage. During the implementation, a wide variety of special departments, such as the stress calculation department, are required, which have to be coordinated. These are often complex modification projects that must be coordinated by the CM.

4.4.3.8 Enabling industry 4.0 (POT8)

One aspect of potential is enabling Industry 4.0., which became a theme in this study and an important area of interest for future for companies and their future development, which is discussed in more detail in Section 4.4.4.

4.4.3.9 Enabling internet of things (POT9)

As has already been pointed out with other potentials, such as POT6, delivering services over the whole product life cycle, with increasing activities, such as the data-based live monitoring of engines, are moving towards Internet of Things. As Participant B impressively demonstrates, Internet of Things in the industrial sector is not possible without CM. Participant B being a consultant in this area, has already worked with a large number of examples and in various companies in the aerospace industry.

> “Then of course what plays into our hands at the moment is the whole topic “Industry 4.0”, Internet of Things is not possible without CM” (Participant B).

Companies are increasingly using the *Internet of Things* as they are forced to use CM on a high level due to the importance of valid data structures. Participant B confirmed, by stating:

> “The pressure to manage configurations in the context of industry 4.0 and Internet of Things will be much, much bigger” (Participant B).

The potential that CM offers for companies that want to use Internet of Things is enormous for the reasons mentioned above and must therefore be adequately considered in the framework that is being created.

4.4.3.10 Enabling new services for customers (POT10)

CM has great potential to create conditions for new customer services in the aerospace industry. Not only customers of aerospace manufacturers benefit from this, but also the entire production process. As Participant B stated, the compressed air suppliers, for example, used CM data to improve their services in the production process of commercial aircraft.

> “There are well-known examples such as Kaeser, which no longer sells its compressors, but simply sells compressed air in cubic meters to companies. The Kaeser compressors are serviced by Kaeser employees and of course when a compressor reports something back to Kaeser, I have to know exactly which configuration is on site, what happened, when the last time a field service employee was on site, and what he did. CM is really increasing in importance. It’s independent of KPIs, it’s clearly so” (Participant B).

With the background of the developments over the past decade, it has become clear what potential CM has in particular in the provision of new services for the customer. All of the participants independently highlighted the amount of data which is constantly increasing in development, production and operation, and thus also in services. Of course, there are differences in the individual companies regarding the potential opportunities to be achieved. Therefore, a weighting is also necessary here in order to be able to use the framework optimally for the entire industry.

4.4.3.11 Summary of potential opportunities

As is evident form the interviews, (e.g. Participant A and Participant B) future potential opportunities are not the same for each company and these are dependent on many different characteristics such as a company's location, what it produces, or what the future prospective for a given branch is. For example, aviation has grown quite strongly in the last few decades, but this level of growth may not be sustainable due to outside influences such as environmental concerns and related future legislation. Again, this points to the necessity for a framework of weighting. Weighting can isolate the external factors which have nothing to do with CM and which can disturb measurement. Weighting thus makes it possible to effectively determine the impact that CM can have on a specific company. In summary, however, it can be reiterated that CM has extreme potential for the development of aerospace companies. Participant D encapsulates this by stating:

> "It is also an important result that the scope of work can be simplified under certain circumstances, that processes can be streamlined and thus time, money and effort can be saved. One can save organisational effort. In any case, there are hardly any cases where this system would not lead to improvements" (Participant D).

4.4.4 Industry 4.0

4.4.4.1 Introduction to Industry 4.0

What emerged from the study was that Industry 4.0 was a sub-theme of potential opportunities in the development of a framework. However, due to its importance for the future of the aerospace industry, it is worth discussing in greater depth here. Industry 4.0 is generally used to refer to a change or development that has occurred in the whole philosophy of industrialisation in which data has become the central focus. It is therefore not merely a matter of a comprehensive digitalisation of the industrial revolution. Rather, it is a matter of interlocking these with modern information, network and communication technology to such an extent that *self-organised* production processes can be achieved as far as possible. With the idea of Industry 4.0, it is not enough for manufacturing

processes to be computer-controlled; the objective is for people, machines, plants, logistics and products to communicate and cooperate directly with one another. As a result, it is no longer just *one* production step that is optimised, but the *entire* value chain. This means that the momentum of Industry 4.0 encompasses all phases of the life cycle of a product, starting with its conceptual brainstorming through its development, production, use and maintenance to recycling at the end of its existence. CM is the location where the data is held and managed, and it also is the way that the data is kept up to date. Proper CM guarantees that there is precise, valid, and up-to-date data for a certain product at every instance and that the complexities are interlinked.

4.4.4.2 Industry 4.0 and CM

Participant B says:

> “Then of course what plays into our hands at the moment is the whole topic Industry 4.0, Internet of Things is not possible without CM” (Participant B).

CM is delivering data clarity to all business processes and therefore Industry 4.0 is not possible without CM. The central sentence from the interview with Participant B is formally a simple statement but in terms of content of far-reaching importance, as is shown in the following illustrations. Participant B advises CEOs of important aerospace companies, among others, in the CM area and, by creating a PLM Big Picture, ensures that the workflows in companies with complex processes become more transparent. In addition, he supports companies in the introduction of Industry 4.0. From this extensive background of experience, he realises that without intensive CM, Industry 4.0 is not possible. The reason is mainly due to the complex data structures generated and managed by CM, which serve as a basis for the processes used by Industry 4.0.

> “We now suddenly need to know exactly which sensor is installed exactly where, what does it do exactly and when it reports data i.e.,

> the pressure to manage configurations in the context of industry 4.0 and Internet of Things will be much, much bigger" (Participant B).

In order to be able to work at the level of what is technically possible and obtain the necessary information from the workflow, a lot of sensor technology must be built into the hardware. This sensor technology must be reliably mastered at all times so that a continuous process overview can be maintained even with the most complex systems and production processes. In order to ensure this, the most up-to-date product structures of the product to be produced as well as the production equipment are necessary at all times. The management of such product structures is not possible without an advanced CM system. The sensors are part of the production equipment structure and they necessarily deliver enormous amounts of data.

The term 'Big Data' stands for such enormous amounts of data where it is impossible for various reasons to evaluate them using manual or conventional methods of data analysis. In this context, Participant B raises the following exemplary questions in his interview: "Where is this data stored? Where are they lying around? Which systems are used to manage this data? Are they also traceable?

With this statement, Participant B points out that the use of Industry 4.0 can be worthwhile, especially in the competitive environment of high-price countries, as it allows many processes to be automated across the entire process chain.

> "Others say we need to evolve in Industry 4.0 and so on. So, there are several reasons why we are investing in Product Lifecycle Management and CM" (Participant B).

As Participant B stated, this is not possible without investments in PLM and CM. This statement of Participant B is interesting for the generation of the framework, because it helps to consider the future reorientation of a company. Such arguments flow into the framework by means of the core concept of potential and are thus considered in the application.

4.4.4.3 Summary of the relevance of industry 4.0

Industry 4.0 was a significant issue for the interviewees. This is because in Industry 4.0, all departments rely on data, and all departments are interlinked. This means that CM has influence over all of the data in all of the departments, and becomes important enterprise-wide. Whereas this might previously have only been the case for considerably large and complex companies, in the era of Industry 4.0 this has become the norm for all companies, as has the central importance of CM.

4.4.5 Costs

4.4.5.1 Introduction to Costs

As senior management is usually cost sensitive, when designing the framework, it was decided to use costs as a sub-theme to support the main themes of complexity and potential opportunities. It costs money to install a sophisticated CM system, so CM must provide a clear and measurable benefit to management. For example, rework always involves more costs for a company and being able to reduce rework can reduce costs. However, it is necessary to identify whether, for a given company, CM is capable of reducing mistakes in a given instance, thus reducing the amount of rework.

4.4.5.2 CM's influence on the costs of a company

Participant A explained that it is necessary to have the right amount of CM for each specific company, which is important to keep the costs and the resulting profitability under control. This necessity of CM application depends on different parameters like the complexity of the produced good or the risks associated with the application of the product.

> “If we only had customer satisfaction in mind here, we would be performing a rather difficult and complex CM and would not have to keep internal costs under control. In principle one could put a configuration manager behind every worker, who pays attention to what the worker does. At the end of the day, the customer is satisfied and controlling would say that we still have six months to live. As a

> result, there is a conflict between government requirements and customer requirements on the one hand and profitability on the other. Ultimately, CM has to somehow organize something" (Participant A).

As Participant A stated, CM can also be used to monitor costs and control profitability due to data transparency. In general, the management of each company has to find out individually what they want to achieve with CM. It is imperative to meet the requirements of the authorities. In order to survive in the market in the long term, it is also essential to meet customer requirements based on CM as long as they are profitable. The framework created in this thesis is designed to support the management of this decision-making process.

> "Yes, it depends on many complex factors. Firstly, it depends on what I want to achieve with my CM. Do I only want customer satisfaction, or the ability to deliver different characteristics of a product at a glance? Or do I also have government requirements that I must meet and do I also want to control my profitability via CM. I want to use CM through the traceability of my product data to understand whether I'm really on my target path, when I check my costs and my sales targets, etc. I want to be able to use CM to check whether I am really on my target path" (Participant A).

Participant A points out that especially large OEMs use their own complex CM systems, which have to be implemented by the suppliers at the lower levels. In general, Tier 1 suppliers have to manufacture their own CAs, undergo complex certifications and be connected to the highly developed IT systems of the OEMs. The further the CM system moves away from international standards or contains its own solutions, the greater the entry barriers for suppliers on the cost side. This in turn means that the higher the standardisation of the CM system, the better the requirements regarding CM can be enforced against the supplier without incurring huge additional costs. The OEM's competitiveness therefore increases massively with increasing standardisation of the CM system across the entire supply chain.

> “They have to learn the language, learn the procedures and so on and so forth and thus the cost of entry becomes relatively high” (Participant A).

It is particularly difficult to fully understand the effects of changes in complex systems. Only if the impact of the change on the overall system, including the underlying systems, is fully understood, can the costs of the change be fully determined. CM can make a significant contribution to this through the product structures provided. Participant A points out the importance for the customer to be able to calculate with the exact change costs.

> “First of all, it is important for the customer how much this change will cost him, and for the shipyard it is incredibly important to understand the change effects” (Participant A).

In this context, Participant A provides a particularly understandable and specific example in the field of cruise ship construction. These are particularly large and complex machines, which contain many different, interdependent systems. In this example it becomes particularly clear that companies offering changes at a fixed price need to understand these changes and all the associated effects particularly well in order to keep the risk manageable.

> “What we didn't consider was that televisions generate heat and a lot of it when there are many televisions suspended on the wall. They realised this relatively late but just in time, otherwise it could have cost millions. It now became necessary to enlarge the cross-section of the air-conditioning ducts and to increase the efficiency of the air-conditioning units. The enlargement of the air-conditioning ducts resulted in a lowering of the cabin ceiling and so on and so forth. It would have cost millions if they hadn't noticed. Had they offered this change at a fixed price they would have had to bear the additional costs themselves” (Participant A).

Another example of the costs that arise if CM is not applied to the right extent is the following. If it is not possible to easily determine the design and

manufacturing specifications for a complex product, there is a high risk that a company will not be able to react sufficiently to changes in regulations. As a result, it will be necessary to make very complex and expensive conversions.

> “Bombardier, for example, had 30 trains on the siding in Berlin because they could not deliver. Why couldn't they deliver? Because they took a five-year-old project and said when they ordered the new one, we'll just copy the five-year-old project with all the stuff on it, like data and tinker with it. What they didn't notice was that the approval standards had changed in the meantime and built a design that wasn't even eligible for approval anymore. This is how it can work if you don't do configuration management. It's impossible to quantify the costs” (Participant A).

Participant A points out that there are cases in aviation where the costs are no longer asked for, for example in terms of accidents where people die, costs are no longer counted. Therefore, it is essential to apply a sufficient amount of CM, especially in aviation and manned space flight. Even if, for example, entire aircraft projects are to be approved, failure to apply the right amount of CM can have an extreme impact and may not result in proportionate costs.

> “The simpler cases are those in which you don't have to quantify at all but have to deliver business cases. So there has been an accident and 50 people have died and you notice that this was due to a faulty component and nobody asks for the price anymore and then it is actually already too late. But even so cases where we have introduced delta costing with the help of several systems, which was a tinkering work to temporarily remedy the lack in data management. That cost a lot of money and then at some point the question was asked by the management, why are you doing this? The explanation was, if we can't do that, you can't certify your A380, which was just about to go into production, that you won't get it from the yard and it'll stand here” (Participant A).

Participant B shows with the following statement that CM must be applied according to the complexity of the product in order to keep maintenance costs manageable. If the necessary product structures are not available for complex products, troubleshooting becomes very complicated and time-consuming. The sometimes very expensive equipment is therefore not available for a long time and this can lead to massive incalculable costs in a complex and multi-layered production process.

> “Then I have a problem because I have too high maintenance costs and I have to prove to the customer that he caused the problem. This means that we now need to know much more about the “As Built” configuration. We now suddenly need to know exactly which sensor is installed exactly where, what does it do exactly and when it reports data” (Participant B).

CM can also help to secure production in high-wage countries, because it enables the individual production of customer requirements at batch size one at competitive prices. In this way, companies can distance themselves from mass production in low-wage countries, as can be seen with Participant B.

> “Another problem is we have customers who say we are being blown away in Europe with our cost structures by Asia and Latin American competition. We can only survive if we become premium in our field and this of course includes certain benefits etc. Others say we need to change our processes to batch size one” (Participant B).

The consulting company of Participant B offered its customers a so-called PLM or Big Picture Workshop, in which, among other things, the costs that arise or are avoided by CM are analysed in detail. From the comments of Participant B, it is obvious that the type and scope of the CM application must be adapted to the specific needs of the company in order to work at optimal costs.

> “Then a report on what has been discussed with all findings. In this report there is a grouping of the findings and then the Excel sheet which the customer can fill it out for himself, the findings are all in it,

> there are certain basics in it and where he can provide quantity and cost rates and then the Excel adds up certain values for him. There are always three results that appear after such a PLM big picture workshop. That is then the basis for a decision" (Participant B).

The bottom line, for Participant B, was always about error reduction and the associated cost-saving potential. These savings result from the reduction of intervention costs and intervention resources, which arise from the reduction of rework. CM makes an important contribution to reducing the necessary rework and can, through the configuration overview, point out solutions that make it possible to find the most cost-optimal solution, as can be seen again with Participant B:

> "So the bottom line is always error reductions and cost reductions. CM2 talks about intervention costs (intervention resources). The bottom line is that when we talk about savings it is mainly about cost reduction and effort reduction, further when it comes to costs it is partly about error costs" (Participant B).

Participant B shows further interesting cost saving potentials that can be realised with the help of CM by presenting the following interesting example of foundry engineering. In principle, this example can be applied to a wide variety of manufacturing processes, in that CM monitors the data of the tools according to a previously defined algorithm and initiates the procurement of new replacement tools in good time, so that there is no cost-intensive downtime of the production facility.

> "They are die-cast parts, our problem is actually the die casting tool and we know nothing about the tool i.e. the tool suddenly in a state that we can no longer use it. A die casting tool of a die casting machine that closes with several thousand tons. This costs 250000 Francs or Euro and if the tool is broken then the plant stands still for three weeks until we have built another tool. We would like to extract data from the machine now. We would like to equip the tool with sensors to extract the data and we would now like to try to make the

> connections. This data of the machine and data of the tool with the quality of the parts provides algorithms to determine when we have to order a new tool because we know this data will change in four weeks. This is also CM. That's what it is. Therefore, there is CM, i.e. the administration of data in precisely defined states in order to then link them, to establish associativity traceability" (Participant B).

Participant E stated even more clearly what happens to the costs if no CM is applied in the aerospace industry or if the application is insufficient. The interviewee also commented that this goes so far as to calculate the costs incurred for the non-delivery of a commercial aircraft due to the lost service time. Due to the high cadence of the large commercial aircraft manufacturers, the costs can quickly reach enormous values.

> "Without Configuration Management this would be a total mess. But it's hard to assess what it would cost us. The end line would be blocked, there would be delays in delivery, the customer would have recourse, there could be problems with the authorities. The costs can be roughly calculated by multiplying the flight cadence to be produced by the blocked time" (Participant E).

Participant E also points out that the cost savings in his company are not recorded and that only the costs of changes are recorded. The use of CM can also have a positive effect on costs for changes. In general, it can be derived from the following statement that the cost savings attributable to CM are not sufficiently recorded and must therefore be considered in the framework to be developed.

> "We do not record the resulting cost savings. However, we do capture all the costs of change, i.e. RC and NRC. The CM also creates added value by combining the introduction point of several changes into batches and therefore not having to touch the construction documents several times. So, there are predefined machines where we summarise the standard changes. So, CM also has an influence on keeping engineering costs low. For these

> savings we have KPIs and make corresponding evaluations" (Participant E).

Participant F points out that, with regard to cost monitoring, it is necessary to examine customer complaints and to check the planning data and cost estimates for their compliance afterwards.

> "It must be checked whether the customer subsequently requested corrections. We also analyse the planning data and cost estimates" (Participant F).

It is also essential that the costs which are measured can be assigned to the individual cost centres, for example in the area of specifications. Participant F expresses this in the following words:

> "There are specifications, legal specifications that can be used to make them accessible to a third party, etc., or then there are cost-related specifications that are only for the particular item, not system-related. That was the quantity to be measured" (Participant F).

As Participant F continued to explain, cost control in the area of CM by means of KPIs has recently increased massively. Although cost control values have always been collected, the interest in cost-control data is growing at the management level. From this statement, it can be seen that the availability of reliable data is becoming increasingly important. In addition, due to the complexity and quantity of the data, it is becoming important to develop advanced evaluation and presentation systems.

> "Yes, before we had nothing at all, we have always had something but it was never valued and now suddenly someone has been interested to have KPIs, quality work, quality delivery time, quality of costs that do not have to increase" (Participant F).

An important task of the CM is to understand, interpret and document what the customer wants. A central point is to document the costs in a way that is

understandable and comprehensible for both sides, so that complex projects can be planned and risks can be controlled. Participant F mentions this connection by stating that:

> “The technology is not the problem but it is to understand what the customer actually wants, which is relatively complex to write down and in the feasibility report to point out all the difficulties, to point out all the risks, to make the large costs from this analysis understandable. To make this understandable is not so easy. If you suddenly come up with two pages and say it costs 1.3 million then the questioning starts” (Participant F).

Participant H also mentions the fact that the targeted application of CM generates the necessary data to explain project costs both internally and to the customer.

> “I establish a maintenance process within a project by bringing all changes that take place within the project into a regulated change process and thereby giving the project management a means to record the costs and to present this to the customer and say, ‘you want to see what this will cost you, so and so much if you want it’, that is also a benefit” (Participant H).

As Participant H stated, the decisive factor in being able to record costs is the creation of necessary product structures in which the documents are linked directly under the corresponding materials. In this way, all changes that have been integrated into the complex product, such as military aircraft, over decades can be tracked. This makes the costs of maintenance work traceable throughout the entire life cycle. Even at the end of the life cycle, when the product is scrapped, it is clear which parts have been used and which documents must be destroyed, as is seen below with the perceptions of Participant H.

> “Then there is also a topic that you must again contractually regulate with the client, how are the development costs shared. Are we allowed to develop this further or do we have to make a payment or

> whatever? This is again the subject of negotiations. It is effective, for example, for the F18 or F5 it's fundamentally important that you set up the product structures, because the order in this context is for us the whole configuration responsibility, as all the changes that come from the US Navy or Boeing or from ourselves must be added to the configuration. At the end of the day when a system is scrapped you need to be able to tell what documents and what data I need to destroy" (Participant H).

A determining characteristic in determining the benefit of CM is to record costs incurred because the goals defined at the beginning were not achieved. This statement was made by Participant J. However, it must be added that the costs incurred must be investigated on the originator side and it must be determined that these costs would not have been incurred if the CM had been applied sufficiently.

> "So, you have to calculate the costs I have because I don't reach the goal I defined at the beginning" (Participant J).

In the further course of the interview Participant J gives an example that describes costs that can be prevented by the correct use of CM.

> "At the beginning I have requirements for my product to be developed. After production, for example, I notice that the requirement has not been met. This implies a lack of CM and unforeseen costs for reworking or re-development. I'm losing time because of this. That would have to be recognised and that would be the potential I could realise through my CM" (Participant J).

Participant J attributes another potential that CM offers for cost savings to the cross-departmental optimisation potential. If, for example, documents are changed, CM ensures that all departments have access to them electronically with the right effectiveness. Participant J cited several examples from his company that prove this advantage generated by CM.

> “By the good overview which the CM provides over the product, costs can be optimised for example also in co-operation with the purchase, which could also be measured. A big advantage of CM for us is also the management of the influences of changes on our aircraft documentation such as pilot manual maintenance manual or limitations” (Participant J).

Another advantage of using current and comprehensive CM data is the possibility to provide comprehensive and realistic training tools. These training tools such as simulators can correspond to the original down to the smallest detail and enable realistic training. Especially in the aerospace industry, this is extremely important for cost reasons. Participant L provided an interesting insight into the field of space travel, which underlines this fact.

> “I've seen it twenty times in water and I've worked with it there and I know it very well. Yes, that was exactly the same thing up there. And it costs a lot to have training equipment that is just like the equipment up there, which is sometimes quite complicated, but all the details. They opened Hubble's doors and inside there were instruments, there were cables, there were circuit breakers just like in the machine. That was great, that costs but the result was success” (Participant L).

4.4.5.3 Summary of costs

As can be seen, costs are one of the areas where the benefits and limitations of CM, and especially the specific usefulness of CM for a given company, become visible. The costs must be examined with regard to their origin in relation to CM. This is also only possible through the involvement of a CM expert who sees the whole context by acting inter-company wide along the entire PLM chain. Normally, it is the programme department that looks after costs. However, a change can affect multiple hundreds or even thousands of parts, and it is the CM manager who is able to have an overview of the entire product structure, and thus fully understand the origins of the costs.

4.5 Chapter Summary

The interviews were analysed using a thematic approach. Two recurring main themes emerged that are of central importance: Complexity and potential opportunities. In addition, three supporting themes emerged: Individuality, Costs and Industry 4.0. The evaluation of the topic individuality showed that the benefit of CM cannot be determined by generally defined KPIs alone. Each company has its individual needs and therefore the measurement framework and its parameters must be adapted to these needs. This can be achieved by applying influencing factors. Different companies have different complexities, both internally and externally. Therefore, a company-specific weighting is required. These weightings are difficult to determine; therefore, experts are needed here to take on this task. There are also striking differences in the potential opportunities among the various companies, which must be taken into account accordingly. Industry 4.0 is extremely dependent on data. CM is absolutely necessary to make this controllable. Costs are important in the framework because management is very cost-sensitive. Controlling costs through a suitable tool is essential. The decisive factors that are constitutively included in the generation of the framework have thus been elicited from the interview evaluation.

Chapter Five: CREATION OF THE FRAMEWORK

5.1 Introduction

The literature review in Chapter Two, clearly identified the necessity for a new and precise means to measure and represent configuration management, which was supported by the primary data in the previous chapter, Chapter Four. The existing literature suggests there is a need for providing a new revised framework through drawing on existing models. Currently, these existing models do not accurately represent the measurement needs for CM. Therefore this study provides the means to evaluate the differences between companies and projects. The framework developed in this study can be applied in any project situation without needing to be adjusted or reconfigured. The existing frameworks in contrast (e.g. Staats, 2009), have been predominately based on the KPIs which did not provide an accurate holistic perspective to represent the benefits of CM.

For some of the participants in the main study, as presented in Chapter Four, the consultants in CM indicated that some companies already use an advanced measuring process. These consultants identified that often when applying these existing measuring processes CM measuring framework companies did not consider absolute values, but instead concentrated on a percentage measurement to fulfil a project and its completion rate. During the interviews, the consultant participants indicated and provided a general consensus that there was a need for a new model to measure the value of CM which could provide an easier way to compare different levels within a project, or at an organisational level. The basis of this finding was centred on the need for the measurements to be reflective at a company level, location level, product level, department level or project level. Interestingly, there was no clear hierarchy of levels identified in the main study which could be related to the different organisational structures studied. For instance, for some companies which are managing large projects this can involve a large number of departments, and potentially over different locations all over the world. Managing projects like this in different departments becomes increasingly difficult as the complexity increases. This does not apply merely to large, complex companies. Even small companies who are involved as partners in large complex projects need to have a refined and carefully designed

CM that is compatible with international standards. In this case, for a small company like this, it is important to measure the value of CM at the project level rather than the company level.

What emerged from the literature review was, firstly, that a design review needed to be reconsidered. This reconsideration needed to consider that often corrections were necessary to be re- configured and corrected after a design freeze (Guess, 2013). Therefore, the product would have to be redesigned or predesigned, and would therefore be costly and time inefficient. Related to this theme is the necessity for a baseline to be set correctly. The second emerging point was related to on time delivery.

With on time delivery of the product or service, this KPI ought to provide the means to measure on time delivery information accurately and therefore measure the performance. However, current existing models of CM are not sufficiently precise as the KPI often omits information beyond CM, for example, if the supplier has had a delay and the potential ramification of this. Therefore, there is a need to consider all external and internal factors.

5.2 Development of the measurement framework of CM

Drawing on Chapter Four, this section presents the framework derived from the insights gained from the literature review combined with the interpretation of the interview data. In analysing the interviews, the data indicated that there were specific qualitative and quantitative measurable benefits of using configuration management in the aerospace industry. Drawing on Chapter Four, it is necessary to focus on the main emerging themes, which are complexity management and the need to identify potential future business opportunities. In the main study, all the interviewees agreed that there were insufficient key performance indicators, and that the existing KPIs were generally not suitable to be used or transferred across project, businesses, or sector.

In analysing the interviews, the study found that performance indicators can be used to establish a useful evaluation framework for configuration management within the aerospace industry in a single company. In analysing the interviewee data, it became clear that there were different requirements for CM application,

but this was very much dependent on the company. During the interviews, it became clear from the majority of the interviewees, and in particular the consultants, that there existed a number of large differences between CM project requirements, which were invariably influenced and dependent on the project or company needs. To illustrate this, the original equipment manufacturers (OEM) which produced entire aircraft or spacecraft have a higher level of requirements of CM compared to a smaller supplier, who does not supply complex parts. For this reason, the KPIs therefore need to consider and include weightings based upon the specific needs of a specific company. Therefore, in addressing the central purpose of the study, it became clear that it was not possible to accurately measure or capture the benefits of CM in the aerospace industry with the existing KPIs alone. As was shown in the literature review, (Staats, 2009) developed a method of measuring with KPIs. However, as was also shown, there has so far been no consideration of the limitations of using unweighted KPIs for accurately measuring CM in different companies. To address this gap, this study contended that a new meta level framework was needed to be created to represent the functionality of the entire measurement process of CM application in a company (see Section 5.3).

Many of the existing measurement systems as presented in the literature review have been based on the evaluation of KPIs. As seen in the literature review (e.g. Staats, 2009), these measurement systems have been predominately based on KPIs, which have not been comparable with each other and therefore cannot be transferable throughout the aerospace industry. For example, as identified in the interviews, if the project needs to be reworked, the lack of any weighting based on the complexities of the change, means that the KPIs cannot accurately be compared with other projects. Therefore, it should be noted that the benefits of CM had a number of limitations as to its traditional usage and application of KPIs, as the complexity of the project was often omitted. Reflecting this, the KPIs therefore need to be tailored or weighted to characterise the project specifically, and therefore avoiding KPIs which are inaccurately measured or omitted. As seen in the study, often the company has its own individual requirement, therefore this specific need has to be considered and incorporated into the measurement of CM. This individualisation of KPIs has to include influencing factors including the size of the company, the kind of product

or service offered, together with the risks accompanied with the product or service.

Through analysing the interviews, it became clear that the benefit of CM was dependent on the complexity and potential opportunities within a company. Therefore, reflecting this finding, CM should be used according to the individual requirements of the specific needs of the company, project, or sector. The existing literature supports the consensus of the participants that CM is often not implemented effectively due to neglecting individual requirements of the project often because of the lack of management support. This lack of managerial support can result in CM not being fully implemented and therefore becoming ineffective. From the findings, it was identified that a new conceptual CM framework was needed to map accurately the corresponding complexity of the project, which extended beyond the traditional usage of KPI measurements, and to include a meta-level. In representing this finding, Section 5.3, Figure 5-1, shows the measurement system of CM as to how the new framework can be used effectively through the organisation and project.

As presented in Chapter Four, five themes of analysis were identified and defined. Of these, two main themes emerged – that of complexity and potential opportunities – while the remaining three themes related to individuality, Industry 4.0 and cost. During the interpretation of the data, the theme complexity was found to have different types of complexities based on the project or organisation. However, for CM to be effective the different complexities need to be managed irrespective of the size or type of project. For example, in the management of a high security risk, CM needs to be sufficiently adaptable to respond to this particular complex issue, while on less security focused activities, the focus needs to be focused on other activities with the same complexity level. If this is not accurately represented in CM, the result can lead to failure and potential reworks, culminating in increased costs. Another example highlighted during the study was that the degree to which complexity needs to be managed is often dependent on whether it is safety critical or not. The study found that the importance of managing complexity is much greater for safety-critical parts than for parts that are not safety-critical. From these examples, it is possible to conclude that CM needs to include a weighting in order to be able to individually

evaluate the complexities of the task. To achieve this, this study has created a framework that is able to measure accurately the degree of implementation of the *actual* and the *target* requirement, of what must happen. Because of the degree of implementation (DIA) of the CM, this process must be determined accurately by a specialist, due to the nature of the calculations or the need of an accurate evaluation. The study found that the advanced model of IPX (2018), could provide the basis for the framework for the DIA, and related calculations. However, a number of associated weaknesses where individual projects or business requirements were not considered were identified. To reflect this weakness, this study adapted the original IPX model by adding weightings. This element of the DIA is presented in further depth in Section 5.4.1.

Through the interpretation of the interviews, the topic of potential opportunities was very different depending on the project or the company. The theme of Industry 4.0 for some businesses or projects was paramount, however for others, it was less important. In relation to costs, the study found that the CM provided an accurate means to evaluate costs. Costs were seen as being of particular importance because of the management focus and sensitivity to controlling costs. Leading from this, the study highlighted the need for an expert who has an oversight of the entire process chain, and an expertise and a comprehensive knowledge of the industry and project.

5.3 Fundamental structure of the framework

To represent the findings of the above, this study advocates the following model shown in Figure 5-1 page 168. The model is based on a number of existing CM measuring frameworks, for example, IPX (2018), Staats (2009) and Guess (2006). In developing this model, the framework below represents the existing models for measuring CM. This is labelled as measuring of first system order. This is based on KPIs only because it is not weighted, which is a flaw in the existing CM measuring frameworks. To address this, the second system order provides a meta level which is based on determination elements, which is both calculated and weighted.

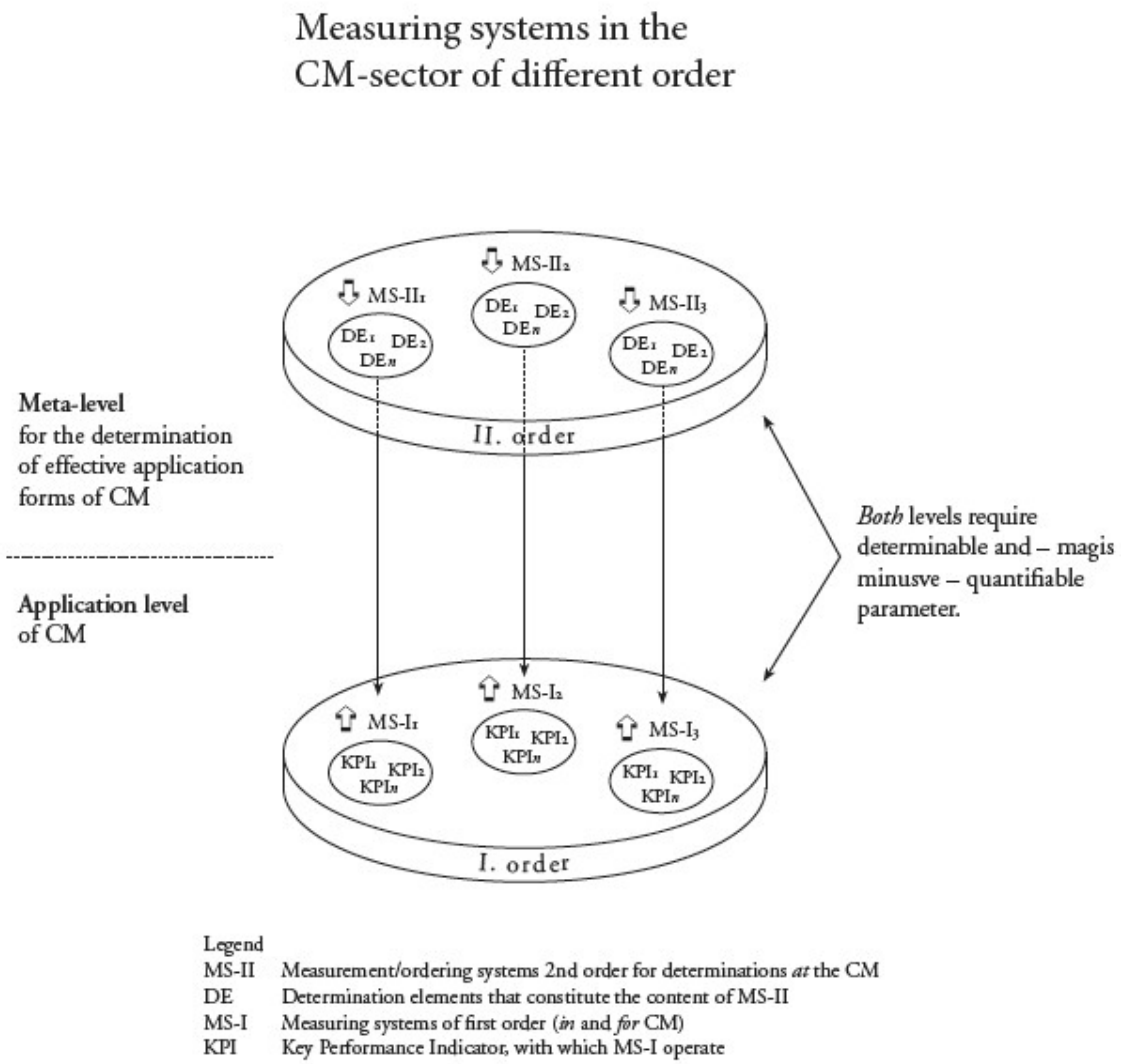

Figure 5-1: Measuring Systems in the CM-sector of Different Order

During the literature review, it became apparent that there were a significant number of CM measuring systems, however these in the main were unable to capture the organisational or project needs. It also became clear from the findings that it was possible to build on these existing CM frameworks, but it was also necessary to include the needs of the organisation or the project. The central weakness was found to be the need for a model to be transferable and to also include weighting to represent the project needs. Therefore, it is only possible to understand or capture a project in its entirety using a superordinate matrix.

Figure 5-1 has two orders. The first order is based on the findings of the literature review where the measuring systems are mainly KPI based. However, based on the interviews conducted it was necessary to introduce a second order,

which is based on determination elements. As the interviewees described, there is a wide variability among companies in the aerospace industry. Each company has to use CM differently because they have different complexities and potentials. For example, companies have different complex products, supply chains, company structures, customer needs and requirements as well as different potentials for future production such as industry 4.0, or different marketing models. Through these statements form the interviews it was clear that the measuring framework also has to be adapted to the different needs of each company to be able to measure the CM and, in addition, to have the opportunity to optimise the application of CM. This means that for a company with safety critical products it normally makes more sense to invest in a highly developed CM system.

In order to address the problems identified from the interviews, it was necessary to develop a second order. In the second order the individual needs of a specific company can be taken into account. This can be done by an appropriate weighting method where individual determination elements (DE) can be given greater or lesser value. Although this method of weighting was not directly suggested by the interviewees, it successfully solves the problem of different necessities that they identified. In addition, in the literature review, where it was found that it was necessary to develop a new system for each company, the new weighting method can be used for any company.

In terms of how the new framework is used, the user commences the process by starting at the first system order, with MSI1 to MSIn, which are configured metrically using the key performance indicators from KPI1 to KPIn, as advocated in the existing models. From this, the second system order, MSII1 to MSIIn is then assigned to a higher meta weighted level. This process involves the selection and, if necessary, combination of these weighted KPIs to be assembled. The second order is determined based on the project or the organisation needs.

5.4 How the framework is applied

Based on the results of the interviews, it became clear that there was a necessity for a project or a company to follow a criterion which is based on the proposed

theoretical framework. This was supported by all of the interviewees, in terms of how critical the framework is needed to measure and capture the complexity and potential of the project. Although the framework is only presented from an academic perspective and the application is visible in the appendix as this is not the main focus of study

5.4.1 Description of the necessity of the weighting coefficient of the individual complexities.

In developing the theoretical model, each criterion in the second order, such as the internal complexity, external complexity and potential, are all separately weighted with a co-efficient value on a scale between 1 and 0 to understand the concept in developing the model. The weighting coefficient for a category may take the maximum value of 1, but cannot be below zero. In every category all the elements are weighted individually being reflective of the needs of the project or organisation, and distributed between the individual determination elements of the respective category. In order to be able to carry out this distribution process to the respective categories, an expert is needed to have certain competences. These competences may differ based on the company or project. To ensure that the process is sufficiently robust, it may be advisable to have an external expert to avoid operational blindness, while also possessing sufficient organisational, sector and project knowledge. These competences should include:

1. An overview within the company and in the industry.
2. Knowledge of corporate strategy.
3. Expertise.
4. Synthetic thinking in complex contexts.
5. Experience.
6. Interdisciplinarity.
7. Vision.
8. Routine.

It should be noted that for this concept to be effective, company wide data collection is necessary. A recommendation from the study is that an independent expert is required to supervise the entire measuring process. Although an independent expert is recommended, the Configuration Manager needs to

supervise the entire measuring process. To achieve this strong cooperation with all the departments is necessary, where accurate data from inside the company and also external business partners are included. Generated from this data, and as can be seen in appendix 7.16.1, a key feature of the study's proposed solution is the distribution of the external complexities, using αi weighting coefficient; therefore, the expert needs to understand how the weighting operates. Furthermore, the expert has to have a working understanding of the internal complexities β_i, and a recognition of the connections with the organisation. With respect to the potential for the company, although external to the business, the weighting coefficient for the potential γ_i requires expert analysis of any future development needs of the business.

Leading on from the core competences, it is important to acknowledge that part of the model includes the categories. However, these categories are not a direct part of the framework, but are instead an assistance to the user or expert. These categories are divided into three groups. The first category relates to the product (Table 5-1) of the organisation or the project. The category commences from 1 to 5 but the scale is dependent on the importance to CM, and is dependent on the complexities of the project. The second category (Table 5-2) is the future development of the project, where the future possibilities are assessed as to its potential. The scale relates to the potential future importance to the organisation. The final category (Table 5-3), is the strategic development of the project, with scale denoting its importance. The tables came out from the interviews study.

CAT1:	Simple physical product with little liability
CAT2:	Physical product or engineering with little liability
CAT3:	Sophisticated product and/or engineering with medium liability
CAT4:	Sophisticated product and/or engineering with high liability
CAT5a:	Sophisticated product and/or engineering with high liability and worldwide support
CAT5b:	Sophisticated product and/or engineering with high liability and lifelong support
CAT5ab:	Sophisticated product and/or engineering with high liability, worldwide and lifelong support

Table 5-1: Product Categories of the Company

CAT1:	Simple physical product with little liability
CAT2:	Physical product and/or engineering with little liability
CAT3:	Sophisticated product and/or engineering with medium liability
CAT4:	Sophisticated product and/or engineering with high liability
CAT5a:	Sophisticated product and/or engineering with high liability and worldwide support
CAT5b	Sophisticated product and/or engineering with high liability and lifelong support
CAT5ab	Sophisticated product and/or engineering with high liability, worldwide support and lifelong support

Table 5-2: Future Development Categories of the Product

CAT1:	Intensive application of CM brings no additional value for the product
CAT2	Intensive application of CM brings some additional value for the product
CAT3:	New business models are possible with intensive application of CM

Table 5-3: Strategic Development Perspective Categories of the Product

Although not directly classified in the three categories above, the interviews reviewed showed that costs were a key detriment and measurement category, due to the ease of measurement which is easy qualifiable, and often a key management focus. In measuring costs, the model of any national currency can be used as a measuring unit, but consideration needs to be given to ensure that a standardised currency is used, for example the US dollar.

5.4.2 Derivation of the DIA

The next part of this Chapter presents the core component of the QDI, commencing with the DIA. This section reviews the findings in relation to the degree of implementation to the application (DIA), which refers to the meaning of the measurement of the application of the current CM being used in the company or in the project. To understand this, it is necessary to present the model of IpX and how this concept informs the new measuring framework. This section is based on IpX CM2, Efficiency of your Organization (CM2), with the categories related to this concept set out in Table 5-4 page 174, and in appendix 7.4 the IpX questions can be found.

IpX (2018) created and advanced CM by providing a more comprehensive means to evaluate the process, by advocating the usage of CM2 (see Appendix 7.4). Appendix 7.4 shows the original model, however, during the interviews, it became clear that there was a need for additional weighting options to be applied, thereby making it able to be applied to different companies. In recognising this, this study contends that the usage of different weighting factors can enable this holistic usage to happen (see appendix 7.15 to 7.16). To calculate this, appendix 7.14 sets out the criteria and formula.

To illustrate the difference and the usage of the new model compared to the measuring framework in Table 5-4, page 174, the categories used are based on a series of questions, which are related and graded on a percentage basis. The problem of the IpX model is that all these questions need to be answered, then evaluated at 100% for the CM2 to effective. As identified in the interviews, CM does not need to be implemented irrespective of the needs of the project or company, but instead by being tailored or weighted.

CAT	Percentage	Description
A	80% - 100%	Core processes provide a competitive advantage. Intervention is minimal. Real improvements are robust.
B	60% - 80%	Core processes have many strengths but areas needing improvement are recognised and addressed.
C	40% - 60%	Confidence in the CM2 principles and their application is growing as corrective action is declining.
D	20% - 40%	The CM process has many weaknesses. The organisation is deeply mired in corrective action.
E	0% – 20%	The CM process is ineffective; there is no accountability. Firefighting is considered to be business as usual.

Table 5-4: Process Efficiency of an Organisation adapted from CM2

5.4.3 Derivation of the DIT

In this section, the second part of the QDI, derivation of the degree of implementation target is presented, with the related calculations in Appendix 7.16. The DIT measures how much a company should use CM. In comparison with existing models identified in this study, these frameworks only measure what currently exists, and does not consider what should be done. In addressing this, the study has created the measuring framework with the flexibility to incorporate what should be happening and what should be done. This was one of the key findings and contributions to emerge from the interviews. Again, cost was found to be a key factor, and needed to be included into the measurements.

Since there are so many categories to measure CM and related disciplines, it is necessary to concentrate specifically on the most important themes related to DIT, which are *complexity* and *potential for future development*. This assertion was confirmed through the interviews. Reisenweber et al. (2009) found that in applying CM there is a need to master these complexities, but more specifically

in relation to internal and external factors. In explaining this, Reisenweber et al. (2009) distinguishes between internal and external complexities as being critical components, however these two complexities were not weighted to be company or project specifically. Reflecting and building on the research by Reisenweber et al. (2009), this study developed a series of new formulas, which were informed by the interviews. The outcome has been the creation of new internal and external weighting which can be adapted to the individual requirements of the individual company or project (see Appendix 7.16 for the formula). The use of the DIT to receive the QDI is described in the next section.

5.4.4 Quotient of the degree of implementation (QDI)

Based on the theoretical framework above, this section will present the central findings of the research. To determine how CM application is applied, it is necessary to define and ascertain the degree of the implementation target (DIT). In achieving this, the study advocates the need to calculate the exact degree of implementation (DIA), which is divided by the degree of implementation target (DIT) and can be found in appendix 7.13. If the QDI is 1, this is seen as being the most optimal value as the project is using CM effectively. If the value is less than 1, then CM is not being used sufficiently, while over 1, then CM is being over-used.

Often CM is implemented using the value within a company based on real existing values, however these are invariably not weighted. Moreover, the target value being based on the future needs to have values attached, but cannot be easily measured, while often based on estimates and judgments, which are open to misinterpretation. To address this, it is necessary to generate the DIA and DIT data to provide an accurate representation of the project.

5.5 Validation of the evaluation framework

To ensure that the new framework developed by the study could be effective when used in CM, an additional interview was conducted. This chapter shows the outcomes of the experts findings. This section contains two additional interviews which potentially could be aligned to the findings chapter, because the framework has already been devised. Two experts validate the framework based

on the central findings. These two expert opinions are presented below. Two interviewees were approached. Expert 1 was a vice president in an international company which delivers aircraft structures to different original equipment manufacturers. Expert 2 was an expert in the field of drones, who is responsible for the development of the service sector for the drone development in his company.

The interview initially focused on whether the framework would be sufficiently beneficial to CM in the aerospace industry. For these experts there was an agreement:

> “The framework is sufficient to evaluate the perceived benefits of CM in aerospace industry. The Configuration Management itself is an essential and mandatory part of development and production” (Expert 1).

In evaluating the comments of Expert 1, the interviewee considered that the new measuring framework was perceived to provide several beneficial advantages to CM application in the aerospace industry. Expert 1 noted that the responsibility for the quality management for an international aerospace supplier group was often dependent on a functional CM and the need to optimise the profit through looking at the possibilities which the new measuring framework offers.

In addressing to what extent, the new measuring framework could be used in comparison with the existing models, for Expert 2, it was related to the lack of the weighting and instead focused on meeting criteria, which may not be relevant:

> “I would like to argue that the present framework you have presented is valid and potentially can deliver. I base this professional decision on the following reasons: the framework seems not to be primarily aimed at providing a binding content which needs to be completed and does not reflect reality. The strength of the new framework lies in the fact that it views the topic structurally from a second level of order, i.e. from a superordinate viewpoint; from a kind of bird's eye view, one

> could also say – looks at the topic. Therefore, it can be applied in a more general way compared to the other models, as they look at specific KPIs only. In comparison, this new structure-based approach with the weighting permits individual requirements to be determined" (Expert 2).

From the perspective above, it is possible to see that Expert 2's answer highlights the benefits of the new model and the fact that the weightings enabled the CM to be used more effectively, and potentially provide a practical benefit to the aerospace industry.

In addressing whether the model provides an accurate representation for CM, both the interviewees agreed. This agreement can be seen in the comments of Expert 1 who highlighted that the new framework provided specific tailored questions:

> "The questions [in the model] are well tailored to gain an impression about reputation and perceived benefits from an outside point of view. They [questions] have the potential to reveal gaps between what it is and exists now" (Expert 1).

From the comments of Expert 1, it is clear that the questions of the framework are formulated in providing sufficient insight to make an accurate decision as to how to apply CM. It is particularly important as Expert 1 then elaborated on the potential differences between the existing models used compared to the new measuring framework.

> "I think that the questions asked in the model have a reasonable depth. The strength of the framework, as I have just explained, lies in its structural approach. If the questions were to get lost in detail, it would be counterproductive for efficiency. On the other hand, this does not rule out the possibility that, in a concrete application, one must look at very small details. But that is quite normal. And this necessary, additional detailed consideration can be all the more fruitful if the general setting,

> as defined by the framework, has been applied beforehand. If, as is the case with this topic, you want to gain an overview of complex interrelationships, it is always first a question of the logical scope of the means used. And that seems to me to be well met here" (Expert 2).

Clearly for Expert 2, the new framework identifies the nuances of a project need, but also the flexibility through the weighting to make a project more tailored when using CM.

When the experts were asked the question as to whether there were any unnecessary questions or additional questions which should be asked, there was an agreement amongst the interviewees that the general criteria were captured:

> "A self-assessment of the respondent could be helpful to rate the quality of the answers: 'How do you rate your knowledge about Configuration Management compared to other disciplines, e.g. Manufacturing, Engineering, Sales? But this is only a minor change, overall, the measuring model captures what is needed, very interesting" (Expert 1).

Expert 1 noted that it would be useful to establish further questions, but these would be sub-themes or questions. The interviewee did not see the addition of sub-themes as a shortcoming of the proposed model, but the recommendations are constructive enhancement of the framework.

> "I think that the questions asked have reasonable depth. The strength of the framework, as I have just explained, lies in its structural approach. If the questions were to get lost in detail, it would be counterproductive for efficiency. On the other hand, this does not rule out the possibility that, in a concrete application, one has to look at very small details. But that is quite normal. And this necessary, additional detailed consideration can be all the more fruitful if the general setting, as defined by the framework, has been applied beforehand. If,

> as is the case with this topic, you want to gain an overview of complex interrelationships, it is always first a question of the logical scope of the means used. And that seems to me to be well met here" (Expert 2).

Expert 2 also stated that the questions were sufficiently robust to capture the project, and were able to be adapted further to meet more specific needs.

The study then asked the experts as to whether the framework would be helpful in their position to develop CM. For Expert 1, it is was related to the potential opportunities offered by the framework:

> "Yes, very much! It will show areas of opportunities to highlight the importance of CM compared to other disciplines" (Expert 1).

For Expert 2, the answer was extensive drawing from an extensive professional perspective on CM in the aerospace industry.

> "In my personal professional career, I originally came from quality and knowledge management for educational institutions. Currently I am working as a project manager for an institute that wants to develop the business field of services for / with drones or UAS [Unmanned Aircraft System]. In this working environment I am confronted with the task profile of planning, coordination and documentation under the difficult conditions of complexity and interdisciplinarity of this activity. Furthermore, there is a lot going on in this business field, both in terms of technical development and the legal framework, which is to be readjusted at European level at the beginning of 2021. In addition, from an economic point of view, there is a vulnerable dynamic of the market with a strong fluctuation of players. Due to all these factors, the activity is moving on a challenging, variable terrain which requires highly effective control instruments. CM is of great importance for these are often-interwoven processes, and in particular the question of how

> much of it makes sense under the aforementioned changing conditions. The developed framework can provide good services for this purpose. I expect the element of weighting to play a central role in this context. I also see the innovative matrix of the different categories as helpful for such concrete application scenarios" (Expert 2).

From these experts, the developed framework provides a good basis for determining the effective usage of CM through capturing related data, and then weighting them. It can be deduced that the new measuring framework can be applied in different companies in the aerospace industry, with the additional possibility for the concept to be versatile enough to be refined in the future.

5.6 Chapter summary

This study contends that the existing CM2 has now become an established and recognised industry standard to be used in CM, however the existing model does have a number of limitations including the assumption that CM needs to be applied the same way irrespective of the sector or project. Reflecting this, this study has developed a new measuring framework with new parameters which are now weighted. While the existing models in the CM, including IpX, the nature of these concepts in their practical application requires a more precise description and in-depth instruction to apply these models. The main contribution of this work is therefore:

a) based on the existing structure of CM2, the new measuring framework can enable a more differentiated future-oriented application in a company-specific way; and

b) through the introduction of new weighting factors, this conceptual model provides a new level for experts to apply in a technical environment. This new conceptual CM framework introduced provides more company-specific characteristics and requirements which are both calculable and scalable. Through using this framework, it is possible to know how to provide an accurate representation of actual/target ratios. It has to be carried out by an external

expert who is familiar with the specifics of the company and has an industry-wide overview.

In addressing the central research question, and the extent to which the study has answered this, Chapter Six, presents the contribution to knowledge and practice, a critical evaluation of the limitations, and an indication of future research.

Chapter Six: CONCLUSION

6.1 Introduction

Based on the results of the study as presented in Chapters Four and Five, this Chapter concludes the study. In this Chapter, the findings are presented, the contribution to the theory and understanding of the new measuring framework which uses specific weighting, together with the benefits of Configuration Management to the aerospace industry. Finally, this Chapter sets out the limitations of the study and then makes suggestions for future research, before finally presenting a concluding personal reflection.

6.2 The aim of the research

The aim of this thesis, as set out in Chapter One was to create a framework to measure the benefits of CM. To reach this goal the study addressed the following research questions:

Research Question One: What are the specific qualitative and quantitative measurable benefits of configuration management in the aerospace industry?

Research Question Two: What key performance indicators (KPIs) can be used to measure the value of the CM in the aerospace industry and determine their effectiveness?

Research Question Three: How could performance indicators be used to establish a useful evaluation framework for configuration management in the aerospace industry from a management perspective?

By investigating these questions, the study has found that it is possible to accurately measure the value of CM as a means of developing this concept, and for it to be effectively applied in the aerospace industry. In reaching this conclusion, it was necessary to build on existing models and then introduce a new weighting. This study found a new dimension generated from the thematic analysis, and also the need for KPIs. The study also revealed that there was a

need for development of a framework with the inclusion weighing, as can seen in Chapter Five, Section Three.

6.3 Overview of the study

The research project involved conducting semi-structured interviews with thirteen professionals who have a professional usage of CM. The interviewees were grouped into three categories: the largest group, which comprised of seven participants who were configuration experts, a second group of four participants who were CM consultants and finally, the last grouping of two participants who represented the senior management. Following the creation of a new measuring model with specific weightings (see Chapter Five, Section Three), together with the formulas, as presented in appendix 7.14 to 7.17, two additional experts who validated the study's findings were interviewed. For the main study, the selection process involved applying a competence matrix to the participating interviewees so ensuring that all necessary competences, such as practical CM knowledge, theoretical CM knowledge, general management knowledge, special knowledge in the aerospace sector as well as scientific knowledge in the aerospace sector were present.

The evaluation of the existing literature indicates that extensive measurement schemes already exist in CM, and in particular IpX (2018) and Reisenweber et al. (2009), together with existing studies (e.g. ICM, 2016; Staats, 2009; Reisenweber et al., 2009; Guess, 2006) showed that the existing methods of measurement had a weakness of not being comparable between different companies or projects. Another weakness identified in the literature and during the main study was that the measurement processes or the evaluations cannot be individually adapted to the different companies, which means that the measurement processes currently available are not sufficiently individualised. To address this, the study created a new conceptual model presented in Chapter Five. The next Section 6.4 presents the key findings and contribution as to how this new measuring framework can effectively measure CM.

6.4 Key findings and contribution

This section critically presents how the three research questions set out in Chapter One, Section Five, address the central aim of the study through presenting the contribution to knowledge and practice.

6.4.1 Addressing the first research objective and question

The first research question is: What are the specific qualitative and quantitative measurable benefits of configuration management in the aerospace industry? A key finding and contribution of this study was the identification that CM is an effective means to be able to report and manage internal and external complexities. However, in Chapter Five, the study identified and then provided a new conceptual model as a means to capture these immediate and mediate short-term benefits, as shown in the Table 6-1. The framework and the usage of the calculations in the DIT (see Appendix 7.16), enables the generation of a target value, which represents the external and internal complexities, together with the future possibilities. Depending on the value, this will indicate if the CM is suitably optimised or whether further investigation is needed. From the outcome of this calculation, is then possible to determine the immediate and short-term mediate benefits, as show in table below.

Immediate benefits:	**Mediate benefits:**
• Supplier quality fluctuations • Fluctuation in customer demand • Customer specific adaptations (customizing) • Rate of change of product requirements by customers • Rate of change of product requirements by authorities • Fluctuations in delivery times of suppliers • Exchange of information with the customer	• Generation of new business models • Cooperation between different locations of a company • Overview of a company • Reduction of rework • Finding new customers • Delivering services over the whole product lifecycle • Ensuring the individualization of a product • Enabling Industy 4.0 • Enabling internet of things

• Exchange of information with the supplier • Diversity of product range • Multidisciplinarity • Variety of applicable processes • Exchange of information between different locations of the company • Period of product development • Period of production • Parallelisation of development and production	• Enabling new services for customers

Table 6-1: The measurable benefits of the application of CM using the framework

Table 6-1 shows potential, internal and external complexities together with the future possibilities for a project and the company if managed correctly. These benefits include whether it is necessary to manage customer specific requirements through an adaptation strategy or alternatively through customization. Customer-specific adaptation or customizing refers to the adaptation of a product based on the individual needs of the customer, then whether an existing specification or a new solution is needed. In the case of complex products, such as aircraft structures, this immediate benefit while representing a major challenge, as often the configuration involves thousands if not hundreds of thousands of different alternatives, with effective optimisation of CM, the entire supply chain may be synchronised. As to the parallelisation of development and production, this immediate benefit refers to the data generated during the development engineering stage where the production can commence without minimising disruption, and any changes to be seamless acted upon due to the interlinkage of the data.

As mentioned above, the division of complexities indicate to management the benefits in both the immediate and short-term (mediate). However, it should be noted that not all benefits, as indicated above, are always of the same importance or relevance to every company or project. Reflecting this, this study has created a new methodology and output to inform businesses whether the

complexities require specialised CM tools, such as software programs, to be used. This framework creates an accurate indication as to whether CM software, which is often expensive, is a viable investment option or not, dependent on the project. This framework can also be used for assessing in potential projects and determine whether future potentials are worth the investment.

6.4.2 Addressing the second research objective and question

The second research question is: What key performance indicators (KPIs) can be used to measure the value of the CM in the aerospace industry and determine their effectiveness?

This study has identified the need to focus on two main themes, and three supporting themes to determine the degree of implementation target (DIT). The two main themes are complexities and future potential, and the supporting themes are individualisation, effective management of costs and Industry 4.0. The most important KPIs for each main theme are presented in Appendix 7.16. Figures 7-5 to 7-10 show eight identified external complexities, seven internal complexities together with the ten potentials including the generation of new business models and the generation of greater synergy and cooperation between different locations, which have been consolidated and displayed graphically. It should be noted that Figure 7-5 is the theoretical representation of the external complexities, while Figure 7-6 relates to one of the study organisations.

The KPIs from the IPX (2018) valuation approach were used to determine the degree of implementation (DIA). By linking the KPIs from several existing models and then focusing on the most important underlying themes related to the key performance indicators, it become possible to determine, as indicated during the interviews, that a KPI grid could be created and then applied to a project. This study contends that these KPIs can provide the basis of their usage to measure the benefits of CM. However, it was also found that the use of KPIs alone is not sufficient. Therefore, to address this, additional weightings of the individual KPIs must be carried out, and the findings and contribution is presented when critiquing research question three.

6.4.3 Addressing the third research objective and question

The third research question is: How could performance indicators be used to establish a useful evaluation framework for configuration management in the aerospace industry from a management perspective?
The study found that there are two key findings. The first finding, which is related to the second research question, is that it is necessary to establish an evaluation framework which has weightings associated with the needs of the company or project being measured. The second finding indicates that the applied CM needs to be reflective or optimised based on the specific requirement.

The study found that the existing models and theories (e.g. IpX 2018; ICM, 2016; Staats, 2009; Reisenweber et al., 2009; Guess, 2006) have a number of informative applications in configuration management, however, as indicated in Chapters Four and Five, there was a need for the generation targeted framework to be developed. This was initially identified through conducting the literature review, which provided an indication for the need for a new evaluation of the existing CM framework. This was then supported by the findings of the study, where the interviewees highlighted that although there were CM frameworks a general weakness of these models invariably needed to be adapted and modified for a project, which often was costly. To emerge from this, was the need to create and provide an evaluation framework, which incorporated a measuring system with different weightings added, as seen in Chapter Five.

To emerge from the study was that individual companies and projects tended to measure variables differently, and therefore the framework needed to represent and map these differences. This technicality was solved by the introduction of weighting coefficients, as presented in appendix 7.15 to 7.16. The weighting coefficient solution could potentially provide a highly integrative function, as it bundles different measured variables to generate a meaningful value between zero and one.

6.5 Contribution to academic knowledge

The aim of this study was to develop an academic and practitioner's framework to evaluate the benefits of configuration management in the aerospace industry. It includes recommended proposed parameters provided by external experts to

use the framework effectively. This aim was achieved by drawing on existing industry knowledge based on IPX (2018) and ICM (2016), combined with the academic studies of Staats (2009), Reisenweber et al. (2009) and Guess (2006), which informed the main study, then from the findings, a new project management insight was develop to show how CM can be more effectively optimised. In the existing measurement models for CM developed by IPX (2018), ICM (2016), Staats (2009), Reisenweber et al. (2009) and Guess (2006), these studies have focused predominately on existing values in a company, such as complexity or potential, and neglected the individual needs of the project, focusing on existing values and missing what the company should do, like the degree of implementation target (DIT). In these existing measurement models, the concepts were designed to determine the current status of a project, consequently focusing on current and actual values, while not linking these to target values. This omission means that the existing academic models of Staats (2009), Reisenweber et al. (2009) and Guess (2006), only provided a generalised and often inaccurate representation of how to effectively use CM. To address this, this study found through the interviews that invariably projects and businesses needed to have more tailored measurements. This potential gap was partly reflected in Staats (2009) study where the model was seen as not being interchangeable between different companies or projects, therefore lacking the necessary flexibility. Reflecting this potential limitation of Staats (2009), this study's first academic contribution, as set out in Section 6.5.1, has been to create a new model through the introduction of weighting. This study in effect has extended the original theoretical contribution of Staats (2009) by introducing both a theoretical and also practitioner's insight into how CM can be more effectively viewed. This new academic creation is further based on robust empirical evidence provided during the interviews, then re-evaluated with two new independent experts from the aerospace industry to arguably triangulate the data, whereby providing increase confidence as to its potential usage in the sector.

The second academic contribution of this study suggests that CM could be optimised and used more effectively throughout the field of project management and in particular for the aerospace industry, as presented in Section 6.5.2. This contribution relates to an optimised application of CM in a specific company.

Existing theoretical literature in this field including Reisenweber et al. (2009) and Guess (2006), have in the main provided a very generalised and focused academic interpretation as to optimising CM. This new insight could enable the company to save money and develop the business further in a digitalised world, while also providing a new perspective into how CM is viewed in the field project management research. This conclusion is further supported during the qualitative stage of the study, where it became apparent that digitalisation is often hard to effectively manage, however in applying an advantaged approach to CM it is possible to address this. This new academic contribution to the field of project management of using this study's advantaged CM approach, it may be possible to introduce through the Internet of Things, the ability to enable machines operating in different plants or locations to work together co-ordinately. The introduction of the study's new academic model therefore could enable management to make this strategic decision as to whether a particular approach to CM is financially viable, a theme which previous academic studies including Staats (2009), Reisenweber et al. (2009) and Guess (2006), have omitted to see the connection.

6.5.1 Contribution to academic and project management practice of CM optimisation to industry

The usage of CM as identified by key authors including Ali (2014), Kuttig et al. (2007) and Burgess et al. (2005), have independently highlighted the importance and value gained through using CM. However, unlike the findings of this study, these authors did not acknowledge that CM's value could differ between companies and / or projects in the aerospace industry. When investigating existing CM studies on measuring the value of CM, Staats (2009) and Guess (2006) provide an informative insight, but avoided acknowledging that invariably differences do occur between projects and organisations, therefore current CM models were unable to be applied holistically. This was confirmed through the interviews, which led to the development of this study contribution to CM. In developing this framework, this study identified that it was necessary to develop a weighting system. This weighting system as set out in Figure 5-1 in Chapter Five page 168, offers a two-level system, based on the application and meta level, which can be viewed both from a project management theoretical and also practitioner's perspective.

In the creation of the weighting system, the study (see Appendix 7.15 to 7.16), also provided a series of formulas developed to assist in the practical implementation of the concept. In creating the model and associated formulas the complexity and application was broken down. The complexities of these formulas are able to provide both a theoretical insight and practitioner's application into how this weighting system works. This strategy was reflective of the advice of Reisenweber et al. (2009) to provide a systematic approach through focusing on the weighting, together with Ali and Kidd (2012) contention of ensuring that costs are incorporated through the framework. By concentrating on the complexity of CM as a generalized concept including the need to include costs, this study was able to generate a usable and easily understandable framework to convince the management of a company of the usefulness of CM and to optimize the application of CM in different companies.

With the introduction of the new weightings, the measurement processes can now be easily adaptable to individual companies and projects. The weighting of individual measurements makes the framework able to be applied throughout the aerospace sector. In achieving this, this study also closes the research gap of the need for comparability between different companies and projects as identified by Staats (2009).

6.5.2 Contribution to academic and project management practice of CM optimisation in the aerospace industry

The key contribution for the aerospace sector is that CM can be effectively optimised throughout the entire supply chain. To achieve this, it is necessary for CM to be optimised to the correct degree. Through adopting this study weighted framework, the interlinkage of different projects and companies can work more effectively. The framework provides the means to assess whether a company is using CM correctly, and highlights areas where CM can be more optimised. The framework can also provide the means to permit the user to identify where there are deviations in CM application.

Most of the existing studies, including IPX (2018) and Staats (2009) from an academic perspective, have mainly focused on the measurement currently applied to CM. The exception has IPX methods of measurement, which proved

to be particularly effective in CM, as it does not only consider the application of the classic CM processes, but also includes the associated processes such as requirements management. However, there was a general weakness of the IPX (2018) measurement process, in that the individual measurement results are not weighted according to their importance for the individual company, instead it is based only on the degree of fulfilment in general.

Again, this is potential gap and weakness in the existing model, and the necessity for corresponding weighting to be introduced into the new model and associated formulas. The determination of the QDI provides the user of the framework with a concise and easy-to-understand value as a result. This has the advantage that there is something tangible for decision-makers in senior management that has been condensed to a single value. In addition to the monolithic value of the QDI, the details can be captured at any time by looking at the categories below and fanning them out. Graphical evaluations are also available for this purpose to improve clarity. One result of this work is, among other things, the final compilation of a target/actual comparison for the CM area. This makes it easy to see whether CM is being used to the right extent. This is a global, general statement. However, in the sense of a more detailed differentiation, it is also possible here to deal with the existing deficits in detail by comparing the individual IVs and measured values and drawing conclusions about the application of the CM.

6.6 Limitations of the study

As already set out throughout this Chapter, the application of the framework developed in this study has provided a new insight between the actual and target implementation of CM in the aerospace sector. However, the study cannot be seen as proving whether the model can be applied, as the sample size for evaluation and verification was only two experts. Being based in a qualitative paradigm, this study can confidently conclude that the findings are an indication of a potential insight into the creation and usage of this new model and associated formulas. To prove this model and associated formulas are reliable and validated could only be achieved through conducting a generalised quantitative study. This was however out of the scope of the research, as the central aim of the study was to create a framework to measure the benefits of CM as accurately as possible, therefore it was necessary to understand the

perceptions and experiences of CM through conducting semi-structured interviews. These semi-structured interviews have provided a new and rich insight into how CM is currently used while also highlighting potential gaps in the existing models and constructs, which could not have been identified through a quantitative study approach.

Although the study focused on only 13 participants, which came from three distinct professional backgrounds and was therefore a relatively small micro sample size, the richness of these individuals provided an invaluable insight. If a quantitative approach had been adopted, although the sample size would have been larger, the outcome would have proven an assumption or hypothesis, as opposed to generating new theory.

While the study generated a new framework for CM which includes a series of formulas, the process needed to take the additional step to prove or validate the outcome. Reflecting on the philosophical position of the study being from an interpretivist standpoint, an additional two interviews were organised to confirm the study's outcome and new theoretical outcome to practice. A potential limitation of this approach was that the two individuals cannot prove the concept, but the outcome is an indication as to the potential benefits. To prove the concept, a quantitative study would needed to be conducted, but in doing so the research paradigm would be shifted to mixed methods, thereby changing the philosophical position of the researcher of seeking a rich insight into the reality of using CM.

6.7 Areas for further research

While the study provides a critical and new insight into CM, there is still a need for future research to investigate the added value of the proposed framework. As acknowledged in the limitations of the study, recommendations would be that the study is both broadened to include other sectors and projects on their usage of the model and associated formulas. Recommendation would be to extend the research beyond the interpretivist study and to test and prove the new concepts and formulas in either a mixed method approach or using a quantitative perspective. A further extension of the study could be a comparative study of existing models and concepts together with this study's findings, and then plotted

against previous projects and subsequently applied to a series of different projects. This would include applying these constructs to different projects in terms of size, location, industry and business requirements.

6.8 Chapter Summary

This last section is a reflective and summarisation of the study and the findings. Firstly, the proposed newly developed framework has made it possible to use a single measurement method which can be used across location, supply chains and companies in the aerospace industry. At the same time, the single measurement framework provides an optimisation of CM, as to how a company can benefit from using its resources more effectively.

Secondly, it becomes possible to compare the benefits of the CM from project to project and company to company through the specific weightings. As indicated in the literature review, which was confirmed during the expert interviews, the existing framework while expected as industry standards showed a number of limitations which needed to be addressed, both theoretically and in practice.

Finally, the development of the study's framework can provide management with an efficient tool to individually optimise the benefits of CM in the respective company or project, thereby potentially saving costs and positioning the company strategically for future developments. This is particularly relevant in the context of Industry 4.0 and Internet of Things, where the framework offers a practical tool to master these dynamic requirements of the present and the near future.

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APPENDIX

7.1 Presentation of the participants of the interviews

Participant A is a CM consultant who works for a large CM consultant company. With his overview over different programs he was able to give very important information. Participant A has also worked for other industries, such as shipbuilding, and therefore knows exactly what the special characteristics and peculiarities of aviation are and through his work can give aviation-specific hints, which are important for the development of the framework. The company participant A works for is a consulting and services company headquartered in France, which works mainly for a large aircraft manufacturer, among others. Since this company develops customer-specific solutions along the entire process chain, Participant A has a good overall view. The company has a holistic approach and optimizes the product life cycle of complex products and processes, including PLM harmonization projects. The company also implements and improves PDM, optimizes CM processes and improves cooperation with manufacturers and suppliers. Since this company is active on a large scale as a consultant and optimizes the CM process in many companies or provides cross-company optimization, it can be assumed that experience in measuring the optimization results is also available and relevant for this study.

Participant B is a CM consultant who works for an IT consultant company which is specialised on CM. He has extreme deep CM knowledge and develops together with his clients the CM of the future. Besides CM this company is specialised to consult the CM related disciplines like digital transformation, PLM, smart manufacturing concepts, Industry 4.0 and Internet of Things.

Participant C is the head of Configuration Management at an highly specialised aircraft manufacturer which is focused on business aircrafts and military training aircrafts.

Participant D has worked for the German Aerospace Authorities and was responsible to audit the Configuration Management Systems in many Aerospace Companies all over the world. Therefore he should be able to give information about the official requirements for CM. Additionally as he has audited many companies around the world he knows the different levels of CM implementation in many companies in the aerospace area.

Participant E is Head of Configuration Management at a large aircraft manufacturer. He works from CM perspective in the most sophisticated aircraft programme of this manufacturer. This means he is able to give answers to the most recent practices and problems. As the aircraft participant E is responsible for, is the latest program at Airbus, Participant E answers will help to incorporate the latest innovations in CM into the work. For the development, construction and operation of these aircraft, state-of-the-art, future-oriented PLM software is used. The experiences and knowledge from the application of future-oriented technologies are incorporated into this study through the answers.

Participant F is an already retired Configuration Manger who worked for an aviation company. With his knowledge which he created the last decades especially about the measuring he could provide important information for this thesis

Participant G is the CM process responsible in an aviation company. He has very deep process knowledge and provides the trainings for all Configuration Managers of all locations of his company. Moreover he developed several company internal measurement systems to evaluate the efficiency of CM inside the company.

Participant H is a team leader configuration management at an aviation company. He has experience of reporting CM KPI to the Management and deep CM knowledge to support the maintenance of the aircrafts for the Swiss air force.

Participant I provides officially the CM2 trainings in Europe and certified many CM specialists of different companies with the CM2 certificate. As he works in addition as a consultant he has a large overview about the CM systems of many companies and should have ideas how an efficient measurement of CM implementation could be possible.

Participant J is Configuration Manager and responsible for the airworthiness of the aircraft type Do228. He is using a sophisticated PDM System to manage the CM of this aircraft. Additionally he shares his knowledge by speaking in technical conferences.

Participant K is responsible for the CM at a large space company. As Configuration Management is very important in the space industry it was expected to receive very useful information. Participant K is a speaker in international CM conferences and has knowledge in additional industry sectors.

Participant L is a former ESA astronaut and professor at the Ecole Polytechnique Federale de Lausanne. Participant L spent over 1000 hours in space including a spacewalk of more than 8 hours. The reason for choosing Participant L as an interviewee is the fact that CM is extremely important in space industry. He was totally dependent form the working technology. In addition, Participant L is an aerospace advisor to the Swiss government. Participant L has in particular scientific and special knowledge in the aerospace industry as well as general management skills. He has been consulted many times for his advice during the development of high complex international aerospace projects. Furthermore he is in several boards of important international technology organisations. Due to his decades of experience in the aerospace sector, where CM plays a prominent role, and his contact with the highest decision makers in business and politics, answers were expected for the measurement system to be developed, regarding future requirements for the framework. Since he is a worldwide known, proven specialist in the aerospace sector, it is particularly important that he could be won for this interview.

Participant M is the CEO of an international aerospace company. He is representing the senior management in the interviews. Because of his former work experience he has a deep knowledge about CM. It was important to interview him because he enriched the knowledge a lot from the perspective of the senior management. As this work is intended to provide management with a well-founded and generally valid basis for decision-making in the management of CM, the answers of such an experienced manager are particularly valuable.

7.2 Interviews with integrated analysis

Interviewer Manuel Maier (MM)

7.2.1 Interviewee A:

A: If we look at the suppliers of A350, they are risk sharing partners who also help develop the design, we can say that we have developed score cards for these different suppliers. These Score Cards are an example for this named supplier and classified from A to F. It starts with the so-called Physical Product Conformity. That corresponds to what the supplier really delivers to the end line what Airbus actually requested. In the best case this is of course great while he delivers exactly what we want, in time and quality and so on. If not, this is an indication that there is something wrong with CM. Of course, it is possible that a worker simply screwed up of course, but it is also possible that there is CM behind it, and then there is a status.

MM: If I may interrupt for a moment, how do you distinguish that? Is it filtered, whether it is CM or something else?

A: Unfortunately, there is nothing systematic about it. It is one of many approaches where we have examined how we can start, and this is not a consistent concept. In principle, we call people we happen to know, such as those working in the quality department of FAL, the end line. We ask what the situation is, are the galleys arriving acceptably or not? Then he tells us no, this week six of them should have arrived, five of them were damaged. What you could do of course, would be to say, for example, sit down with the boss of the Operational Support Team for Concessions and have a look at what root cause captures they have in their systems and if they can deliver any KPIs. If you say, for example, you're now getting a barrel from PAG, a segment, and because we need that and the configuration, then you go virtually automatically to the root cause stored in SAP, there we can identify which root causes are typically a configuration problem. A large number of concessions doesn't say anything about configuration, but you have to look for the root cause first. However, this is not systematically communicated to us. We really don't have a KPI in the real sense for something like this. It is always only a rough indication in different directions, in order to then investigate in which direction we can go on. That's what we suggested when we applied as the

Cimpa company for the Post Concession Mode. We had proposed to establish such cross-connections. It is concession analyses where you can see where CM is behind it. Another approach is to look at the number of supplier modifications and determine the number. How many doesn't say anything yet. Then try to evaluate, but when evaluating you are very quickly involved with the human component and feeling. It is difficult to say when it could be or may be a configuration problem. We have not yet been able to measure this rigorously. We had also used the Operational Methods Index once, where both sides were involved. On one side is feeling, which of course is very controversial if it works at all. If you have experience, it works a little bit. On the other hand, you try to process all KPIs that you can get in some form, evaluate them and then draw results from them, which are then reflected again in a scorecard. This is a points system. We also gave that up, because at some point it remained on the emotional level. Partly it is also a political issue, because some people do not necessarily like to be measured. It is a political matter if the data is then published.

MM: I've heard that statement before. When things become transparent, there is a lot of resistance, because it is simply not desired that the matter becomes transparent.

A: However, this is a CM problem in itself, not specifically the status accounting. As soon as you want to roll it out correctly in the company, you will come to these points in the individual departments. The better you manage to involve them, so that they change their attitude a bit and become a part of the whole, the better it works. This is very hard work to really convince at the human level. I believe that the companies that are doing well have managed to advance this some way.

MM: Actually, everyone benefits when the data is distributed. Engineering knows exactly which data is valid for engineering. If the data is consistent and is distributed through one system, everyone benefits. The interfaces that arise in the various systems are sources of error. Information does not flow beyond what the next stage would need. A great deal of work is

then done several times, because the data is lost, which then has to be procured again laboriously.

A: That's right. The will to have a unified tool landscape from Airbus, or shall we say to reduce the many tools, is there right now. With every action, in this case a new aircraft program, this is also done a small amount. It's also damn difficult, because things just simply run as a process. We had the interface newly connected. Actually, it is much easier to get to the interface then. Then I don't move any further because I want to become better, want better data flow and better server connection. So I do something new and have interfaces again. In the long run, these may be reduced if everyone follows the same path.

MM: The aim of my work is to develop a framework with performance indicators. I want to specialize on the aviation industry how to measure the benefits of CM there. For this, I initially have to have the Key Performance Indicators, as we mentioned earlier, for example the reduced rework. In your experience what are the most important KPIs?

A: What I just wanted to point out, we have just introduced these score cards for the important suppliers. As you can see, there are no most important KPIs in this sense. These are the things we're recording right now. Of course, these are not mathematical KPIs. There are of course Score Cards (A-F), behind which of course the individual information stands. These are the number of changes and the number of loops when changes need to be reopened. These are topics that appear again and again and have been discussed for years as to whether this can be systematically recorded and qualitatively evaluated. The question is, a loop is not the same as a loop. For example, if there was a typo correction, then of course it's something different than if the design was really nonsensical. That's what makes it so difficult to understand. That was exactly what we tried to do with the KPI. Initially, simply counted them and then one tried with a factor to make an evaluation. That was two levels interacting together. That simply makes it complicated. and once you start again from the top, from the conformity, you have of course first in the Aircraft

Inspection Report fixed work. There's the story with the concessions, supply modifications, late changes and so on. To measure the weighting, that is exactly the difficulty. You have the numbers. You already know how many open changes there are. Then you can compare with different MSNs (aircraft). The first 50 are difficult, then it gets better and better. There are fewer concessions, the curve goes down.

MM: This has to do with the ramp-up, with the experience curves basis behind them.

A: This means that certain things can serve as indicators, but it does not mean that there are clear indicators. As we had already discussed the topic with Interviewee E, I measure the number of Late Changes, for example. This can be, for example, an indication of quality problems in the design, or in CM. It can also point to a fickle customer. You know the company story of the airline boss's wife, who suddenly didn't like the carpet when the plane was handed over. It's the same with concessions with the distinction of whether I have a configuration problem, a design problem, or a manufacturing problem. Now, of course, you could go in and refine the concession process accordingly, and introduce a classification. This could mean for example Concession CM, Concession Design, or Concession Manufacturing. You could do that and I have the impression that the trend in companies is to do that. Interviewee E says he would like to measure the number of late changes, nonconformities on delivered CAs and such things, but these are wholly KPIs if they are not assessed. This evaluation is carried out using the human element of feeling. This can be used to determine how many percentage points were caused by the config. For example, this could be a maximum of 20 percent CM. Then we try to filter the root cause and work on it. That also works practically. Now to the topic measuring. One must take in addition to the concessions a second factor and include other facts. If one combines different things together, one might get a value. When it comes to late change, for example, the airlines have a factor from engineering that measures complexity with a kind of score number. The airlines often have very special wishes which they express very late. However, we have already

developed such a factor bit by bit. This is the key, I think, that you don't just have the naked numbers as a base and then try to compare other numbers. One could of course also look towards the future, that one might conduct big data analyses and not only find KPIs but associate KPIs with them. I have a non-conformity on a part plus a MOD that is still open in status and has an impact on the Constituent Item (CI) to which the part belongs. If I bring all this data together in big data and if I recognise any algorithms, I could extract much more accurate KPIs. However, that's a point we're not yet at.

MM: That's a future development opportunity that will present itself. But it's more quantitative if I link different key figures.

A: Describing quantity and quality.

MM: That's a point I haven't had yet but where the future lies, that the linking between the individual values is taken into account.

A: In principle, with soft factors and big data, you have completely different amounts of data that you can process. The question is whether we have enough data at all. For example, for A350 cabin we will not find the data together. It's already too little. If we do a manual evaluation, we have too little information, not enough number of changes that we can really evaluate. It is the question of how the data is gathered. Where is it delivered to? Speaking of the Suppliers, which contractual organizations do the Suppliers actually have with whom they have to deliver data? But I think that's really still a dream of the future. My impression is that you measure roughly. I'll just say the product quality that results, even in the intermediate steps, hence Delta Reports with Conformity Evaluation. One then tries to derive an individual analysis. If this was a configuration problem or another problem and then the KPI level below the process level is examined on the next level, One virtually introduces a process, configuration and change process or a non-conformity process in which then just is evaluated is the root cause of the non-conformity is evaluated. One has to report back, open a design query note, write a concession and

these are the processes themselves where one has arrived at a point in the company where one says, I now have a process that ultimately enables this human evaluation to be made. This manual evaluation has to be done in the configuration. First and foremost, I measure the quality of how well the process works in the first place, if you stick to it at all. At Conformity we had a project a while back, it was all about looking at what is the lead time of a concession and how to shorten it. What is the response rate of a concession, a non-conformity that I enter into a system. For example, I have a non-assemblable part or a scratch in a component etc. and then I introduce it into the process. This is then somehow investigated by some group. It is also possible that there is feedback information because the worker may not have written reasonably what he saw, thus it is not conclusive. For CM, it's clear how we're evaluating this now, i.e. the quality of the process I use to manually determine overall construction quality and configuration quality. First and foremost, it is attempted to gain a sense of control over the quality of the processes. CM Delivery Performances are the real CM deliverables, that can be the TRS concept, the Technical Changes Principle, which consists of change documents. Then there is the topic of Data Exchange, so how does data exchange work right now, when the development phase is about design data that is repeatedly pushed back and forth in new iterations. This is about the final part, which is to be produced in the meantime. With all the process tools and the organizations, is this actually going on? In the A350 area, we have reinvented the organisation over and over again during the development phase, new people have been hired and have been reorganised. In the supplier organizations too, the whole issue has been underestimated because the development effort is so great. Especially due to the high proportion of customisation. Are the processes from the process description really applied? They may have put nice descriptions in their files. However, one really follows these processes in the sense of quality and observes the so-called adherence. The last one is Corporation of Commitment, quite easily said, but how do we actually deal well with the Suppliers. Do I get it on the phone and call him, get an honest statement, or does he not answer and stalls me? There I think we have all gathered a lot of experience in all directions.

MM: That's a very qualitative point, and I like it very much because I haven't heard it before.

A: That's what we're writing here in this spider diagram and hopefully it's far outside, that is green and in the worst case it's red. Cooperation and Commitment that is partly a question of understanding, partly it is also a contractual question because it was not understood by listening to hearsay. Especially at the beginning there is a lot of discussion between Airbus and the Suppliers. They say it's not in my contract to do CM. That will have to be renegotiated first. I can remember the story about the manufacturer of slides who made a very simple window slide, and who was hard to educate about why he had to stay up to date. The supplier of a super simple product thought he could make ends meet without CM and didn't realise that he was classifying himself as a complex product. That is why the OEM, in this case Airbus, demanded a certain configuration standard. When people know about it and understand it, then you are at the point where it gets better. So this is related to the acceptance of CM.

MM: That there's an understanding.

A: Right, the funny thing is, people tend in their daily work not to count explicitly the things they do to fix some mistake. If someone now comes along and says you should use CM, they obtain a Delta report and says here and there is Outstanding Work that has to be prioritized. First of all, this is unwanted and undesirable interference. The Delta process, for example, was very unpopular, nobody wanted to know about it. There are always people coming up and saying Delta 1, open the design documents again and you have to do that and that's now a priority because the milestone is coming up. Nobody wanted to know. We have enough mods to choke on, and it takes time for that to stabilise. This has levelled off as people have understood that at some point they will get less complaints if they stick with it. If the Delta 1 Report can perhaps even be used to proactively take a large part out of what work we actually need to prioritise in order to generate as little disruption as possible in the industrial

process. They block at the beginning, because CM generally makes you more transparent.

MM: Yes, it is therefore essential to overcome this resistance, through information, so that everyone involved understands where he himself has a tremendous advantage through the application of CM.

A: Yes, every department, every group, every function is part of the whole, it's like clockwork, if you will. The clockwork works well when the individuals actually know where they are in the system. When you do that there are consequences. The more people open up to this and perhaps change departments once in a while, the better everything becomes.

MM: As I said, the goal is to create an evaluation framework, and I have thought about it this way, the deeper a company organization CM operates, the more complex the measurement has to be. If you think about it that way and use CM by default, as it was actually described in the Mil Standard with the most important functions, a quantitative measurement is enough. The more elaborately you use it, i.e. if you use it like CM2 or beyond, for example if you operate the industry 4.0 standard, the more complex the measurement becomes. It would also have to include qualitative aspects that go beyond the company and also include the customer. The idea is to create a comprehensive measurement process, possibly also with surveys that are carried out at customer and supplier premises and are linked to each other. This, I think, is also important so that the matter is not person-dependent, as you said earlier, but that data is generated on a scientific basis that is useful. How would you go about doing that?

A: First of all we would have to define more precisely what the individual people understand by quality. Quality in CM or quality of the product, what is the connection. How do you asses this connection?

MM: That the relationship is between CM and the customer. Therefore CM of the production company and its customers arrive at a common denominator.

A: You say how does the fact that you use CM affect customer satisfaction? That is the focus, customer satisfaction.

MM: As I said, if the customer doesn't receive the product in this state, because that is the main task of CM, that the customer gets the product in the state he wanted it to be. However, one also must differentiate the customer satisfaction again, because there are very many influencing factors which have nothing to do with the CM.

A: Yeah, but it depends: Customer satisfaction, as Interviewee E already said, we have different customers here. We have the customer, the end customer, the operator, the airline, we have the authorities; they are also a kind of customer. Or one has a strong connection, as we use CM also to satisfy the authorities to remain approved. That is a very important factor here at Airbus. Ultimately, the controlling department is also a customer, who demands customer satisfaction while maintaining the company's economic performance. CM also contributes to this.
If we only had customer satisfaction in mind here, we would be performing a rather difficult and complex CM and would not have to keep internal costs under control. In principle one could put a configuration manager behind every worker, who pays attention to what the worker does. At the end of the day, the customer is satisfied and controlling would say that we still have six months to live. As a result, there is a conflict between government requirements and customer requirements on the one hand and profitability on the other. Ultimately, CM has to somehow organize something.

MM: That's an optimization problem, so to speak.

A: That's right, that's an optimization problem. There is even a perception within Airbus that the quality that Airbus delivers is too high because

customer complaints are relatively low compared to the competition. Some say we could make more profit if we delivered less quality, if we did less internally to maintain the high quality. Many years ago, when Mercedes fell behind Japanese luxury brands for a while, I can remember the statement in the press by the CEO of Mercedes. He said that at Mercedes you have to teach the engineers that sometimes the second-best technical solution is the best one for the customer and for the company. Well, five years later Mercedes had a massive quality problem and had to get out of this situation again. Clearly someone had overdriven the profitability and one had to get out of this situation again. However quality distinguishes Mercedes. Worldwide Mercedes stands for solid and long durability cars. Yes, Airbus also measures customer satisfaction. Ultimately, you have to measure all three dimensions in order to achieve a good tax ratio. Customer satisfaction ultimately affects customer support, which effects customer surveys. And the customers also have local representatives. It is not the case that the customer simply selects the aircraft from Airbus, then gets it delivered to Dubai and then has to live with it. They also make their own inspections.

MM: But right now it is actually very interesting here at Airbus, because the customer benefits directly from CM. He receives the data for the entire product lifecycle management, which is then of interest to him, for operation, maintenance and so on. That is not the case with many products, that it goes so deep, now, particularly in the field of aircraft, it is very interesting because the customer again directly benefits from the data. When there is a service bulletin, as we discussed above about spare parts, you know that the customer knows what he is able to reorder, what has been installed, or what still needs to be done. It's very consistent, the whole subject.

A: The customer has two ambitions. On the one hand he wants to have delivered a super quality and that speaks for CM, the customers know that too. On the other hand, he has the ambition in operation and in maintenance to be as simple as possible.

There are points in CM such as the interchangeability rules and so on that we have talked about. These can also be an obstacle to its own economic success. Yes, quality is a point that is firmly established. Thus every customer will expect the perfect quality of the aircraft and its maintainability. The customer wants performance during operation and maintenance. That's another point that says CM, but it has to be effective. However, it must not only be effective, but also efficient. If you build the configuration too complex, one sometimes comes to the point where the customers no longer feel comfortable. They demand something simpler without anyone knowing how to make it simpler. Yes, in any case CM is required to question itself again and again and to optimize itself.

MM: Then how does it work with the interaction with the customer? You have to use the feedback you get from the customer to improve yourself.

A: At Airbus, the customer is the airline, e.g. Lufthansa. The customer is already present on site during the construction phase and he already discusses everything that is needed. At the final acceptance, he goes through everything again in detail and also receives the complete aircraft documentation as well as the inspection reports. He can see which MODs have been installed, that's what he asked for. What nonconformities have occurred, what concessions exist, and what important construction deviations remain. That's an important subject for him. The people here at Airbus say that every concession is counterbalanced with a suitcase full of money on the pilot's seat. The airline is paid for every concession. They consciously look for mistakes. There are also airlines that are short of cash. They look even more deliberately for mistakes to save money. That means the feedback is very direct. At the time of delivery, you are told that this and that are your mistakes, this and that you have to rework. Thirdly, for this and that we want to have discount. This is how they measure and express quality.

MM: That's very good, because that's a direct feedback and the customer is very interested in giving feedback, as it also delivers him a direct benefit.

A: Yes, of course. And the next level is that regular feedback comes to the company from Customer Support. I'm not into the details, I don't know exactly how they do it, but they track aircraft reliability. They also track downtimes, i.e. periods when the aircraft cannot be used because something has to be exchanged, or something has to be repaired and replaced. All these things are tracked and are included somewhere in the top quality rating. I've had a client ask questions before like: How do customers rate the cooperation with Airbus, how well do they feel involved in the configuration process? Thus, the part of the configuration process that directly affects the customer, is essentially the change process, the customisation process and for all that there are surveys. This is a large number of KPIs that report status. One can't say there is a KPI where you can now say that CM was good or bad.

MM: Yes, in principle you agree with me there, with the idea that I have had so far that one simply says that the more extensively one uses CM, which is quite vast at Airbus, the more complex the measuring or the measuring method becomes.

A: Yes, it depends on many complexity factors. Firstly, it depends on what I want to achieve with my CM. Do I only want customer satisfaction, or the ability to deliver different characteristics of a product at a glance. Or do I also have government requirements that I must meet and do I also want to control my profitability via CM. I want to use CM through the traceability of my product data to understand whether I'm really on my target path, when I check my costs and my sales targets, etc. I want to be able to use CM to check whether I am really on my target path. What do I want to do with it? Duality, I think it already exists. The more complex the analysis, the more difficult it is. The product complexity is added. If I now configure red and green matchsticks, that's something different than if I configure an A380. The complexity of the supply chain is added, so as Heiko said, if everything could be done in one plant, from start to finish, it would be easier to do CM than if I had to involve Riskshare partners.

MM: And what is also highly interesting is what you have said, the way the CM is viewed, or how it is implemented, that is a very strong guiding component. Of course, this also has a huge influence on the measurement method.

A: It is always said that the main components of CM are product identification, change management, configuration status accounting and configuration audit. I'll say that 90% of companies I've encountered during my consulting life don't get beyond change management. That's the first thing people do. They perform a change process. Fine, then they have a basis. There are some database entries that say ideally, I made a change at a certain time that includes certain adjustments. That shall be recorded in writing. For example, Bernd Müller as Change Coordinator or whatever you want to call the role, has decided. That's it, then. In fact, it should always be done this way, even if it's really a small change, as the matchstick example shows. Then it's very simple. The more complicated the part or product that the suppliers we support become, the more they have to move towards full CM. The dependence is there absolutely. For those who deliver a very simple product ("Built to Print", we design the finished product), this is reduced to a few important points.

MM: It is also very important, I think, that in such a complex supply chain everyone works according to one standard and is oriented towards the customer, for example as with CM2. The interfaces must be clearly defined and the data flow to suppliers is also essential. For example, there is a change, then the question is how do I notify the supplier of the change. In the end, everyone benefits again when the systems are compatible.

A: That's where the economy comes in. Airbus, for example, does exactly that with the A350, they impose the Airbus configuration rules relatively forcefully on the supplier. That's why there are auditors who go and look, the supplier does everything as Airbus dictates. Meanwhile Airbus is also at the point where they say it's all very nice now how people are so much involved in the process. However, we must also introduce tools that they

would not naturally have as the company PAG or Honeywell or whoever. They have to learn how Airbus does it. They have to learn the language, learn the procedures and so on and so forth and thus the cost of entry becomes relatively high. They have to invest relatively heavily to be able to work with Airbus at all. That's another Sanding Storm, where Airbus says that if we're looking for an alternative to a cabin supplier that doesn't perform, and we want to take another one on board now, it's not easy to find one because everyone's shy of investing millions.

MM: However, the action backfires because you are then dependent on a few suppliers, which can drive up costs enormously.

A: This does create problems for the A350. It has been specially split up on the A350, because you suddenly had this principle, but nevertheless or just because of it you still had this interface. Suppliers have their own tools and we have our own tools. Partly we say they should use our tools, if they don't, then there is an interface. The difference is when one does not have an interface involving a complex product, when one works with such partners, one only has suppliers of parts manufactured on an extended workbench. It's a lot easier this way. It also depends on market power. Airbus has relatively large market power with the relevant suppliers and can assert itself. If one takes the engine manufacturer, it is different, because the engines are usually provided by the operator. The engine manufacturers are operating at very high production rates. Train manufacturers e.g. the Bombardier, Siemens and so on, they have in terms of purchasing volume no such a market position that they could impose their environment on the Suppliers. They can't manage this contractually because it is expensive for the suppliers and they would have to learn a new configuration system. The suppliers also have their own tools if the Airbus business only accounts for a small percentage of business. If we now take Panasonic or Thales, Airbus is of course only a small part of business. Therefore, these companies also have their own complete company tools and of course have exactly the same problem within the company. It's all about where you have the interfaces. At Airbus we get the parts and what happened in the supplier's system is a black

box. A supplier, on the other hand, who supplies elementary things such as fuselage shells or barrels, such as PAG for example, begins to integrate. What exactly does RUAG do? All I know is that RUAG joins sections together, for example Section 19, I think.

MM: Whereas Section 19 is being built in Augsburg by PAG. RUAG build the Section 18 ourselves. The shells for this are supplied by Airbus Spain or the subcontractor TAI from Turkey

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A: For Single Aisle?

MM: Yes, for Single Aisle, and RUAG also delivers the Section15 Main Landing Gear Bay (MLGB). The side shells and the pressure bulkhead which form the enclosure of the Landing Gear Bay.

A: The Pressure Bulkhead?

MM: RUAG also builds the rear bulkhead , as already said, the bulkhead belongs to the landing gear bay. Also side shells in the upper Section 15 where the emergency exits are. RUAG build all this for the Single Aisle. For the Long Range RUAG has the A330 Section 14A . This is the section that represents the lengthening between A330-200 and A330-300. RUAG is for all these sections of CA manufacturer.

A: For CM of the Single Aisle, they certainly also have CM plans where they have the interface with Airbus.

MM: Right, but so far RUAG has primarily used Airbus systems. RUAG gets the configuration from the TAKSY. This is part of history because Dornier designed the sections. It would make sense internally and RUAG is currently preparing the data for its industrial engineering in such a way that they have a better overview and know exactly what needs to be included in individual machines for their work plans. Of course, creating an own PDM system would be a huge advantage for RUAG.

A: Not yet current but you want to install it?

MM: Right, yeah. RUAG is on it right now. We are also producing the Aft Fuselage for the Bombardier CRJ and we have already implemented it. RUAG took over this program (work package) from MHI Mitsubishi Heavy Industries in 2008. We have built a product structure from the ground up in our own PDM system and manage it.

A: Interesting, which means they'll try to roll it out on Single Aisle as well. Would they then still use the interfaces with TAKSY or would they break away from them?

MM: No, that would continue to be done via the TAKSY, because the design responsibility for some sections that we build lies with Airbus and therefore the default system is still TAKSY.

A: What PDM system do you have?

MM: We have the SAP based ProNovia and for Airbus we are trying to set up our own system.

A: That's what we do. At PAG we have our own tool PM Light and the Team Centre at Diehl Cabin. With regard to the comprehensive qualitative measurement method, it is not an easy task to do something like this. Ultimately, CM helps to ensure that the relevant high-level parameters such as time and quality are right for such complex products and supply chains. But there's a lot to it, not just CM. You have to go one level deeper to determine criteria such as the goals of CM, the fulfilment of which contributes to the overall quality of the product and the overall quality of the delivery. There are still deltas to be covered, across the supply chain and defined configuration milestones. How well I'm doing with my CM is something I can almost always see through the supply chain or the process chain.

MM: That the model is no longer only seen within the company, but that it is spread across the entire supply chain, with the deltas and the delta measurements then being practically made cross-company.

A: Throughout the entire supply chain, the internal process chain, one would have to collect the densities of all configuration stakeholders when evaluating CM. Customers or authorities or whoever the approval authority is. After all, controlling is a quality factor, how economically do I deliver? That's what I already said, overlapping. If I now look at the example of the scorecard with a supplier, that is an attempt to capture and display all these areas. Where we have KPIs, i.e. hard data, you take those and where you have soft factors, you take those. You're trying to optimize a part, that's one direction. One has a supplier and an aircraft program. Now take for the program several suppliers and fabricate together the Aft Fuselage. You do the same for the cabin and for the systems and then you have the A350. Once again if I think further for Airbus it would be the whole programs and then again development. Where are we on the A380? Will that get any better with all the tools we rolled out there? That's exactly what I'm thinking.

MM: Yes, but they do that for one supplier, but this delta measurement across the entire supply chain is not yet done. That would actually be an interesting step.

A: There are different deltas depending on the type. It starts at the very beginning with the requirement and ends with the delivery. This is really considered across the board, per aircraft program, i.e. per Single Aisle or A350.

MM: Very importantly, as has already been mentioned, one has to involve the individual stakeholders, such as the authorities. It is not only one individual who benefits from CM or wants to see the benefit or the result, but also various stakeholders. Both on the one hand and on the other, such as customer and supplier sides, as already mentioned, everything is linked with the help of Big Data.

A: Within each company, the emphasis on CM is very different, especially when it comes to the value of the CM. There is the strongly controlling component, also because one has the authority and documentation

requirements. I used to spend some time at Meyer Werft and they have a completely different product. One thinks of a product that is complex in terms of configuration, one builds it in series and configures it in series. Meyer Werft has a repetition rate of 1.3 for its products. It's rare that they ever build a sister ship. Usually these are always individually configured items, and they can design again and again from scratch. They do very little reuse in shell construction and interior finishing, because they plan individually and are architecturally designed so that it is simply not worth doing. What they do however, is change management and that is to the point, because they have fixed-price contracts with their customers then tighten the specification and say, I am now delivering the ship. If the customer still has change requests, then he must pay extra for these. First of all, it is important for the customer how much this change will cost him, and for the shipyard it is incredibly important to understand the change effects. When we talk about configuration changes here, we are talking about heavy steel construction and welding work.

MM: Then the supply baseline has an immense value. If this is closed, the costs for changes can be passed on to the customer. Thus it is very important to determine what is the subject of the offer.

A: That's right, and I can give you an example. When they were building the first ship for Disney, the customer came and said: "The casino has wood panelling, we have changed our mind and want it to have a video wall. "It was a huge video wall made up of many modules and Disney movies were supposed to be shown there, trailers and so on. A really great idea and we said that we planned not to install wood panelling but television sets and electrical wiring. What we didn't consider was that televisions generate heat and a lot of it when there are many televisions suspended on the wall. They realised this relatively late but just in time, otherwise it could have cost millions. It now became necessary to enlarge the cross-section of the air-conditioning ducts and to increase the efficiency of the air-conditioning units. The enlargement of the air-conditioning ducts resulted in a lowering of the cabin ceiling and so on and so forth. It would

have cost millions if they hadn't noticed. Had they offered this change at a fixed price they would have had to bear the additional costs themselves.

MM: It is therefore important to have an overview of the repercussions..

A: Yeah, and that was important to them. Configurable product structure, validity control does not interest them, even status accounting is not so important for them. Of course, they compile their construction documents, but what matters to them is change management.

MM: Then you can generally say that a common concept of how to measure does not work, so one must look at each company individually. One also has to look at the surroundings of the company, then very very importantly how does the company perform CM, what are the customers and then the production rate what you already mentioned.

A: What are the initial requirements and what can be achieved with CM? Meyer Werft could also introduce a configurable product structure, but that wouldn't do them any good, because they always build only one (as we say) MSN.

MM: It's worthless to them. For Airbus, on the other hand, this is one of the most important things. The measuring system must therefore be individual to the company, tailored to the company, the product.

A: Other companies could do much more, as I just told you during our little tour. Companies such as Siemens Mobility or Bombardier could certainly tolerate a configurable product structure, but as a rule they do not. There are individual areas in which it is done, they have recognised that it is important. Others don't do it, they simply copy from project to project, then have to rebuild the whole train and that's not efficient and has a lot of problems. For example, they have 60% expenditure only for colour changes. It is partly the understanding simply not there. For example, Siemens Highspeed Trains which have many ICE platforms, which sell the ICE as a platform, also talk about platforms, this is only a marketing tool for them, there is technically nothing behind it. Only the marketing

department has thought about this - it's chic for the customer when he buys a proven platform. However, the platform is always newly developed for each individual train. It's not just that the colours are different. The ICE can have a railcar concept, the ICE can have an underfloor concept, the ICE can have air-conditioning under the floor or the ICE can have it on the roof. That there isn't yet a diesel version of the ICE is all there is to it. Only these are not variants in the sense of our CM, these are real individual products. A slightly cynical employee at Siemens told me that the only thing the ICE has in common is the front mask.
So he looks like an ICE. Nobody cares what happens behind it. This is owed to the business that the customer demands a fully individual product. So they count on doing configuration management, but it also causes them a lot of problems to deliver. You're incapable of comprehending. Bombardier, for example, had 30 trains on the siding in Berlin because they could not deliver. Why couldn't they deliver? Because they took a five year old project and said when they ordered the new one, we'll just copy the five year old project with all the stuff on it, like data and tinker with it. What they didn't notice was that the approval standards had changed in the meantime and built a design that wasn't even eligible for approval anymore. This is how it can work if you don't do configuration management. It's impossible to quantify the costs.

MM: There is one point that we have not addressed yet, and that is the topic of Management Perspective. What about Airbus, how is CM anchored in senior management? What support does CM have in the management here at Airbus? This is an important point because management can use the measurement data to further develop the CM and lead it in the right direction. How's that going?

A: This has improved a lot in recent years. It was a fight, but when mistakes were made, it was realised that they could have been prevented by CM. Well, I'd say it's very good but not optimal yet. CM has a very strong controlling component, what is seen. It comes however again and again to situations that CM prevents something which one would like to do actually. The CM ensures that the processes are strictly adhered to. The benefit of

the CM is then again considered for each individual case. One has to ask oneself, what are the consequences if I don't control my configuration properly? I would say that in the vast majority of cases, if you look at the whole chain, you somehow come to the conclusion what the possible effects can be in operation, if, for example, a holder has to be inspected regularly, that it is better to control it cleanly.

MM: Just that one sees this whole picture, and only the OEM, in this case Airbus, actually sees that. From our side, it is often difficult to make such statements, because we no longer know what our customer is actually doing with the product. We're missing the whole picture.

A: As in this example in which he says well we could have withdrawn this thing still, the wrongly controlled MOD, but Pfalz Flugzeugwerke has already started. They say you're crazy to back down now. Here we are again on the conference topic transparency and under certain circumstances also where we are at the moment on KPI level, how to measure the whole thing. If I can measure it, I can show it. Then I can play the chain. If you play it through, you understand that, and the whole thing optimizes itself and it is easier to explain etc. etc...

MM: So the best thing about simple examples that had a big impact was to explain that, because you pick up people and you promote understanding very strongly.

A: If communication is better in CM, acceptance is also better. It's all linear. So you had to communicate relatively much in the area, because that is also one of the basic characteristics that says ever just CM allows communicating the other disciplines with the help of tools from requirements, change processes, etc.. The simpler cases in which you don't have to quantify at all and have to deliver any business cases. So there has been an accident and 50 people have died and you notice that this was due to a faulty component and nobody asks for the price anymore and then it is actually already too late. But even so cases where we have introduced delta costing with the help of several systems, which

was a tinkering work to temporarily remedy the lack in data management. That cost a lot of money and then at some point the question was asked by the management, why are you doing this? The explanation was, if we can't do that, you can't certify your A380, which was just about to go into production, that you won't get it from the yard and it'll stand here. Nobody will ask for the price anymore. And, of course, there are also regulations that have been tightened up. With the A380 the EASA wanted to know for the first time at different times, where you actually stand. The requirements are getting stronger and this is a good thing because complex problems can be solved faster. The question is always, what do I want to achieve with my CM? This must be incorporated into the measuring system. In CM, there is a tension between different stakeholders. The complexity depends very much on the type of product. For example, the difference between Airbus and Meyer Werft.

MM: Thank you for the interesting information and that you have taken so much time.

Analysis:

Excerpts to Degree of individualization of CM:

[1] What I just wanted to point out, we have just introduced these score cards for the important suppliers. As you can see, there are no most important KPIs in this sense.

[2] If there was a typo correction, then of course it's something different than if the design was really nonsensical.

[3]To measure the weighting, that is exactly the difficulty. You have the numbers. You already know how many open changes there are. Then you can compare with different MSNs (aircraft). The first 50 are difficult, then it gets better and better. There are fewer concessions, the curve goes down.

[4] This can be used to determine how many percentage points were caused by the config. For example, this could be a maximum of 20 percent CM.

[5] Especially at the beginning there is a lot of discussion between Airbus and the Suppliers. They say it's not in my contract to do CM. That will have to be renegotiated first. I can remember the story about the manufacturer of slides who

made a very simple window slide, and who was hard to educate about why he had to stay up to date. The supplier of a super simple product thought he could make ends meet without CM and didn't realise that he was classifying himself as a complex product. That is why the OEM, in this case Airbus, demanded a certain configuration standard.

[6] Some say we could make more profit if we delivered less quality, if we did less internally to maintain the high quality.

[7] Thus, the part of the configuration process that directly affects the customer, is essentially the change process, the customisation process and for all that there are surveys. This is a large number of KPIs that report status. One can't say there is a KPI where you can now say that CM was good or bad.

[8] The more complicated the part or product that the suppliers we support become, the more they have to move towards full CM. The dependence is there absolutely. For those who deliver a very simple product ("Built to Print", we design the finished product), this is reduced to a few important points.

[9] They do very little reuse in shell construction and interior finishing, because they plan individually and are architecturally designed so that it is simply not worth doing. What they do however, is change management and that is to the point, because they have fixed-price contracts with their customers then tighten the specification and say, I am now delivering the ship. If the customer still has change requests, then he must pay extra for these.

Paraphrase:

[1’] A score card system is introduced, but there are no most important KPIs.

[2’] The importance of corrections is very different.

[3’] The problem of an exact measuring is the weighting.

[4’] The problem is to find out how many of the problems are created by the configuration department.

[5’] There are many different products in the supply chain, but a certain standard has to be established to meet the Airbus needs.

[6’] The quality have direct influence on the costs.

[7’] The configuration process that directly affects the customer, is essentially the change process and the customisation process. There are different KPIs, but no KPI can evaluate the configuration process sufficiently.

[8'] The more complicated the part or product that the suppliers we support become, the more they have to move towards full CM
[9'] For different products the individual CM areas are of different important.

Reduction and Summarisation:
CM is differently important for different products. There are no KPIs to measure the CM sufficiently in general. The challenge lies in introducing a weighting.

Conclusions:
There are different KPIs, but no KPI can evaluate the configuration process sufficiently and therefore the introduction of a weighting is necessary.

Excerpts to Complexity

[1] Then try to evaluate, but when evaluating you are very quickly involved with the human component and feeling. It is difficult to say when it could be or may be a configuration problem.
[2] The will to have a unified tool landscape from Airbus, or shall we say to reduce the many tools.
[3] In the supplier organizations too, the whole issue has been underestimated because the development effort is so great. Especially due to the high proportion of customisation.
[4] The complexity of the supply chain is added, so as Heiko said, if everything could be done in one plant, from start to finish, it would be easier to do CM than if I had to involve risk share partners.
[5] We have the customer, the end customer, the operator, the airline, we have the authorities; they are also a kind of customer. Or one has a strong connection, as we use CM also to satisfy the authorities to remain approved.

Paraphrase:
[1'] The complexity of the evaluation is the human component and feeling.
[2'] A multitude of systems with interfaces make a system complex.
[3'] Customisation leads to a high complexity.
[4'] A complex supply chain leads to a high complexity

[5'] There are a lot of different stakeholders like suppliers, customers, operators and authorities. CM manages the complexity between the stakeholders.

Reduction and Summarisation:
Complexities like, customisation, complex supply chains, a multitude of systems and interfaces, the human component and a lot of different stakeholders in the aerospace industry make the use of CM indispensable.

Conclusions:
The complexities in aerospace business have to be managed with sophisticated CM systems.

Excerpts to Potential

[1] The customer has two ambitions. On the one hand he wants to have delivered a super quality and that speaks for CM, the customers know that too. On the other hand, he has the ambition in operation and in maintenance to be as simple as possible.
[2] Yes, it depends on many complexity factors. Firstly, it depends on what I want to achieve with my CM. Do I only want customer satisfaction, or the ability to deliver different characteristics of a product at a glance. Or do I also have government requirements that I must meet and do I also want to control my profitability via CM. I want to use CM through the traceability of my product data to understand whether I'm really on my target path, when I check my costs and my sales targets, etc. I want to be able to use CM to check whether I am really on my target path.

Paraphrase:
[1'] CM allows a high quality as well as a simple operation and maintenance.
[2'] The use of CM has the potential to manage a high variety of different business functions.
Reduction and Summarisation:
The use of CM has the potential to manage a high variety of different business functions for different demands.

Conclusions:

By using CM, new business potentials can be developed.

7.2.2 Interviewee B:

MM: Many thanks, Interviewee B, for allowing me to interview you as part of my doctoral thesis on the topic: "How do I measure the benefits of CM? The goal is to create a framework which is the result of the work. You work in the field of CM and have a very sound knowledge in this area, especially as you work with many different customers. I wanted to ask you how you would measure CM and where the problems are and how you could solve them.

B: Yes, very good. Now maybe basically. We really understand CM to manage the most diverse configurations from the beginning of a product's lifecycle to the final sales out That means, we really start with system engineering, with requirements management we have the so-called development configuration, so we manage everything in a big note structure, which is created in system engineering. In aviation, for example, the ICAO structure is organized in chapters; in the rail sector, there are ISO standards, where there is a functional structure for trains. We have made projects in the field of ships and submarines, where there are also structures. In tank construction it is the so-called Gatel structure, i.e. also a standardized functional structure. This means that very many companies have functional structures from within their industries where they can structure the systems. Then, on the other hand, we have the so-called work-breakdown structure in addition to the development configuration. This means that we not only manage a functional structure of the systems, but also all activities that arise in this development in this system engineering. This starts with the topic Requirements, Requirements structures, then of course to draw any baselines, then the baselines I would like to prove that I fulfil the requirements, about analysis and testing. These requirements are then broken down and linked to these functional structures. This gives me a requirement specification for the function which must then be fulfilled by engineering. At the same time, I know that if I get a design from engineering, how can I analyse it or if I

even need it, how can I test it. In aviation, for example, with component tests, system tests, ground tests, flight tests. And then we have all the To-Be configurations. The most important is certainly the Technical To-Be Configuration, which comes from engineering and typically ends in a type design in aviation. Then comes actually the Process Engineering, which is defined as To-Be Configuration, how do I want to implement this design. This has something to do with internal procurement, external procurement, quality management etc. and then part of the design were the manuals, i.e. we also have the To-Be-Processes, how would I like to conduct Emerald processes in the future, based on the manuals. Then we often have the Configured Configuration when it comes to order fulfilment. Many products are configurable, i.e. I have a customer order where I see what the customer actually wants. “As Should Be”, “As Planned” or “As Configured”, there are different terms. And then, of course, comes the “As Built”, which comes out of the supply chain, which is the generated hardware configured as to-be and then as-maintained with the lifecycle across the entire Operating and Maintenance. Why is CM so important now? We maintain that we can only measure the progress of processes if we apply CM, if we have configurations that we can report, while that is the only truth. When I hold a meeting on Monday mornings, where I am in the project, where are we in the process, everybody can do something but that's not entirely clear. The only thing that is clear is what I can really report and substantiate in structures, with all associative data, documents, article masters, structures, and everything that depends on them. What I can't report in associative systems is hearsay, is difficult, what lies around in file systems, etc. This means that from our point of view, process control is also the be-all and end-all of CM. A second point: I am basically not interested in processes. That’s a bit black and white, because processes are expensive and prone to errors. You need people for that. People want a chair, an office, they even want a salary and… and … and.... Actually, I'm only interested in configurations. Why? Configurations are results. Maybe a little sloppily said. When you build a house, all you get is trouble. Having a house or not building house is good. Having a house, the end is good. As an entrepreneur, I'm only interested in the result, so I'm interested in type design. The path to a type design, i.e. the

process, should be as short as possible. I'm just interested in the results. How do I get from one configuration to the next? I'm interested in an ‘As Built’. Why? From an ‘As Built’ I can write an invoice, I can deliver something. That means I'm interested in the shortest way from ‘As Configured’ to ‘As Built’. That is, I build processes by saying what configuration I need and what is the shortest possible way to create a configuration and not vice versa. I look at how I can create a nice process and if a configuration should fail it's also nice. With us, it's the other way around. So these two things may show how important configurations are for us. Then of course what plays into our hands at the moment is the whole topic Industry 4.0, Internet of Things is not possible without CM. If we take customers, companies that sell products today and their customers use these products, there is a huge change in progress. For example, medical technology: Roche Diagnostic, which builds blood diagnostic machines, is increasingly in distress because customers say that these large laboratories worldwide say we no longer want the machine, because we live from diagnosis. We want to perform so many thousand diagnoses a day. This means that Roche remains the owner of these machines and the customer simply charges Roche, or Roche charges the customer for the performance of the machine. Let's take Pilatus. It's relatively new, and for me it's amazing that for example the Kuwait Air Force didn't buy their training aircraft anymore. They say we don't need training aircraft, we need flight performance and availability. That is, Pilatus had to offer you the entire operation, the total maintenance expenses and so on. Only now, of course, the problem is that I now need a lot of information about these flight diagnostic systems of these aircraft, because if the maintenance I have calculated is not correct, because the customer uses the aircraft incorrectly because, for example, the Kuwaiti army flies outside the flight envelope. Or because in Nairobi in a laboratory the power supply does not work properly. Then I have a problem because I have too high maintenance costs and I have to prove to the customer that he caused the problem. This means that we now need to know much more about the “As Built” configuration. We now suddenly need to know exactly which sensor is installed exactly where, what does it do exactly and when it reports data i.e., the pressure to

manage configurations in the context of industry 4.0 and Internet of Things will be much much bigger. We are currently doing many projects in this direction because the business models are simply turning around. The topic of CM is therefore becoming increasingly important, not only because regulations are becoming increasingly stringent, but also because business models are turning around. There are well-known examples such as Kaeser, which no longer sells its compressors, but simply sells compressed air in cubic meters to companies. The Kaeser compressors are serviced by Kaeser employees and of course when a compressor reports something back to Kaeser, I have to know exactly which configuration is on site, what happened, when the last time a field service employee was on site, and what he did. CM is really increasing in importance. It's independent of KPIs, it's clearly so.

MM: The thing is, I see CM as a management process in my work.

B: Yes

MM: Not only that, how should I say, the product controls, but actually like the CM2 says, the CM controls the whole company.

B: Absolutely.

MM: It provides an overview like the product that one can use for the whole company.

B: That's absolutely true. And there are actually a lot of different areas. One is that my company is developing in exactly the same way. So it is really the case that we are now trying to implement a so-called Enterprise Development Manager at the companies, which is actually based exactly on a Development Configuration, which Requirement actually says, where the company is heading. We have very similar processes there. When we implement a new business process in a company, we have exactly the same configurations. We also define the requirements of a business process and try to live it analogously. When we do IT projects in a

company, we try to control them using analogue CM principles. That's absolutely correct. But you also have to say that these thoughts are relatively new when we present them in the company, and people find it difficult to do so, because in contrast to the products, where we have a certain history on the subject of CM and also because of these new tendencies we have a certain pressure to create something, there is quickly the thought, yes, that is now a bit overpowered. And it takes a lot of persuasion to use these thoughts generically in all areas of the company. It's not that easy.

MM: There is simply a lack of understanding in all departments, because you simply don't know the background and don't see the big picture.

B: That is one point and the other point is the management would have to live by it. This means that it is sometimes easier to order and enforce something in the organisation rather than to act as a manager yourself. Well, we feel that too. Much will then become more transparent, more controllable and that is not in demand everywhere, also at management level. That's a problem.

MM: That is a problem, the overview which one receives is not desired from all sides.

B: Yes, I think so.

MM: My next question is about measurability and KPIs. It's been found out that it is very difficult to measure the benefit. How would you proceed specifically?

B: Yes, so we typically have a defined procedure when we now reach a customer's project or discuss the problems with the customer. Perhaps the first question is why is a customer interested in CM? The problem can be, he wants to operate in a new market and there are regulations present. Another problem is we have customers who say we are being blown away in Europe with our cost structures by Asia and Latin American

competition. We can only survive if we become premium in our field and this of course includes certain benefits etc. Others say we need to change our processes to batch size one. Others say we need to evolve in Industry 4.0 and so on. So there are several reasons why we are investing in Product Lifecycle Management and CM. When the customers come then we always say, but the bottom line is we are in an integrative environment we need to understand a little bit more how you are positioned. And then we usually create a PLM Big Picture.

What does that mean? So we really go on, we stay with a product from requirement to phase out, go through these configurations and try to analyse what the customer is already using in these configurations, what he needs, what he doesn't need. For example, when I'm on the road in medical technology and produce hip joints, I never need an as maintained configuration because I don't do maintenance. I just need an 'As Built', I need to prove what I delivered to a hospital, but I don't do maintenance. That doesn't mean every industry needs the same thing. Once this has been defined, we define which IT systems are in use for these configurations. What have you got? What do you do with Requirements Management? What do you do for safety analysis? Logistic Support Analyses? ILS Integrated Logistics Support? What do you do finite element calculations with? and … and … and …. Where is this data stored? Where are they lying around? Which systems are used to manage this data? Are they also traceable? That means for example if I have a problem in Field Service that I see this equipment is based on this material. This material has this revision. How did it progress in the supply chain? This state of the article, with what did we test and analyse at that time? Can I also trace the field service data via Ragas processes and say, for example, yes, we have calculated a MBTS time, what now comes back from the field service on real objects. We go through it all. In the end we have a map ─ most of the time these are huge flags, all configurations are on it, all IT systems with the data generators, data users, applications down to the shop floor, manufacturing execution and so on to the end. Then we have all the databases we need and below we note that many of the objects are not integrated, we have gaps because certain configurations do not exist. The Field Service has no chance to somehow

fall back on Requirements Management. Just as engineering has no chance to access objects in the field service and then we have findings. Then we cluster all these findings on defined topics. And these topics with these findings are then listed in Excel sheets. And then we say, how often does this topic occur? How often do you have this finding per day, week, month or year? And how much effort do you have now because that is not integrated and or because you have a gap here. If this finding occurs, how much effort do you have to put into this now? If we were to solve this differently now, how would this be reduced or how many problems have arisen because the requirements management was not good, we would have put projects in the sand. In the end it was a black zero instead of an EBIT from the project, because we didn't have Requirements Management under control and then had to do so much rework. We really try to make a ROI consideration on the basis of these Findings. This is always customer specific, based on this PLM big picture. This is a fixed service product that we offer, we do it maybe ten times a year. This is actually the basis for management to decide whether or not to invest in the associated processes and IT infrastructure in certain CM topics.

MM: So that the decision-maker has a clear overview and also what benefits he has from it.

B: Exactly

MM: Simply analyse the requirements and see exactly where the problems are, where are the gaps in them that need to be closed.

B: Yes, and so there are still three results from a PLM Big Picture Workshop. One is this huge map where really starting from requirements management up to phase out, all configurations are displayed with all IT systems and all the related processes. Then a report of what has been discussed with all findings. In this report there is a grouping of the Findings and then the Excel sheet which the customer can fill it out for himself, the Findings are all in it, there are certain basics in it and where he can provide quantity and cost rates and then the Excel adds up certain

values for him. There are always three results that appear after such a PLM big picture workshop. That is the then the basis for a decision.

MM: Yes. So which KPIs would you specify where you would say they would be most interesting and that is where you would see the most?

B: So the bottom line is always error reductions and cost reductions. CM2 talks about intervention costs (intervention resources). The bottom line is that when we talk about savings it is mainly about cost reduction and effort reduction, further when it comes to costs it is partly about error costs. Then there are other things at stake. Naturally, we also try to say we can open up new business processes. For example, we are thinking of the example at Roche Diagnostic. There are new business models. We may now be able to sell a blood diagnostic machine or an entire laboratory facility to customers who would not have been able to afford it before, because they had this one-time financial contribution but if I now charge via Services that is a completely new business model and that is another story. It is therefore also about presenting in the form of KPIs, there are new EBIT opportunities. New processes where I can generate an additional EBIT.

MM: Where one has new possibilities and just charges for the service that the customer has actually used, that you simply bill for the blood diagnostic machines by the number of its uses and then of course it becomes more interesting for the customer to buy the product because he simply does not have the financial risk of the one-time purchase.

B: Exactly, Quite Exactly.
Precisely since we make this PLM Big Picture, there are of course hundreds of scenarios. Suddenly we realise we have certain problems for example in order fulfilment. There are companies that say you know what our biggest problem is, we want to deal with it. We carry out quality inspection of our parts and we notice that the quality of the parts changes. They are die cast parts, our problem is actually the die casting tool and we know nothing about the tool i.e. the tool suddenly in a state that we can no

longer use it. A die casting tool of a die casting machine that closes with several thousand tons. This costs 250000 Francs or Euro and if the tool is broken then the plant stands still for three weeks until we have built another tool. We would like to extract data from the machine now. We would like to equip the tool with sensors to extract the data and we would now like to try to make the connections. This data of the machine and data of the tool with the quality of the parts provides algorithms to determine when we have to order a new tool because we know this data will change in four weeks. This is also CM. That's what it is. Therefore, there is CM, i.e. the administration of data in precisely defined states in order to then link them, to establish associativity traceability. That's what happens when you look at the details at many points. There are companies that say, let's stay with Pilatus, we are building new facilities for the PC24. There is a new assembly hall and a new production hall. We will have completely new possibilities to manage data with these new milling centres. We will also adjust or introduce SAP Manufacturing Execution. This means that we will manage all work activities down to the shop floor. Yes, now suddenly we have completely new possibilities. For example, we can directly store the production manufacturing information from CAD. When we have ten screws on one flange that need to be tightened where all have different torques. Now I can store this directly in the CAD and SAP knows I have a parts list item with quantity 10 (10 screws), but because I have now integrated it that way, I have actually stored the transformation matrix. I know every single screw and I can even provide this PMI data, I can even integrate a torque wrench in my Manufacturing Execution, I can animate it and when the torque wrench reaches the right place, the torque is already pre-set. This is also CM, which is also how do I get from the technical To-Be Configuration, where I have already stored a lot of data, how can I transfer this data into a Supply Chain to be Configuration. That is, that's why they are not the standard KPIs but these PLM Big Pictures with the problems of customers lead to suddenly to this data. Yes, we do not have to integrate it. Of course, this leads to a completely new situation in the change management process. It's therefore difficult to say they are the standard KPIs, there's a standard procedure as we find the customer

specific KPIs, that's there, but CM is so enormously broad the data integration that it's most difficult to say there is this table.

MM: I like very much what you say, because my goal is to develop a framework and I already had the assumption that you have to make it customer specific to define the KPIs. Then one would practically have to divide the company into different categories, i.e. into different areas. Initially the company: which product does the company produce, which risk is involved and then define the Key Performance Indicators for the individual companies accordingly. This should be some kind of matrix I would imagine. As you know many customers, how would you do that precisely so that this matrix is as meaningful as possible?

B: What you just mentioned is certainly absolutely correct. Well that is a big topic, we often have big vertical silos in the companies. These are the Lines of Business. We have sales, we have system engineering, we have engineering, we have a supply chain, we have preparation activities, we have order fulfilment and we have all customer service. What we notice when we optimize a Line of Business, every Line of Business is optimized, that does not mean the company has saved money because maybe everything has become so lean, but the whole process has become fatter. That means if we look at these vertical silos, PLM is the cross-sectional process that connects all these silos. That's an important principle. That means you now have to find a framework where you can say on the one hand how you can really streamline the individual silos, how we can nevertheless ensure that the cross-section process provides all the data where everyone enters their data once in such a way that it can all be used again where the customer currently has a problem. That can be in Customer Service, it can be with new business models, it can be as mentioned before in Order Fulfilment, it can be in front in System Engineering in Requirements Management and so on. That's an important thought, that one satisfies the individual silos, because every Chief Operation Officer or Chief Technology Officer or whoever has his goals, he has to satisfy them, but we also have to indiscriminately satisfy the whole process and a framework would have to contain both thoughts,

otherwise we pursue the wrong goals and in the end we have no baseline added value.

MM: That is very interesting because it is exactly the problem I am facing at the moment of how I tackle this as practically as possible so that it becomes a positive result as far as possible.

B: Yes. We really do this ourselves, so we say this framework actually contains this so-called PLM Big Picture for us. There we have a standard agenda as we actually go through the organization through these lines of business. With these configurations we can really query things from the customer so that we can really create this PLM Big Picture. At the beginning a Best Practice Template is always presented. That means, we actually say, in your industry customer there are regulations, there are best practices and an actual CM Model of these configurations from the Development Configuration over the different To-Be's then As Planned and As Is. It looks something like this. Everyone is involved in this initial workshop because everyone must have understood this template. We always go through one line of business per half-day. Then we also have predefined questionnaires available. That's our framework.

MM: This is very interesting, because you are in a consulting company as Chief Technology Officer and so you have to convince the customer that he benefits from the introduction of CM in order to get the job done. You have to show your customers where their benefits lie, how the investment can be recouped and how the corresponding added value can be generated. The interesting question is how do you do this exactly when you are with the customer, that you convince him that there is extreme potential behind it and then a great deal of benefit comes out in the end for him.

B: Yes, sir. Surely, we can show him examples of other projects so that he understands as quickly as possible what is the result of these workshops. It is fascinating when we show an example of such a map, we also have customers in the aviation industry, FACC for example, which manufactures all type of carbon parts, such as winglets, turbine fairings

and items present in the aircraft interior and the CEO has these maps in his office. It's the first time I've had an overview of all the data and IT systems that actually generate that data. I finally understand what is happening underneath, which means that if someone now comes and says we have to invest in these and that areas, then he stands in front of the wallpaper and says where are you, what are you talking about? That means there are side effects, which also provide safety for the management and often it is these effects, which inspire the management to invest in such a workshop, to have this overview at all. Then another aspect of how to convince people to invest in this workshop is that they are approaching us because they have a concrete problem. For example, a company that comes and says, look, we have to move in that direction by 2020. Or have a look, we would like to have introduced that digital product by 2020. We want to do everything in a consistent visualisable model. Above all, look we are investing in a new factory building, how can we integrate that. So there are always the concrete reasons why a customer comes to us at all. There are these big forklift truck manufacturers in Germany Linde, Stihl and Jungheinrich, we are working with all three, they know field service, we need apps where they can scan the field service anywhere and in Hinbugduland (an imaginary place in the middle of nowhere) and that they can easily scan a forklift and immediately have a 3D model of the whole forklift as As-Built configuration as As-Is configuration, as it stands now along with the whole history. All that with a 56 kbit line, because someplace in Hinbugduland we simply don't have another network. How do you do that? This means that there are very concrete customer needs, and of course that is where our first question comes in. Do you have a consistent As Built configuration per vehicle at all? How do you actually manage that? Have they actually extracted a clean As Built configuration from the supply chain? Or do they only know what the customer has configured, which means they only have an As Configured configuration, as that was the contract at the time. Like with a car, I as a customer know what I have had configured, mostly it is in the contract. Do they even have all this data and if they want it in 3D, are they even able to resolve an As Built configuration from a technical point of view because we only managed a visual 3D configuration from the To-

Be CAD. With the Technical To-Be configuration that we have, we are already inside the Big Picture. So often the requirements come from concrete customer projects. He never says I have to invest in CM, he always says I have problems and then we say yes, we understand, CM is part of the solution. But he doesn't want to use CM. He wants his problem solved. We say CM is part of the solution. CM is never the goal, but he realises in the end, aha! I need CM to solve my problems.

MM: How often, if there are problems, in the aviation industry etc., is it CM? You say CM helps, when a customer comes to you.

B: I say very often, because what does problems mean, what is your problem? One problem is the non-fulfilment of a goal. Immediately have a configuration problem somewhere that someone says I have an As-Is and I have a target, a goal, so I already have two records and I don't realise the mappings, so I have a problem. Now the question is immediately there, why does this data diverge and how did one determine this? How can we improve in the future that these data no longer diverge? Thus we're already somewhere in Configurations. It's always that simple, the question is what one understands by CM? If you understand that broadly, it is always that. Or always the customer says I have data there, I have data here, I cannot connect them. Yeah, it's a configuration problem. Clearly it is also an IT problem, but it is a CM problem.

MM: I think the answer is great, because you can clearly see that CM is actually always involved, because it overlooks the entire process and helps control it. What I find very interesting about a product, because you often mention the lifecycle. It starts with the development of the product until the scrapping of the product. It is so, CM covers the entire life span. Are there areas where you say that CM now offers a lot or the measuring procedure in the case of development would have to be tackled differently than in the case of scrapping. In the end, the basic data of the product runs from beginning to end. Yes, for example in the case of scrapping, this has an advantage in that you know which materials are used and then you

also know how to dispose of the product. So the benefit spans the whole and continues so that the whole can be seen as an integral.

B: Exactly, that is the decisive point and the other decisive point is that I can only do with the product at the end what has already been defined at the beginning. And that is also something quite decisive. That means if we now want to use the product in a completely new way, we will stay with Pilatus, which no longer sells aircraft but only sells services. I have greater demands on the sensor technology, yes this must have been defined as requirements up front, because the sensor technology must be integrated into the product. Evaluation systems must be made available. Systems, where I now have to retrieve much more data, manage it and to evaluate it for these configurations, yes, someone has to create these software solutions. That means already at the very beginning of the product I have to determine the requirements management and also record it so that I can use new processes in the future, with the product I have to engineer a product completely differently. And so that I can engineer something also completely differently, I must define completely new requirements. And this already shows that CM is something all-embracing. What's not possible at the beginning can't be done at the end. And what we want to evaluate in the end must have been born somewhere in the beginning. What you can evaluate at the end should be of interest to the beginning again so that they can determine did we achieve what we have defined. From this point of view CM is an absolutely all-embracing topic.

MM: To get back to my framework now, that's exactly what you would have to show. That in the measurement framework, the lifecycle and the topic time I have to say is taken into account. So, it's not just the product itself that counts, which makes things even more complex, but time also plays a role.

B: Of course, what is a big topic is time. So if we stay with the trains, a train can be in use for forty years and of course the topic often comes up that a customer says, do you know, we must solve retrospective problems where we don't have any data anymore? And then you also have to look for

hybrid solutions, that is, we have modern trains, we have very old trains and we now want to operate hybrid trains, it's really like when I approach a train with an app that in a modern train provides me with a lot of data, I scan it and I have everything in available and in other trains there are just quite conventional documents appearing. This means that it must always be borne in mind in these issues that we are sometimes talking about very long product life cycles and, that the products are used as hybrid by the customer. Finally, we need to deliver processes and CM solutions that support his older as well as his new products. Often he doesn't have the money and it doesn't make sense to upgrade all old products to the latest data structures, because that simply doesn't pay off anymore. This is still an important point, if one conducts these discussions, that one is ready, to explain to the customer you have to think hybrid, because if he always comes with the argument, the problem is that he is never innovative, because he always looks at the old and forgets that the new will be the business of the next twenty years, that just now he must invest there.

MM: Yeah, that's another very important point, interesting. Well then, thank you very much.

B: You're welcome.

MM: That was very interesting, because completely new aspects have emerged.

B: Yes, that pleases me and I wish you every success.

Analysis:

Excerpts to Degree of individualization of CM:

[1] In aviation, for example, the ICAO structure is organized in chapters; in the rail sector, there are ISO standards, where there is a functional structure for trains. We have made projects in the field of ships and submarines, where there are also structures. In tank construction it is the so-called Gatel structure, i.e. also a standardized functional structure. This means that very many companies

have functional structures from within their industries where they can structure the systems.
[2] So we really go on, we stay with a product from requirement to phase out, go through these configurations and try to analyse what the customer has already using in these configurations, what he needs, what he doesn't need.
[3] That doesn't mean every industry needs the same thing.
[4] There are new business models. We may now be able to sell a blood diagnostic machine or an entire laboratory facility to customers who would not have been able to afford it before, because they had this one-time financial contribution but if I now charge via Services that is a completely new business model and that is another story. It is therefore also about presenting in the form of KPIs, there are new EBIT opportunities. New processes where I can generate an additional EBIT.
[5] It's therefore difficult to say they are the standard KPIs, there's a standard procedure as we find the customer specific KPIs, that's there, but CM is so enormously broad the data integration that it's most difficult to say there is this table.

Paraphrase:
[1’] For structuring systems in different projects different structures are necessary.
[2’] The configurations determines what the customer expects from a product from requirement to phase out.
[3’] Different companies and industries need different CM.
[4’] With different depth of the application of CM new business models are possible which have influence to the KPIs.
[5’] It is not possible to measure CM only with standard KPIs.

Reduction and Summarisation:
CM is based on a large variety of product structures, which determines the requirements over the whole product lifecycle. The different depth of application of CM makes various business models possible for different companies, and therefore there cannot be uniform standard KPIs for measurement.

Conclusions:

The product of the company has influence on the application of CM and on the measuring system.

Excerpts to Complexity

[1] This means that we not only manage a functional structure of the systems, but also all activities that arise in this development in this system engineering.
[2] Many products are configurable, i.e. I have a customer order where I see what the customer actually wants. “As Should Be”, “As Planned” or “As Configured”, there are different terms. And then, of course, comes the “As Built”, which comes out of the supply chain, which is the generated hardware configured as to-be and then as-maintained with the lifecycle across the entire Operating and Maintenance.
[3] The only thing that is clear is what I can really report and substantiate in structures, with all associative data, documents, article masters, structures, and everything that depends on them.
[4] In the end it was a black zero instead of an EBIT from the project, because we didn't have Requirements Management under control and then had to do so much rework. We really try to make a ROI consideration on the basis of these findings.
[5] Yes, and so there are still three results from a PLM Big Picture Workshop. One is this huge map where really starting from requirements management up to phase out, all configurations are displayed with all IT systems and all the related processes.
[6] We have sales, we have system engineering, we have engineering, we have a supply chain, we have preparation activities, we have order fulfilment and we have all customer service.
[7] That's an important thought, that one satisfies the individual silos, because every Chief Operation Officer or Chief Technology Officer or whoever has his goals, he has to satisfy them, but we also have to indiscriminately satisfy the whole process and a framework would have to contain both thoughts, otherwise we pursue the wrong goals and in the end we have no baseline added value.
[8] This means that it must always be borne in mind in these issues that we are sometimes talking about very long product life cycles and, that the products are used as hybrid by the customer.

Paraphrase:
[1'] CM manages the whole variety of complex structures.
[2'] The different "product views" As Should Be", "As Planned", "As Configured", "As Built", "As Maintained" has to managed over the whole product lifecycle.
[3'] Data, documents, article masters and everything that depends on them have to be organised in structures.
[4'] To minimize rework Requirements Management has to be under control.
[5'] The result from a PLM Big Picture Workshop is a map over the whole product lifecycle where all configurations are displayed with all IT systems and all the related processes.
[6'] All complex operational tasks have to be managed and linked together.
[7'] As the different managers have different interest in their area it is necessary to take care to satisfy the whole process, otherwise there is no baseline added value.
[8'] The complexity of the long product lifecycles has to be taken into account, as well as the different patterns of mixed usage.

Conclusions:
CM manages the whole variety of organised complex structures and "product views" over the whole product lifecycle. The complexity has to be managed with the help of Requirements Mangement, PLM Big Picture as well as the linkage of all complex operational tasks. An overview is necessary, otherwise the whole process cannot be satisfied and the complexity of the long product lifecycles as well as the different patterns of mixed usage cannot be managed.

Reduction and Summarisation:
Without the use of a modern CM system with sophisticated linked product structure the management of the complexity of advanced technical products over the whole lifecycle is not possible.

Excerpts to Potential

[1] Then of course what plays into our hands at the moment is the whole topic "Industry 4.0", Internet of Things is not possible without CM.

[2] The pressure to manage configurations in the context of industry 4.0 and Internet of Things will be much much bigger.
[3] The topic of CM is therefore becoming increasingly important, not only because regulations are becoming increasingly stringent, but also because business models are turning around.
[4] So it is really the case that we are now trying to implement a so-called Enterprise Development Manager at the companies, which is actually based exactly on a Development Configuration, which Requirement actually says, where the company is heading.
[5] Another problem is we have customers who say we are being blown away in Europe with our cost structures by Asia and Latin American competition. We can only survive if we become premium in our field and this of course includes certain benefits etc. Others say we need to change our processes to batch size one.
[6] That means if we now want to use the product in a completely new way, we will stay with Pilatus, which no longer sells aircraft but only sells services. I have greater demands on the sensor technology, yes this must have been defined as requirements up front, because the sensor technology must be integrated into the product. Evaluation systems must be made available. Systems, where I now have to retrieve much more data, manage it and to evaluate it for these configurations, yes, someone has to create these software solutions.

Paraphrase:
[1'] CM is necessary to use “Internet of Things” and “Industry 4.0”
[2'] Configurations have to be managed in the context of “Internet of Things” and “Industry 4.0”.
[3'] The value of CM is increasing, because of more stringent regulations and more complex business models.
[4'] New technologies like the Enterprise Development Manager which is based on the Development Configuration can be used.
[5'] To survive in a high wage country it is necessary to become premium and be able to reduce to batch size one.
[6'] For the creation of new business models new technologies have to be integrated and managed.

Conclusions:

The importance of CM increases in the context of “Internet of Things” and “Industry 4.0” and due to more stringent regulations and more complex business models with new technology. In addition, the survival of companies in high-wage countries can be ensured by concentrating on the premium segment and reducing to batch size one.

Reduction and Summarisation:

In order to survive in the future markets that will be characterized by internationalisation and new technologies, the use of CM is indispensable.

7.2.3 Interviewee C:

During a telephone call an attempt was made to arrange an interview. Mr. Tsantre informed me that an interview seems to be obsolete, because Pilatus does not measure the value of CM and this is not planned in the future.

Conclusions:

This statement that a measurement of the benefits of CM is not necessary is astonishing in this area (see the statements in the participant B interview) because it is a key technology with special potential.

7.2.4 Interviewee D:

MM: In the companies you were responsible for, did they measure the CM process?

D: Most of them have systems that are different in nature. Of course this depends on the size of the company as well as on the products they produce. The individual methods often differ considerably in scope but also in terms of content and the way in which they are carried out. Of course, the scope also depends on the complexity of the product or products, but not only with complicated products, some companies have relatively simple systems others very well elaborated systems, which produce essential results.

MM: Why do companies measure the benefits of CM?

D: There are naturally different reasons. The main reason, of course, is always to make sure that an expensive system is worth the effort and where improvements can be introduced. In addition there are of course still legal demands from different sides that one must prove somewhere that the introduced system fulfils certain conditions. Of course, there are also internal financial demands or financial reasons why one runs such systems. Reasons of environmental protection, reasons to be able to work out the future company strategy where inputs from the current production are needed. There are reasons of different kind which lead to the introduction of such a system.

MM: Why are there companies that do not measure the benefits of CM?

D: There are, but these are exceptional cases. Mostly there are reasons that some managers think they can save effort, or they know facts that they don't want to enter into e.g. Quality management but this is a short-sighted approach, because it damages the company and sooner or later it will prove that it is not possible to organize a business in this way. It is therefore an exceptional case and of course does not lead to good results.

MM: How do the companies carry out the measurement process?

D: As already mentioned, there are different methods here. You can do it partly through the quality management system but you can also do it through very specialized systems. A problem with many companies, even larger ones, is that they usually carry out a rather one-sided analysis, which is usually based on cost-effectiveness or on certain information that does not cover the entire spectrum. For this reason, it makes much more sense to use a wide range of methods, such as the Balanced Scorecard System, where a number of different measurements or KPIs, financial or otherwise, are used.

MM: Which Performance Indicators have been important for you or for the companies?

D: One of the most important things especially in the aviation industry or in the supply industry is of course on time delivery, as punctual delivery is extremely important because otherwise the entire manufacturing process at other companies or other company departments are disrupted, which can lead to major problems. It is also an important result that the scope of work can be simplified under certain circumstances, that processes can be streamlined and thus time, money and effort can be saved. One can save organizational effort. In any case, there are hardly any cases where this system would not lead to improvements.

MM: What do the companies generally do with the measurement results?

KK: That of course depends on what kind of results you have. There can be positive results that show you that you are on the right track with the system. For example, after a test run the system will be released for continuous operation. Most of the time, of course, there are also findings that show where there is still room for improvement, here you will then specifically analyse these errors or incorrect processes again and then introduce targeted corrective measures.

MM: A question with the implementation of the measurement. Would you recommend making percentage measurements or rather measuring absolute values?

D: Of course, it is probably or certainly more sensible to take percentage measurements, because if they are absolute values, they are not at all comparable depending on the type of product or the scope of manufacture or quantities. This often leads to distortions of the result, which is why a percentage measurement is normally more appropriate. However, there may be exceptions in special cases.

MM: How important are the measurement results for senior management?

D: For the senior management they are in any case the basis for your short-term as well as your strategic decisions, as the economic success of the company as well as the quality and punctuality of delivery depend on

these results. Actually, all parameters are influenced by it and provided the corrective actions are implemented correctly and in a timely manner. For long-term decisions it also helps, when new programs are introduced that one can draw conclusions on the results of previous programs in advance during planning and thus avoid mistakes from the beginning.

MM: What about the future development of the company in terms of new business areas, further development, new production methods, new sales methods and marketing methods in terms of CM?

D: Here too, significant influences on decisions are to be assumed, because without the experience from an established system, it is not possible to make these decisions at all.

MM: Thank you very much for answering the questions.

D: Your welcome.

Analysis:

Excerpts to Degree of individualization of CM:

[1] Most of them have systems that are different in nature. Of course this depends on the size of the company as well as on the products they produce. The individual methods often differ considerably in scope but also in terms of content and the way in which they are carried out. Of course, the scope also depends on the complexity of the product or products, but not only with complicated products, some companies have relatively simple systems others very well elaborated systems, which produce essential results.

Paraphrase:

[1'] The products of a company and the used system can be different. This is dependent of the size of the company as well as the complexity of the produced product.

Reduction and Summarisation:

Different companies produce different products with the help of different systems.

Conclusions:
The degree of individualization of CM depends on the product and the used system.

Excerpts to Complexity:
[1] The main reason, of course, is always to make sure that an expensive system is worth the effort and where improvements can be introduced. In addition there are of course still legal demands from different sides that one must prove somewhere that the introduced system fulfils certain conditions.
[2] One of the most important things especially in the aviation industry or in the supply industry is of course on time delivery, as punctual delivery is extremely important because otherwise the entire manufacturing process at other companies or other company departments are disrupted, which can lead to major problems.

Paraphrase:
[1'] An expensive complex system has to worth the effort. Legal demands from different sides have to be fulfilled in the systems.
[2'] On of the most important and complex things in the aviation industry is the on time delivery. Late delivery can have a negative impact on the entire production process.

Reduction and Summarisation:
The complex CM systems inside a company have to ensure that the whole production process works without problems.

Conclusions:
CM is essential for the production of complex goods in the aerospace industry.

Excerpts to Potential:
[1] There are also internal financial demands or financial reasons why one runs such systems. Reasons of environmental protection, reasons to be able to work

out the future company strategy where inputs from the current production are needed.
[2] It is also an important result that the scope of work can be simplified under certain circumstances, that processes can be streamlined and thus time, money and effort can be saved. One can save organizational effort. In any case, there are hardly any cases where this system would not lead to improvements.

Paraphrase:
[1'] Potentials of CM application are cost-efficient production possibilities, environmental protection as well as the possibility to realise future company strategies.
[2'] The CM application enables a process streamlining to save organizational effort.

Reduction and Summarisation:
CM application leads to much potential, because it enables process streamlining and the realisation of future business strategies.

Conclusions:
CM application is essential to realise the potential of a company in the aerospace business in the future.

7.2.5 Interviewee E:

E: There are legal requirements that we have to meet with regard to an aircraft. We must provide documentation confirming that the aircraft has been built in accordance with the definition. With the documentation regarding the deviation from the definition, such as concessions, that we have to make, this is first of all, the very upper legal level that we have to meet. But there is also the industrial level that we have, that tells us how we do it so that we meet the legal requirements and we have an industrial process here in the company with different suppliers and there it starts. These contents we take into account when we break an aircraft or product into industrial use, at what frequency, how the parts come to us and what

documentation we need for such parts to meet the legal requirements. These two components, which flow in that we then begin to accommodate the aircraft as a complete unit, which we hand over to the customer industrially in the delivery units.

MM: The quantitative measurement of the quality, that runs over construction deviations and concessions that are on it, but you measure them per CA.

E: The quality deficiencies have various causes. This could be, for example, skills of the employees that cause them to break many things and it does not have to be technical defects, but work errors. The areas of responsibility measure separately for their products. The concessions resulting from the shortcomings are the solution. Concession and DQN describe how to fix the problem. What we are talking about are the so-called Non Conformities, when a problem is detected in the production. The solution is a DQN because DQN means the design has made a mistake and that needs to be corrected. A concession describes a production error. If the causer is not clear, the Non Conformity Board decides.

MM: How do you evaluate this information?

E: For the A350, we have agreed various quality gates. Quality Gates from our supplier to us and the Quality Gate from us to St. Nazaire where we deliver Section 13, 14 and a Quality Gate from us to the FAL. With KPIs we measure how many DQNs we have per delivery component and also show whether the curve goes down or up. The root causes are also examined. If one notices that in some areas errors accumulate, one examines whether this is a systematic error or a human error. Each area has its target numbers where it says you should have only a certain number of concessions or DQNs. We also measure the modifications that lie behind the actual milestone and are still being introduced because they cause additional industrial expenses.

MM: Are values such as adherence to delivery dates and delivery performance also measured?

E: We always measure the delivery reliability, we arrive on time and then there are still the quality indicators or the performance indicators that we show. We also measure how much work is left between the individual workstations. The remaining work can also be missing parts. The missing part situation is also measured. Since we have an industrial schedule and we have to clock, i.e. the components have to go from one building site to the next, you can't stop the running system somewhere. That means if you stop the gears, the whole clock stops. We have components and they have a configuration i.e. we have the element Constituent Assembly. Under the CA are all our assembly documents, i.e. the installation documents with which we build this component. This level is for us the so-called Configuraiton Idem level. The good thing is that due to this relationship we always know whose responsibility it is to do the remaining work until the aircraft is delivered. This means that the remaining work always remains with the producer and this is only possible because we have the configuration with the cascades and we always have the responsibility behind these elements. Without Configuration Management this would be a total mess. But it's hard to assess what it would cost us. The end line would be blocked, there would be delays in delivery, the customer would have recourse, there could be problems with the authorities. The costs can be roughly calculated by multiplying the flight cadence to be produced by the blocked time. With the product to be produced there is always a customer behind it and customer is once the airline itself but we also have changes which we have to bring due to legal changes by the aviation authorities. There are always three aspects we have to consider when making a change. This is the technology, the industrial constraints and the commercial constraints. It defines what we change and when we change it. It is a task of the CM to check whether a change is technically, industrially and commercially acceptable. Design engineers are often very fond of detail and do not always choose the most favourable solution. It is the task of the CM to rebuke the designer. However, we do not record the resulting cost savings. However, we do

capture all the costs of change, i.e. RC and NRC. The CM also creates added value by combining the introduction point of several changes into batches and therefore not having to touch the construction documents several times. So there are predefined machines where we summarize the standard changes. So CM also has an influence on keeping engineering costs low. For these savings we have KPIs and make corresponding evaluations.

MM: We have now mainly talked about quantitative measurement methods. Do you also measure the benefits of CM qualitatively?

E: Internally we measure the TRS changes after we open a MOD, so how good is the quality of the content. So what are the reasons for the change? We measure the lead time for the full change process to see if the change is also through the change process within 60 days. But to measure the quality, which is the big advantage of CM, we do not measure that. Ultimately, the quality of the CM can be measured by the condition of the aircraft after delivery. The quantity of concessions, for example, which the customer can also pay for. The only problem is that there are also errors that are not caused by the CM. It is an important indicator that the configuration is delivered on time and converted into construction documents.

MM: Thank you very much for the interesting explanations.

Analysis:

Excerpts to Complexity:

[1] There are legal requirements that we have to meet with regard to an aircraft. We must provide documentation confirming that the aircraft has been built in accordance with the definition.

[2] We always measure the delivery reliability, we arrive on time and then there are still the quality indicators or the performance indicators that we show. We also measure how much work is left between the individual workstations. The remaining work can also be missing parts. The missing part situation is also measured. Since we have an industrial schedule and we must keep a steady

work flow, i.e. the components must move from one production area to the next, it is not possible to stop the running system just anywhere.

Paraphrase:
[1'] In the aircraft industry there a complex legal requirements. CM has to provide the documentation which confirms that the aircraft has been built in accordance with the definition.
[2'] The delivery reliability, the open work between individual workstations and the missing part situation is measured. Since there is a complex industrial schedule interruptions have an effect on the whole system.

Reduction and Summarisation:
In the aerospace industry, CM must ensure that the complex legal requirements are fulfilled. Interruptions have an effect on the whole system because there is a complex industrial schedule.

Conclusions:
CM must ensure that the complex legal and production requirements in the aerospace industry are fulfilled.

7.2.6 Interviewee F:

MM: I am happy to interview you as part of my doctoral thesis. It's about the benefits of CM and how you measure these benefits.

F: We are active in the military sector and of course we have specifications, from our military customers. CM is already in use, and regarding the benefits we have always justified ourselves by being able to satisfy our bosses and our management by saying, here are the benefits we have brought in with changes. Benefits for the system can be with regard to safety relevance or monetary. Further benefits can be in development, which can then also be used in other systems. We have looked at such beneficial aspects. Regarding measurement, we have looked at KPIs. That's where the difficulty begins. We have been thinking about this for many years and we have developed a phase model. Our CM process has

several phases. We assess the phases with regard to the quality of the documents used for the benefit of the customer. It must be checked whether the customer subsequently requested corrections. We also analyse the planning data and cost estimates. The decisive point however is whether the customer accepts the product immediately as part of a quality gate or whether it had to be corrected. Correction means entering the correction mode. The correction mode is a negative act because it reduces our profit. We report these figures to our bosses. It shows our benefit and also the benefit for our customers. We have carried out this measurement for about two years.

MM: In order to measure customer benefit, you need to know exactly what the customer requires. This is not easy because you have very complex projects. How do you do it?

F: The product or system specifications describe what the object, detail object or module must fulfil in detail. For changes, a detailed analysis with a feasibility report is necessary. The customer must always approve this feasibility report before the next step is taken. The quality of the feasibility report is crucial. This distinguishes the military sector from the private sector. The quality is measured at delivery.

MM: If you say quality at delivery, what is the key metric? How do you measure the quality?

F: No, we only measured the quality. There are the system specific aspects that you have to cover, you have to fulfil. You do them in the lab or on troop trials and so on. You have to fulfil them. Only when we've fulfilled them, we'll present them. With a Troop Trial map, as the documents are called, trial maps are simply project-related. Afterwards we still have the separate criteria which are defined in the purchase order. There are specifications, legal specifications that can be used to make them accessible to a third party, etc., or then there are cost-related specifications that are only for the particular item, not system-related. That was the quantity to be measured. The quantity to be measured was the quality of the change, the specification or the prototype plus the

contractual aspects that are completely covered. That was a quantity to be measurement for us. The order, that covers the requirements of the order one hundred percent and they want to cover the requirements of the specification.

MM: Actually you mean it is a should be-is comparison.

F: That's it. If they're different, you're negative. You never get a plus when you deliver. With the software you may still have that, maybe while programming you still have features in it but at the moment you do not yet need them all. As you have built it modularly, you may have but the customer does not notice that at all. Then you would have a plus, but nobody wants the plus at all. Otherwise purely user or optically you always have an order, system specification perhaps delivery configuration. Then this is the metric of the delivery configuration was then perhaps at first time declined, then judged good, because if it is declined and judged good, that is international actually the point of no return. You do that, you get money, otherwise you get nothing. These are the internal processes, when I have done work then I would like money, preferably a lot of money before you start, or an advance payment. That is then the metric you can bill. Otherwise you have again an internal problem which has again internally somewhere a payment date inside. This is the delivery configuration to the customer and if you do not fulfil that at the time, he appears in the bookkeeping department and says hey we can leave this invoice out. A default. So then you have internal need again to say the money is not coming yet.

MM: Again when you view it from the other side, when one makes an offer as a company and then actually the point of time when you make the offer is when you say you can do that and that is the time when you freeze it, where do you define exactly what you have to deliver? Then this is actually a very important time when one has to be aware of what that means for you so that the matter becomes a deal.

F: Yes, that is the offer baselines, for example. That's system related, because we don't change anything, but we always change on systems that we already have, or we make a supplement to them. This must be documented cleanly. We operate, as you know, in phase 1 to 2 with protocol points, which gives a protocol point baseline. And when it is stated the prototype with the trials was good and was paid and so on, or if there is a next phase, it would be series preparation and series and then the same process starts again. Then you do the data cleansing again, make an offer again, possibly make a separate specification again, make another technical report or a quality report then you have again delivery date lotwise or a scope if there are small quantities, then you have again a quality gate that you can measure for the series. The first phase was quality gate prototype, four pieces pre-series and then for the series you have exactly the same again. This is always the same method in principle. However, to date we have unfortunately not found any KPIs that would be more relevant or more meaningful within the CM process. Our bosses were basically happier than we were. Yes before we had nothing at all, we have always had something but it was never valued and now suddenly someone has been interested to have KPIs, quality work, quality delivery time, quality of costs that do not have to increase. We want to earn money with the quality of delivery, so we have to deliver good quality to the customer. It is always about the customer, the customer is our Lord.

MM: Thus one can actually say that the main task of CM is to ensure that the customer gets the product as he wishes. You can actually say that the main task of CM is to make sure that the customer gets the product the way he wants it.

F: That's it. But to make sure of that, I have to protect myself in that sense. I have to understand it in the early phase. There are many difficulties to prepare a requirement specification or to submit this. Yes, we would like to continue this service. The military can't do anything with it in many cases. It is our duty to find out what the military specifications are actually meant to be. And that is to transform the thinking to the technical basis and to accept it from the customer. Said yes, that's the way, I think that's what we

want, that's our most difficult task. The technology is not the problem but it is to understand what the customer actually wants, which is relatively complex to write down and in the feasibility report to point out all the difficulties, to point out all the risks, to make the large costs from this analysis understandable. To make this understandable is not so easy. If you suddenly come up with two pages and say it costs 1.3 million then the questioning starts. That must not happen that they have to ask.

Analysis:

Excerpts to Complexity:

[1] The decisive point however is whether the customer accepts the product immediately as part of a quality gate or whether it had to be corrected. Correction means entering the correction mode. The correction mode is a negative act because it reduces our profit.

[2] The technology is not the problem but it is to understand what the customer actually wants, which is relatively complex to write down and in the feasibility report to point out all the difficulties, to point out all the risks, to make the large costs from this analysis understandable.

Paraphrase:

[1'] The customer decides in the Quality Gate whether he accepts the product or whether it needs to be reworked. The correction mode reduces our profit.

[2'] The complexity is the understanding of the customer requirements. These requirements are documented in a feasibility report with all risks.

Reduction and Summarisation:

The complexity is the understanding of the customer requirements in the beginning. Otherwise the product is not accepted in the quality gate.

Conclusions:

CM has to enable the complex Requirements Management.

7.2.7 Interviewee G:

He is Manager for CM in Aircraft Construction and he is responsible for

1. configuration management planning,

2. configuration management identification ,
3. configuration management change management ,
4. configuration management verification ,
5. configuration management audit,
6. and accounting

according to the normative requirements of ISO (EASA).

MM: Firstly I want to find out which questions are important and make sense for the development of a performance measurement system, so that I know what to ask in further interviews. My ideas and questions are as follows:

1. Do you make use of CM in your company?
2. To what degree of intensity do you apply CM?
3. Do you evaluate the effects or benefits of CM?
4. How do you quantify these effects and benefits of CM?
5. What are the results of this quantification in your company?
6. In which way do you make use of your results?
   Do you compare your figures and what's the basis of your comparisons?
7. How did you come to your special approach, especially your way of quantification?

G: The first questions are very global and often you can only answer "yes" or "no".
That's the reason why I would first ask about the legal standards or normative requirements companies have to cope with. We in our group for instance follow the European standards of ISO EN 9100 and the aeronautical laws of EASA part 145 and part 21 G/J as well as the American standards, Mil standard 973 and EIA-649.

MM: And what do you think about questions number 2, 3 and 4?

G: If you name one or two possible process indicators and ask your partner if he finds them useful, you may get interesting answers. Further on you may ask what other indicators might be useful and which they work with in their company. In the end you may have about ten proposals and then I

would choose three of the most promising for my study. It depends what you want. Do you want a big variety of process indicators and figures or do you want to have two or three informative and highly diagnostic process indicators, whose data you can collect continuously and consistently?

MM: How many questions and how many interviews should be necessary to get a sound basis?

G: Not more than 15 questions. 12 questions and between 10 and 20 interviews should be enough.
I think you would even get comparable results with 10 interviews.

MM: How would you evaluate and quantify the results?

G: It doesn't make sense to compare the results in Euros or Dollars. Configuration Managers have projects with a huge amount of money and other projects with a small amount.
You only achieve comparability among different projects by thinking in percentage terms.
100% for example means "conditions are compiled"
110% means 10% over fulfilled
90% means 10% below your expectations or 10% over your budget.
In this way you can compare different projects even in different industries.

MM: You could use this indicator as part of a measurement system not only in aircraft construction but also in shipbuilding, automotive, chemical and food industries? It could even be possible to use it in banks and insurances?

G: You are right, because CM has its origin in the software industry.
To get a wide variety of projects I would take one project from the aircraft industry, one from the software industry, one from the automotive industry, one from the chemical industry and one from civil engineering. It might be more difficult to use this indicator in industries based on service providing.

MM: Thank you very much for the interview. It's been very informative.

G: I hope it's been helpful and I wish you good luck.

Analysis:

Excerpts to Degree of individualization of CM:

[1] It depends what you want. Do you want a big variety of process indicators and figures or do you want to have two or three informative and highly diagnostic process indicators, whose data you can collect continuously and consistently?

[2] You only achieve comparability among different projects by thinking in percentage terms.

100% for example means "conditions are compiled"

110% means 10% over fulfilled

90% means 10% below your expectations or 10% over your budget.

[3] That's the reason why I would first ask about the legal standards or normative requirements companies have to cope with.

Paraphrase:

[1'] The KPIs which should be used depends on a high degree on the certain needs of company.

[2'] The comparability is just given if the measurement is done in percentage terms.

[3'] The legal standards are important for the intensity CM has to be performed in a company

Reduction and Summarisation:

The KPIs have to be individual for different companies and the measurements have to be done in percentage terms. The legal standards have a large influence on the application of CM.

Conclusions:

The individaulisation of the measurement procedure is important because there a different general conditions for different companies.

7.2.8 Interviewee H:

MM: Hello Reto, I'm happy to interview you. I've prepared some questions. My work here is about CM, how best to measure the benefits of CM. You have a lot of experience in CM through your daily work and I have some questions for you. I would like to draw on your experience of how you see things and what you think is important and so on. Firstly I have the question how do you accomplish measuring, what is important to you when measuring the CM benefit.

H: Not so long ago, we have defined KPIs (Key Performance Indicators) to measure our process. That's when we said we need to know how many corrections we have after a design freeze. That means when we look at the development process, we have a PDR (Preliminary Design Review), we then have a CDR (Critical Design Review) and then we have a Final Design Review before the prototype flies. We review the documents for the production of the prototype and after the review the technical data package is released. We sometimes measure how the TDP Technical Data Package must be adjusted following this freeze, after establishing the prototype baseline due to design errors or due to manufacturing errors simply by re-checking the documents in the TDP.

MM: That's after the Design Freeze.

H: Exactly.

MM: That means in plain text you can measure how much effort was put into the changes after the actual freeze. In other words, the less changes were made, the better was the original data quality.

H: That's it. We start at the beginning with a request and then we do a feasibility study in the system I am using, so it is a viability study. When we have identified a problem making the viability study, variants are developed that might be a solution and then there will be a preferred solution offered by RUAG to the Government that we propose to make. As soon as this feasibility study of the viability report has been approved by

the authorities, actually by the bodies that can decide that, we go to phase 2 with the prototypes and then the design documents are created. This also means the electrical load analysis for electrical changes, the fatigue-critical analyses, all aspects are developed including the technical data package. One then says OK, this is a milestone we come to at the Critical Design Review and the documents are then all checked for status. The design review effectively reviews each document and says it is correct, only then can we prepare it (= technical data package) at all, are all the radii matching and if we are at the end of the design review, yes everything is OK for us and the government says it is OK then the technical package is released. Then the prototype is produced. Now everything is corrected, or measured. Then if we now have to touch the TDP again because we have somehow forgotten something, will be measured in time and effort. This is important for the prototype phase and also for the final design review phase. As everything has happened after the Final Design Review, the TDP is released, there's nothing more to be done. It is rolled out and the standardization takes place in the fleet.

MM: Then how could you practically measure that between the individual projects? There are complex projects as well as less complex.

H: The problem is, we measure the individual steps in each project. Of course, we can't say we have always done this. I now suggest we find three corrections after the Final Design Review. If AVOR (Industrial Engineering) isn't prepared, haven't they studied their manufacturing documentation and supplied their input too late that we have to change the design again because they can't manufacture it, or what is the cause. Thus, we too can take corrective action. That is a management instrument for us, of course, so we can actually see where we need to have an effect, that they improve, that in future they do the right thing the first time. That's how we actually measure it. So that we don't have to work with every design three times.

MM: Do you then have benefits for the next project, for example?

H: For example, yes.

MM: Before the first Design Freeze, you have to coordinate the design more precisely with the design, so to speak, that the parts really are suitable.

H: That's it. We see a trend. Where do we lose money and expense through this measurement and can it actually have a corrective effect? Perhaps not for the single project that is currently running, but perhaps for future projects. For example, I propose to Q (Quality), AVOR or Design, look, you have the option to make corrections to the Design Review again. That's the one benefit of CM. I think the use of CM is another way to measure the benefits of CM, if you actually get feedback within projects, positive feedback that really asks you if they have problems with the configuration that involves you. I think that's a big factor, that always sticks negatively to CM, that it's unnecessary to waste money and would have no benefit. I establish a maintenance process within a project by bringing all changes that take place within the project into a regulated change process and thereby giving the project management a means to record the costs and to present this to the customer and say, “you want to see what this will cost you, so and so much if you want it”, that is also a benefit.

MM: Then the matter becomes transparent.

H: Above all, the project management has a means at hand to respond, not just say yes, we will do it for you, they can say, hey look at requirements management. That means if I'm there from the beginning, then it's easy to get consistency in CM. If you only join in mid-way because somebody tells you that we need CM. If you get involved from the beginning to establish an order baseline, and you can establish these are the requirements, the customer requirements, every time a fresh change comes from outside or inside, you can hold up your hand and say, hey are those customer requirements and if the customer comes with a new requirement, you can request money, you have to charge money, so you get feedback back from the project itself and actually also for new projects, that added value

is there, as you are involved from the beginning. We've seen a lot of this now on the big helicopter upgrade we've done. We can see it again with a new helicopter that it is very important that you are there from the beginning.

MM: That one understands the customer's requirements so to speak, are there from the beginning when the offer is written and delivered tailor-made for the customer, so that the customer receives the product in such a form and all requirements are recorded in the offer baseline so that one can make an accurate offer.

H: Yeah, that's exactly how they process them and, for example, with the new helicopter, we did it that way. We've effectively written so-called customer requirements docs. For each subsystem, what exactly the customer wants we have worked out with him and then the contract and the attachments to it. Everything when the contract is signed is the customer documents plus the concepts, no not the concepts, but the customer requirements documents give the contract baseline. From this must now be derived the detail specifications and the interface documents and from these in turn the design derived. Thus, you actually automatically get a contract baseline, your functional baseline, your allocated baseline and your contract baseline. Then you'll have it under control at all times. This is also often the customer's demand. To see these connections is sometimes not so easy and has a lot to do with the working within the organisation, within the project this is a permanent job.

MM: It is also generally the case that the same CM is not to be used to the same extent and manner for every project. It is also important that when one starts to clarify a project with the customer, that the CM is done in the appropriate amount, not too much and not too little, so that the benefit is maximized.

H: Absolutely. This means that the customer has to define this in his order. Often before his order arrives, there's a discussion going on. Then it's really all about what the customer wants, finding out what he really wants

exactly. What demands does he have on us? In many cases it is also the case that he makes reference to RUAG, because RUAG is certified according to DIN EN. This is automatically linked to a functioning CM. So, in many cases, when we get in touch with them, we are informed that we have to be approved according to such standards. Then you can of course deduce what is the right amount of CM. Maybe you'll find out. In the end it is really a finding out what the customer wants in a conversation, or else it still may be in the documentation that he makes available to us. In the military environment, for example, the customer is actually capable of doing configuration management and has purchased the entire technical data package from Boeing, for example. Or in the case of the Eurocopter large-capacity helicopter.

MM: Is it generally the case that I have to practically secure the data over the entire product Life Cycle, first for the construction then for the operation and then also for the disposal? Does the customer, in this case the client or the company that gives you the data, want the data to be destroyed at the end?

H: That's it. It depends if the customer orders us to develop a product for him, then it is our intellectual property. If, of course, it is the case that the customer, e.g. the Swiss Confederation, buys an F18 and makes the data package available to us, then I am with you.

MM: It depends on the order

H: Exactly.

MM: Otherwise it is your intellectual property.

H: Then there is also a topic that you must again contractually regulate with the client, how are the development costs shared. Are we allowed to develop this further or do we have to make a payment or whatever. This is again the subject of negotiations. It is effective, for example, for the F18 or F5 it's fundamentally important that you set up the product structures,

because the order in this context is for us the whole Configuration responsibility, as all the changes that come from the US Navy or Boeing or from ourselves must be added the configuration. At the end of the day when a system is scrapped you need to be able to tell what documents and what data I need to destroy.

MM: This extends to the serial number requirement that you know which serial numbers are installed in which aircraft.

H: That's standard, of course, we know that. That is of course also the problem, that is the task, we have upgrades on equipment, we have upgrades on the whole aircraft, we have to be able to track all of them, often you have more equipment than aircraft, so you have to work with the serial number. My personal opinion is also we have to track it, how much is modified and how much is not. Also in the context of the DOAs, CM is not only about hardware that I deliver, but it can also be documents. For example, if the DOA requests an order to modify a cabin, to make an interior for a business jet, for example, it mainly creates the documents for the design. They manufacture nothing, but I am of the opinion they need CM to record what documents I have given to a POA organization at all. So that I can say at any time, what was our status when we delivered it, that you must have it under control. What the POA organisation does with it is their business but we have to be sure that we know what we have delivered. Whether it's documentation or hardware, or both together.

MM: Now very specifically, when I do interviews in my phase 2 and then lead on to Config Management Interviews accordingly, how would you specifically ask questions to find out how they measure or rather find out how to skilfully measure CM there? Well, I have prepared a few justifiable questions by myself, first of all, is CM used restrictively in the company? What is the intensity of use of CM? Third question, is the benefit measured? Fourth question, how is the benefit measured? Fifth, what are the results? Sixth, how did you arrive at the measurement, according to which criteria, how were the KPIs defined? And seventh, how is the measurement evaluated? That's seven justifiable questions I've prepared.

My question to you is, 'What would you additionally ask or how would you do it differently?'

H: To find out the benefits of CM?

MM: That I simply get examples from companies where I can derive what a meaningful way would be.

H: One has to. I would try to find out how well CM is established in each company. Where's it positioned?

MM: That is important because it is often recommended that it is positioned up at management level and also as it says in CM2, completely introduced and integrated in the processes.

H: I'm not just saying at group level. I say is the management aware that it needs CM, how is the CM supported by the management. It doesn't matter that they are not structured to the CM2 standard, but generally I think it is important to find out how the top management is positioned to CM, does it know at all what CM is about, does it know why it needs CM. Simply to find out where it is established in the company itself, or is it a marginal discipline hidden somewhere in the closet.

MM: First of all, it is important to initially understand the environment in the company.

H: Exactly, because it is often that somehow all are aware that CM is needed.

MM: It is often simply said that it is a necessary evil because it is required by the regulations.

H: We find that somehow everyone is aware that CM is needed, but they cannot express what CM is for them.

MM: It is therefore very important to first determine or define what is necessary for the company, what scope is necessary so that the maximum benefit is achieved. For the product that the company develops or manufactures, what are the positive features that CM offers at a certain depth of application.

H: Exactly, because it is often amazing at the conferences that I attend when I inquire a little bit about my field of work, that CM is even a big topic with insurance companies and banks. Further it is actually amazing, it is also necessary in the service sector, not only in the manufacturing industry. That's actually really astonishing.

MM: Also because of the documents.

H: Documents, procedures, processes, or often software versions, that is a big topic in banks and insurance companies and staff groups. These are all topics that should not be underestimated. It is not only a topic in the aviation industry but it is also a general topic in insurance. The CM2 conferences or CM2 training shows that basically there are people from insurance companies of defence companies who come from everywhere. Therefore, for me it is still fundamental if you want to measure the benefit of CM in a company that first of all you have to determine how CM is positioned, because if it is located somewhere in the third hierarchy level, you can actually already say that probably the benefit will not be so great as it is practically non-existent. There is practically no continuity present.

MM: So, there is no overview of the company and the CM has practically no necessary funds.

H: That's it. It is also that the CM you really need to equip those with the task competence responsibility you need for this job, otherwise it will be bypassed by the design or any superior.

MM: There has been a scientific investigation into why CM does not perform as expected and these issues are addressed. For example, Configuration Management is not positioned correctly in the company.

H: That's right. You'll be reduced to a very small portion of CM scope. I'm going to talk of change management, creating change numbers and whatever and however you track it. It's often reduced to that. I've also heard from our design, they say here every designer is a configuration manager. Now you can imagine what a chaos this causes when you have a big project with 20 designers and everyone has the feeling that they are configuration manager.

MM: There's got to be someone to coordinate it, otherwise things are repeated twice or three times.

H: That's where chaos is pre-programmed. Therefore, it is important to know where CM is positioned. For me, that is the first essential, where it is organizationally located.

MM: Then in the first questions I have to get to know the company first.

H: Exactly. I think that's an important factor. Yes, you have indicated it previously, actually it is the case that the business processes should also run under CM.

MM: Yes, the whole process, if these are changed, one would have to run it through the CM change process, if the CM were fully implemented.

H: Yes, it also depends on that there are several different perspectives of CM. There is the CM for the company and there is CM within a project and that is of course positioned totally differently, The CM for the enterprise focuses mainly on the company-specific processes, such as processes that are established, including HR processes, financial processes and everything under it. The project-specific ones are really specific to the

project technically. These are then already two points of view and often one concentrates only on the technology.
That's not bad, but it can't be that on the one hand you concentrate on the technical side and perform CM there but only at the end change and adapt the processes as you want on the company level. I would say, that must be handled in an orderly way. That's still important to figure out.

MM: First of all, how is CM positioned in the company and then one must consider the product and ask what the company produces. Generally, it is the case if there are products where there is a high product liability, therefore it involves risky products, it is more worthwhile to do more as far as CM and traceability is concerned.

H: Yes, right. I think if you work in the medical sector, for example, you won't be able to sell products where you can't guarantee traceability. You won't get the approval to produce a product if you can't ensure the quality system or the CM system is guaranteed. Yes, product liability is certainly also an issue. You just have to be careful with the interview question that you don't enter the area of showing the benefit of your side as an interviewer, but you want to find out what the benefit is for the company.

MM: I have to formulate the questions as openly as possible, because otherwise I will get manipulated answers.

H: Yes. If you say product liability to Configuration, then he'll tell you something about CM and how they ensure it is safe, but is it really so, does it come from him that product liability is a problem and we actually need CM. You know what I'm saying? If you mention the keyword product liability, then the alarm bells will ring with me, then I know what you want to hear.

MM: Then I've practically already given something away. That shouldn’t happen.

H: That's it. That's the point, I think. Yes, and the other thing is as soon as you find out that they have CM in their company you could ask: if you measure this, do you measure the process. If you're measuring, then what are you measuring.

MM: Then when you measure, what are the results and how do you validate these results?

H: I think you can measure anything.

MM: It must also be comparable. Large project or small project.

H: Yes. Therefore, for example, if we now measure changes after design freeze, in every project I have design freezes. It doesn't matter if I have a big project or a small project. However, if I always have design freeze corrections at FDR or after FDR, then I immediately have a problem in the process. Then the people are either not prepared for the FDR or the design is too poor or whatever. That doesn't release me from this situation, where for example I realise that I always have a problem after the design freeze in FDR to tackle and analyse, then what are the errors that always occur there. What do I always have to correct and then again introduce targeted corrections in the processes and possibly within the organization? With training or whatever. You can, we've asked different companies, what do you measure in terms of KPIs in a CM process? Nobody can really say what the smartest thing is to measure.

MM: Yes, that's exactly the point.

H: We have now defined for ourselves. We measure how many corrections we have after the design freeze and we focus primarily on the FDR, because you see you have the possibility to work with red corrections on the prototype. It's not so important what I measure there, but after the FDR it has to be clear. The last milestone to introduce corrections.
We measure that, we always measure our process costs for one thing, the project costs, that is another part and also the lead time. So, if we define

feasibility milestones, for example, when does the CDR take place, maybe some two months after the customer's order is received. How do we stand on this date? Can we keep this date or are we going beyond it? We also measure divergences from the planned targets. Whether that is a meaningful number to measure the benefit of a CM is questionable.

MM: The problem that I see here is that you have a problem with large or small projects, because these are absolute numbers and not percentages. That's why I've actually come to the conclusion that the best thing is to measure deviations in percent. One simply says that one has them and the requirement, then one has deviated so and so much percent.

H: Yes, but the problem with the requirements also depends on the complexity of the project. It's insanely difficult, so you can't just make a general statement. You can say, yes, you keep the proposed milestones for the most part, or and if you then have deviations, you must actually specifically commit to the individual deviations and say what actually was the problem there. Incorrect delivery, incorrect information, etc. You can't avoid it. We really went to a lot of trouble and said what can we actually measure. But it's incredibly difficult. I think basically the benefit of CM is not necessarily measurable one to one. If a project goes through smoothly right from the beginning, of course there are always corresponding problems, but if these are of a technical nature, process-specific or organization-specific then CM definitely has a part to play in this occurrence. I don't think a project will go through smoothly if you don't have CM. I'm convinced of that.

MM: This is of course difficult when you say a project will not progress smoothly if you don't have CM, but it lacks comparability because CM is there. You would have to say how the project would have progressed if we didn't have CM.

H: Yes, you already have the comparisons, you can say the CM is there, but is it involved? Of course, you have CM, you say our company is EN9100 certified. Then you must have CM. Whether CM is established in projects

is a different matter. It doesn't have to be. For some reason it doesn't have to be, it could be that for example project management said we have to save costs and we save them on CM. Or any other reason.

MM: In general, it would be interesting to compare such things and simply state: Before and After. For example, companies that introduced CM a few years or a year ago ask what was it like before and after. Such comparisons.

H: Yes, clearly only the company is growing and is gaining experience. Maybe it didn't have CM once, and it realised it needed CM. I have, for example, the comparison of CM in space flight to CM in aviation. It's certainly two pairs of shoes. So, basically the topics are the same everywhere, but for example, I notice the CM we now do, we are not an OEM. We do maintenance with plus or minus a few modifications to it. However, now for example with the Ariane carrier rockets which we have manufactured ourselves the Traceability is naturally important up to the last rivet. That of course has led to, I remember it was ten to fifteen years ago when we still had Ariane 4 payload fairings, they were riveted together with thousands of rivets and at one stage the rivet supplier came and said: hey, for the rivets in that batch the surface protection and the grease coating on the rivet head is wrong, a production defect. Then you had to be able to see which payload fairings that were in production, those already standing somewhere in Kourou on the launch pad that have been produced with this rivet batch. You have to rework those. That's a horror scenario. This is really a top-level requirement of CM and no reason for lower standard products. You don't want that but under the circumstances you hate the problem of product liability here, or if something happens to this product.

MM: In general, the higher the value, the more traceability you have to have.

H: Yes, of course. This is a difficult topic to measure and show the benefits of CM because much depends on the experience actually gained in the

projects, in large projects, and to show there how it would actually have worked without CM, you can't do that.

MM: Of course, if one had an ideal scenario, then one could juxtapose this with that, but one doesn't.

H: Yes, it is. It is also important what they have actually established in CM, for example if they perform it according to CM2 then they have established the Change Managers 1, 2 and 3. If they have established something like that, then you can already identify the benefit, because then it is relatively well-established.

MM: In the case of Change Managers 1, 2 and 3, in many companies it is the case that Change Managers 1 and 3 are the same person. If there's three people on it, it's pretty expensive. As it is said CM2 is not very practical because only very few companies can employ three change managers.

H: It always depends on how big the company is and what they are dealing with. I am convinced, I think CM is more and more important.

MM: It can be clearly seen in recent years that CM is becoming more and more important and this can also be seen in areas outside aviation. The question is how can you convince managers more easily that CM is an advantage, it is useful to establish it in other industries, where the regulations like EN9100 don't exist, so that you have better reasoning possibilities.

H: I can still tell you that we had an order from the SBB, the Swiss Federal Railways, and it was actually frightening to see that they didn't actually establish a CM. They buy trains somewhere and make changes to the trains but they have been screaming for help that they could be provided with CM support.

MM: I think we're through. Many thanks Reto

H: You are welcome

Analysis:

Excerpts to Degree of individualization of CM:

[1] I have, for example, the comparison of CM in space flight to CM in aviation. It's certainly two pairs of shoes. So, basically the topics are the same everywhere, but for example, I notice the CM we now do, we are not an OEM. We do maintenance with plus or minus a few modifications to it. However, now for example with the Ariane carrier rockets which we have manufactured ourselves the Traceability is naturally important up to the last rivet.
[2] It always depends on how big the company is and what they are dealing with. I am convinced, I think CM is more and more important.

Paraphrase:

[1'] In RUAG the CM comparison between the production of the Ariane carrier rockets payload fairing and the maintenance with the modification of military jets are possible. For the space production the traceability is even more important.
[2'] The importance of CM is increasing generally but it is also depending on the product of the company.

Reduction and Summarisation:

Generally the importance of CM is increasing but CM in space business is even more important than in aviation.

Conclusions:

The importance of CM is increasing and depends on the product.

Excerpts to Complexity:

[1] "Not so long ago, we have defined KPIs (Key Performance Indicators) to measure our process. That's when we said we need to know how many corrections we have after a design freeze. That means when we look at the development process, we have a PDR (Preliminary Design Review), we then have a CDR (Critical Design Review) and then we have a Final Design Review before the prototype flies."

[2] “If you get involved from the beginning to establish an order baseline, and you can establish these are the requirements, the customer requirements, every time a fresh change comes from outside or inside, you can hold up your hand and say, hey these are customer requirements and if the customer comes with a new requirement, you can request money, you have to charge money, so you get feedback back from the project itself and actually also for new projects, that added value is there, as you are involved from the beginning.”

[3] “Yes, it also depends on that there are several different perspectives of CM. There is the CM for the company and there is CM within a project and that is of course positioned totally differently. The CM for the enterprise focuses mainly on the company-specific processes, such as processes that are established, including HR processes, financial processes and everything under it. The project-specific ones are really specific to the project technically. These are then already two points of view and often one concentrates only on the technology. You won't get the approval to produce a product if you can't ensure the quality system or the CM system is guaranteed. Yes, product liability is certainly also an issue.”

[4] “If a project goes through smoothly right from the beginning, of course there are always corresponding problems, but if these are of a technical nature, process-specific or organization-specific then CM definitely has a part to play in this occurrence. I don't think a project will go through smoothly if you don't have CM. I'm convinced of that.”

Paraphrase:

[1’] There are KPIs defined for all processes and project phases.

[2’] It is important to be involved at the beginning of a project and establish the order baseline with all customer requirements. In complex projects the overview can be maintained and the customer can be charged for additional modifications.

[3’] Both the company view and the complex technical project view must be kept in mind. This is the only way to ensure that the quality of the CM system is sufficient.

[4’] The application of a comprehensive CM system is essential for complex technical projects to function without major disruptions.

Reduction and Summarisation:

CM has to be involved from the beginning in complex technical projects. Without the use of CM, the success of these complex technical projects cannot be guaranteed and there will definitely be additional costs.

Conclusions:
Complex technical projects are not possible without the use of CM.

7.2.9 Interviewee I:

MM: I want to find out how to measure the benefits of CM in the aviation industry as effectively as possible and how to convince the management, as you say in CM2. Since you work for CM2 you have a very good overview.

I: CM is required by law in the aviation sector. But there are also industries where there is no legal requirement, but it makes sense. These are, for example, the pharmaceutical industry and the car industry. Not all aerospace manufacturers apply CM to the same extent and use the same standards. CM is used in both software development and hardware development. However, the terms are different. No matter whether the traditional CM is measured or the CM2 is measured, the goals are achieved. That is primarily the reduction of rework, which is the ultimate goal. You can measure that, there is a white paper from CM2. There are formulas where you can see how the rework goes back. In general, you can say that the number of errors must be reduced and the number of improvements must be increased. This can be measured in quantity but also in dollars and euros. Through a proper CM the risk is reduced and everything can be understood. In the aviation sector or in general there are companies that import material and then export finished products again. In the aviation sector there are many suppliers who supply raw materials from all over the world. They have to pay import duty for that. This import duty is normally gone, but if they can prove how much raw material was used when exporting the finished aircraft, they can recover a part of the import duty. To do this, however, they must prove exactly what

was used when and in what quantity. Furthermore, a deadline must be observed for the settlement. For example, within two years the material must be re-exported. CM plays an important role here and with a good CM traceability should not be a problem. The main problem is that the material comes in, but is not exported in its raw condition, because it is used further. Here it must be proven exactly which titanium was used in which assembly, when it was purchased and where it was subsequently used.

MM: There is extreme potential behind it. Not every company generates the same benefits from CM. Which companies have special benefits from CM.

I: Especially companies in the aviation sector with high complexity and the associated risks have an increased interest in CM to make these risks manageable. With a good CM you can make all traceable.

Analysis:

Excerpts to Complexity:

[1] That is primarily the reduction of rework, that is the ultimate goal.

[2] Especially companies in the aviation sector with high complexity and the associated risks have an increased interest in CM to make these risks manageable. With a good CM you can make all traceable.

Paraphrase:

[1'] The reduction of rework is the most important KPI for measuring the benefits of CM.

[2'] Companies with high complexity and the associated risk have interests in CM.

Conclusions:

The benefit of CM can be measured by the reduction of rework.

Excerpts to Potential:

[1] The main problem is that the material comes in, but is not exported in its raw condition, because it is used further. Here it must be proven exactly which

titanium was used in which assembly, when it was purchased and where it was subsequently used.
Paraphrase:
[1'] Through the intensive use of CM, there are new business models, such as the refunding of import duty on raw materials when the finished product is re-exported.

Conclusions:
The application of CM enables for certain products new business models.

7.2.10 Interviewee J:

MM: I want to find out how to measure the benefits of CM to convince the management of CM.

J: We do not measure the benefit of CM. With us, the goal when an aircraft is delivered or a modification is implemented is that the hardware is compliant with the documentation. We can now jointly develop measurement methods, but I cannot report on any. For us CM is important to the authorities. It would be important to find companies that introduced CM not long ago. You could do a before and after comparison. You could measure something from that. Before, for example, a project had a certain lead time and afterwards it might have been faster. Or before it was more uncoordinated and therefore more meetings were needed. However, the introduction of CM should not have taken place too long ago, otherwise the information is no longer available to the necessary extent. In my company CM has been around for a long time and therefore I cannot make a before-after comparison.

MM: For which applications do you find CM particularly important?

J: Complexity of products of processes and procedures where you have to combine a lot. Especially for start-up companies, whose product becomes more complex, the importance of CM increases massively. For example, if

they had only one product before, CM wasn't that important. If, for example, the number of products and the variety of variants increase, the control of the construction documentation becomes massively more complex. From my point of view, complexity is the most important criterion. Other important questions are how many external interfaces there are and how often the product is changed. If I have a product that has been identical for ten years and will not change in the foreseeable future, CM is not important. If, on the other hand, continuous optimizations are necessary, I have to change frequently and I need a tool with whose help I can manage the effectiveness. Quality measurements are another possibility. At the beginning I have requirements for my product to be developed. After production, for example, I notice that the requirement has not been met. This implies a lack of CM and unforeseen costs for reworking or re-development. I'm losing time because of this. That would have to be recognised and that would be the potential I could realise through my CM. Then I can tell you how close I get. Ideally, I have the product 100 percent according to the requirement I got from the customer at the beginning. The delta I have today I have to determine and that is my potential that I can realise.

MM: So you would have to define an ideal line and then measure the deviation from it.

J: So you have to calculate the costs I have because I don't reach the goal I defined at the beginning. It's the rework or redesign. If there is no awareness for CM, you will have problems implementing your goals. You have to become aware of what goals you can achieve with CM. I conduct a CM training once a year and try to communicate the benefits. An important aspect of CM is to enable clear communication to avoid misunderstandings. Time is also an important measure. The Configuration Manager must have the overview and coordinate the time accordingly so that the deadline can be reached. By the good overview which the CM provides over the product, costs can be optimized for example also in co-operation with the purchase, which could also be measured. A big advantage of CM for us is also the management of the influences of

changes on our aircraft documentation such as pilot manual maintenance manual or limitations. The change description is our communication tool and is controlled by CM. It is important that the quotation baseline is frozen so that later changes can be identified and invoiced. The entry of these clearing figures could also be a measurement variable.

MM: Many thanks for the interesting information.

Analysis:

Excerpts to Complexity:

[1] Complexity of products of processes and procedures where you have to combine a lot. Especially for start-up companies, whose product becomes more complex, the importance of CM increases massively. For example, if they had only one product before, CM wasn't that important. If, for example, the number of products and the variety of variants increase, the control of the design documentation becomes massively more complex. From my point of view, complexity is the most important criterion. Other important questions are how many external interfaces there are and how often the product is changed.

Paraphrase:

[1'] The importance of CM increases with the complexity of processes and procedures. The complexity increases with the number of products and the variety of variants, because the design documentation becomes massively more complex. Another important factor for complexity is the number of interfaces and the number of product changes.

Reduction and Summarisation:

The importance of CM increases with the increased complexity of processes and procedures.

Conclusions:

Complexity is the most important criterion for the importance of CM

Excerpts to Potential:

[1] At the beginning I have requirements for my product to be developed. After production, for example, I notice that the requirement has not been met. This implies a lack of CM and unforeseen costs for reworking or re-development. I'm losing time because of this. That would have to be recognised and that would be the potential I could realise through my CM.

Paraphrase:
[1'] The requirements defined at the beginning of a project are often not met. This implies a lack of CM and causes unforeseen costs for reworking or re-development and a lot of time is lost. The correct application of CM has the potential to meet the requirements defined at the beginning.

Reduction and Summarisation:
Requirements defined at the beginning of a project are often not complied and CM has the potential to ensure compliance.

Conclusions:
CM has the potential to ensure an effective Requirement Management.

7.2.11 Interviewee K:

MM: Do you measure the value of CM in the organization and how?

K: CM value is not measured

MM: What is your experience about the results?

K: Implemented CM process / tools must fit to organization's need
Wrong CM implementation might cause negative impact
Qualitative arguments available based on experience
Quality Assurance is not possible without sound basic CM implementation
Engineering Quality Assurance is Configuration Management

MM: How would you improve the measurement?
K: As designed / as built comparison statistic

MM: Which questions do you see worthwhile to ask in additional interviews (to companies with less intensive CM application)?

K: Do you see need for CM?
What benefit do see in your organization?
Does your top level management support CM?
On what level / department in your organization is CM allocated?

Conclusions:
Since the interviewee Mr. Benke did not agree with a sound recording, I received a compressed written answer of the questions from him.
Key statements of this interview are: The CM process must match the needs of the company and be tailored to the complexity of its products.

7.2.12 Interviewee L:

MM: Thank you Interviewee L for allowing me to interview you for my doctoral thesis in the field of CM. I am currently writing a doctoral thesis entitled "How do I measure the benefits of CM in the aerospace industry". I came to you through lectures you gave in Zurich where I was very enthusiastic about the decades of background you have in the field of aviation and space travel. I think you can give me a lot of useful information. I see CM not just as the discipline of managing parts or documents, but as the discipline of managing the entire process infrastructure of the enterprise. My first question is: To what extent did you deal with CM in the space sector?

L: Yeah, I have to say other people did. As an astronaut, you have to train to complete a mission with the greatest chance of success, so the idea is to really succeed. We are almost obsessed with the idea of success. Of course, CM, where is CM in many areas for example planning the use of time in orbit when we are up there. For me that was four times with the Space Shuttle in the 90s and preparing all the means we need to carry out the mission. Typically called Flight Data File. Flight Data File is the most important document, at that time it was still paper, now it is much more

natural to have electronic documentation on board. We had checklist procedures but all this was made by other people although in the content of the procedures we were very involved. The mission once again always had an absolutely clear goal e.g. to do some repair work on the Hubble Space Telescope such as changing gyroscopes, changing cameras, changing Hubble's main computer had to be done in 99 and you don't just have to learn the nominal mission how to do it. We must study many ways what to do if that and that is not possible. Once again, we want to be successful but this CM was done by other people but we received the results of this management, these are procedures and we were involved in these procedures that are clear. We have to study a lot of ways what to do if you can't and can't do that. And then the whole training how it works, what you have to learn, when you have to slow down a bit in training that we are not too tired when we go up there. This was also due to the great experience of the NASA Mercury program Gemini program and especially the Apollo program you learned a lot about how to plan and train a mission so we have a great chance of success.

MM: CM was used for the first time by the Missile programs in the USA because the technology was so complex there were many versions of products and thousands and thousands of parts that you just must keep track of. Even if a part doesn't work, you know why and you can intervene accordingly.

L: Yes of course we weren't involved in the engineering, the Space Shuttle was a very complex machine and it was of course designed, built, and then tested by space specialists. We were in the so-called operational side. There was a very large document called Failure Mode and Effect Analysis (FMEA). NASA and the industry involved in the construction and testing of the Rockwell International space shuttle in California produced it. The idea was we needed to think that different parts don't work anymore, what can you do so that you can still accomplish the mission or if it develops too far into the area of failure or problems, then you have to know how to survive. There was always this..... Apollo 13 was a good example. There was a clear goal to land at a certain point on the lunar

surface. Then this big explosion happened during the part of the journey direction to the Moon after the Trans-lunar Injection. A trans-lunar injection (TLI) is a propulsion manoeuvre used to set a spacecraft on a trajectory that will cause it to arrive at the Moon. They had set direction to the Moon and there was a Bang, a big explosion in the hydrogen tanks. Then immediately the mission goal became to save the crew where in most cases you have it all in your head but it is maybe not all in the head of the astronauts, and it was all planned in books at this time, now it's more electronic at the space station for example. There were so-called flight rules, if that and that and that happened then you do that and that. One changes the mission objectives or one only does a part of the mission objectives and if it really isn't possible, one simply tries everything to save the crew. This practical CM was not done directly by us but by the operational CM side of the product, that we were involved is clear.

MM: Did you have any experience during a space flight that something didn't work, that you said now you are dependent on CM or that it helped you.

L: Yes, fortunately I have never been in a situation where it was so dangerous, where we feared that we would lose our lives, we could not survive that was never the case. Unfortunately, it was the case for some of my colleagues who did not come back from their mission. That was the Challenger in 1986 and Columbia in 2003. We had a lot of problems. Not so many with the space shuttle, that was luck in the end. Complex machines mean there are many ways for a complex machine to no longer function. We have always had problems with the Space Shuttle but with the redundancy of the Space Shuttle, small problems. We had a lot more computers than we needed. We had more inertial measurement units, we had more hydraulic systems for re-entry, for approach and landing than we needed. If one fails, we could still complete the mission. We had problems on the shuttle but that it was always in the area within the redundancy so we could continue the mission. We had a lot of problems with Hubble. Hubble was never visited during a shuttle mission until 1993. I was there on the first visit in December 93 when we encountered many

surprises with Hubble, but we could always solve them, sometimes with the help of the ground.

MM: I can remember well during your lecture when you said joy reigned.

L: You're right. Of course, we always tried to keep in a good mood. This is very important. It's hard work, it's dangerous, one has to be in a good mood. Happiness ruled. There was happiness when we had success especially for missions where we are not sure that it will work. This was the case for Hubble's first visit. Installing the optical correction unit worked so that Hubble had good eyes again. It worked but we weren't sure and happiness surely prevailed when one realised, wow this time it worked. We saved Hubble.

MM: Yes that's a very valuable thing.

L: Yes, I must say for me my background is in astrophysics. I studied physics in Lausanne and astrophysics in Geneva, I was an astrophysicist and once you become an astronaut you can become an astronaut in different areas. There are test pilots, there are doctors, there are engineers or scientists. I was an astrophysicist before, and then as an astronaut I was asked if I would be willing to go with a crew of seven people to Hubble in late 93's and repair Hubble so that it functioned it didn't function earlier. And for me that was of course the best mission I could have imagined as a former astrophysicist.

MM: An ideal connection.

L: Not that my knowledge of astrophysics was useful, of course we didn't perform astrophysics during our flight, but we did everything we could to make Hubble function again to serve astrophysics. I'd say on the ground with all the astrophysicists who were waiting for a Hubble space telescope to work. It functioned after our intervention. It used to operate but with very blurry images and that wasn't very useful.

MM I conducted the interviews in two phases. In the first phase I have Configuration Managers who are experts in the subject and in the second phase where I am at the moment, I am in the process of obtaining practical benefits from CM. The work is about finding out how to measure the benefits of CM. I'm searching for metrics to establish a framework on how to measure the benefits of CM. From your point of view, what are useful parameters of CM measurement?

L: I'm not sure I understand that. Once again CM was not something we did. We were but a user of a setup where CM played an important role. We weren't directly involved in CM but in more practical things, like when we have a bolt and we want to take it out, it's too difficult then what does one do. There are all the decisions that must be made on the basis of our goals and our technical knowledge of the device and when I say ours it is the whole team not just the astronauts. We had experts on the ground who said yes, we could go a bit further with the torque from the motorized tool to solve the problem. Once again CM was not something, we were directly connected to but rather we had the benefits of CM. I would say our task was much more practical with many technical details we needed to know. Of course, always looking at the overall goal so whenever we were trying to achieve a difficult goal there are always many detailed phases but they all have to be focused on our overall goal of the mission, there was also an overall goal for each spacewalk where we were obsessed with achieving that goal for every part once again so that the overall goal was ultimately achieved. We repaired Hubble, yes. It's functioning again, yes. Once again, we have profited a lot from CM, management created by others. We were more involved in details to achieve clear and sometimes difficult goals.

MM. Thank you very much .

L: Please?

MM: For the interesting information.

L: It was a pleasure and thanks for the interest. I hope this will be useful. Once again, we were very involved in technical details, that was our job. We were confronted with every situation whether it was practical or how to make the management of the safety cable so that it doesn't pass around the telescope, then we can't manoeuvre anymore, those were practical details and of course there are also people who helped us on the ground during training to solve these problems. Then we proceeded with good knowledge of what to do although it is difficult to achieve a big change success to . And we have achieved success. Thank God (laughs)

MM: And thanks to your good performance.

L: And thanks to our training. The training was absolutely great. We trained with very lifelike equipment. For example, with the model of the telescope in water where we trained to simulate the weightless conditions, it was absolutely accurate like the telescope itself. Then we go up there, see the telescope and we say wow I already know that. I've seen it twenty times in water and I've worked with it there and I know it very well. Yes, that was exactly the same thing up there. And it costs a lot to have training equipment that is just like the equipment up there, which is sometimes quite complicated, but all the details. They opened Hubble's doors and inside there were instruments, there were cables, there were circuit breakers just like in the machine. That was great, that costs but the result was success.

MM: This practically means that the documentation was very accurate and it matched.

L: Yes

MM: I still have one question I would like to ask now, namely in other areas in which you have worked you have come into contact with CM. You were a pilot with the Swiss Air Force and with Swissair.

L: Yes I was also involved as I described myself as an astronaut in machines I had to repair. I had to know these machines well and I wanted the

documentation, for the DC9 Airliner that was the checklist, that was in the 70s. In the end it is not so much different than in the airliners today except that then much was manual, now there are a lot of electronics in the Airbus 320 or 330. One has to know the aircraft well technically and one has to train a lot with procedures one has, we were not involved in the creation of the procedures. For shuttle flights or Hubbel we were involved with something brand new, the DC 9 was flying 10 or 15 years before I arrived at Swissair and everything was already prepared, you can say we had to invent nothing. For Shuttle and Hubble you had to invent a lot. That was ultimately more interesting and we were involved in the construction of the procedures. In the military I was a squadron pilot with the Hunter for 22 years in the Swiss Air Force. We had procedures, we had to know the aircraft well from a technical point of view and we had to train a lot, because the aircraft is a device to carry out the mission, it was a ground attack aircraft, one has to use cannons rockets and bombs on simulated targets, of course one has to train a lot. This is difficult and dangerous. We were once again not directly involved in CM but included in the preparation of the mission as I said, route A route B or route C ,if route A does not work we still have B and C, we don't say if something goes wrong then we will return, we have something to do, we have the responsibility to do something properly even if there are mistakes and there are too many problems, if the aircraft has a big technical problem such as an engine breakdown then you just have to use the ejection seat. (laughs).

MM: Last but not least

L: But once again the idea is to accomplish the mission, we do everything so that we can accomplish it properly and if it’s not possible anymore, to survive. An engine breakdown when one can't reach a landing place as a glider and a Hunter without an engine wasn't a very good glider.

MM: Practically a stone

L: If one had that we used a so-called emergency landing exercise that one practised during training, one didn't turn the engine off but switched it to idle and then one tried to land where we could, if you can't, one wouldn't actually use the ejection seat in training but in reality, one would use it. One just had to do your homework, train well for every mission so that we have it in our heads and don't have to look at the map when we are low down at 800 km per hour, that is not possible. Always have in mind to carry out the mission properly if it is not possible, then survive. In space, ultimately, it was the same scenario but the objectives were different. There were no bombs, rockets and cannons and the targets were different but the concept was the same, to perform the mission successfully and if you can't, survive.

MM: It is very important that you can also decide very quickly, e.g. Hunter engine failure, altitude and then immediately decide what to do.

L: Yes and that can be achieved with training, never become panic-stricken and always keep a cool head.

MM: Yes, that's always the most important thing. Thank you.

L: Yes. It was short, but I hope it has brought you something.

MM: Yes, it was super, really awesome.

Analysis:

Excerpts to Complexity

[1] “[…] the Space Shuttle was a very complex machine and it was of course designed, built, and then tested by space specialists.”

[2] “The idea was we needed to think that different parts don't work anymore, what can you do so that you can still accomplish the mission or if it develops too far into the area of failure or problems, then you have to know how to survive.”

[3] “Complex machines mean there are many ways for a complex machine to no longer function.”

[4] “The training was absolutely great. We trained with very lifelike equipment. For example, with the model of the telescope in water where we trained to simulate the weightless conditions, it was absolutely accurate like the telescope itself.”

Paraphrase:
[1’] The space shuttle is a very complex machine.
[2’] The complex technical machines have to be controllable after the failure of critical parts.
[3’] Complex technical machines have a multitude of failure possibilities.
[4’] The training equipment must correspond technically exactly to the complex original.

Reduction and Summarisation:
As the space shuttle is a very complex machine there a multitude of failure possibilities which have to be controllable. The training equipment must have an exact functional mapping of the original.

Conclusions:
Space travel requires the CM to meet extremely high requirements. This is due to various reasons. Space is at the absolute forefront of technological development. The complexity is so high because there are a huge number of interdependent parts and it is very difficult or impossible to maintain or replace the parts during operation. Furthermore, international cooperation between different countries often takes place in space travel. This further increases the complexity because the individual systems must be compatible. Space travel is very cost-intensive and therefore it is important that the complex technical structures are professionally managed via CM. Particularly noteworthy is the high human hazard potential that must be minimized as far as possible

7.2.13 Interviewee M:

The interview began with a short introduction of myself and the doctoral thesis I was working on.
At the outset, I asked Interviewee M whether he would like to supplement the internal memorandum of 18 November 2014 concerning his appointment as CEO of RUAG Aerostructures with further personal data. He declined.
We then started to work on the core questions, which took about 30 minutes.

MM: Dear Interviewee M, how extensively did you come into contact with Configuration Management in your role as CEO and in other positions?

M: In my current position as CEO, I have relatively little to do with CM. In my previous roles I have often come into contact with CM. For example, in my function as Head of Production Control for Helicopter Production, there were many customer options for the product that had to be processed in close cooperation with CM. I also worked with CM as Center Manager Delivery Unit Components. A few years ago, I noticed an imbalance between the factual necessity and the internal significance that CM had de facto assumed. In general, I was mostly responsible for highly complex technical products involving many different configurations. However, as I said, my contact with CM has declined, since I moved to the position of Managing Director.

MM: I see that your professional experience has given you extensive CM knowledge and I'm sure you can answer my next question. How do you rate the usefulness and acceptance of Configuration Management?

M: CM is not only useful, CM is an absolute necessity without whose consistent application there is no traceability of the installed parts. Compliance with the clearly defined processes is absolutely necessary.

MM: I find the newly introduced management system, which is displayed as a process track very useful. Input and output are the most important variables. Already at the beginning of my work I thought about it and based my research on this model, whereby the KPIs are my essential

parameters. Which figures (KPIs) in connection with Configuration Management do you consider interesting as CEO? I have brought you a printout of our three process turtles for CM as a clue.

M: The most important point I see is complaints about misconfigurations. A clear distinction must be made between whether these complaints were discovered by the customer or whether they were established internally. In general, it must be ensured that there is complete traceability. For the KPI MOD evaluation time and adherence to delivery dates, I recommend a cluster formation. The changes must be categorized. The time frame must be proportionate to the complexity of the change.

MM: Perhaps you have already applied this approach in your career to date and can report on untapped potential in projects that could have been optimized by Configuration Management?

M: Often the delivery configuration did not match the customer's requirements. This was due to the fact that the CM did not function properly because no clear product structure was defined. This led to customer complaints. As a result, an elaborate datacleaning was necessary.

MM: The organizational position of CM is currently the subject of intense discussion among experts. At what level in the corporate structure do you position Configuration Management?

M: In my professional career I got to know CM in the program or engineering departments. Personally, I think CM is best positioned in engineering.

MM: Have you heard about the possibility of positioning the CM as a administrative department, as recommended by the CM2 Institute? This would have the advantage, if CM is operated as a management discipline, that all departments could be surveyed and better controlled.

M: Do you know any companies that have already implemented this? I don't know of any in aviation.

MM: I don't know any names either, but I will investigate.

M: Yes, you do that.

MM: As CEO, do you have the time available to personally deal with CM reporting in more detail?

M: I have operational key figures of “On Time Delivery”, all deviations and quality reporting presented to me. However, I do not know the exact cause of any deviation. I don't know if the deviation is CM relevant. In general, I get bundled information, where the percentage trend plays an important role. Absolute numbers are less interesting. This is also the case for other key figures, such as financial figures.

MM: Already in previous interviews it was pointed out to me of the necessity of percentage measurement. This information is very interesting for me. Thank you very much for the informative conversation and for taking so much time for me.

Analysis

Excerpts to Degree of individualization of CM

[1] A few years ago, I noticed an imbalance between the factual necessity and the internal significance that CM had de facto assumed.

[2] A clear distinction must be made between whether these complaints were discovered by the customer or whether they were established internally.

[3] However, I do not know the exact cause of any deviation. I don't know if the deviation is CM relevant.

Paraphrase:

[1’] There is an imbalance of the should be implementation and the actual implementation of CM.

[2’] It has to be a differentiated if a complaint has been discovered internally or externally.

[3’] The CM relevance of a deviation has to be traceable

Reduction and Summarisation:
There is the necessity of exact traceability and overview with the help of the correct extent of CM.

Conclusions:
The correct extent of CM application and the adaptation to different companies is important.

Excerpts to Complexity:
[1] For example, in my function as Head of Production Control for Helicopter Production, there were many customer options for the product that had to be processed in close cooperation with CM.
[2] In general, I was mostly responsible for highly complex technical products involving many different configurations.
[3] The most important point I see is complaints about misconfigurations.
[4] The time frame must be proportionate to the complexity of the change.

Paraphrase:
[1'] In Helicopter Production there are many customer options for the product.
[2'] Highly complex technical products have many different configurations.
[3'] Complaints about misconfigurations are the most important KPI.
[4'] The factor time has to be adapted to the complexity of the change.

Reduction and Summarisation:
The complexity of a product has influence one many different factors like time, customer options, different configurations and problems with misconfigurations.

Conclusions:
The handling of this complexity is not possible without a correct application of CM

7.3 KPIs for measuring efficiency and effectiveness of CM

This chapter is based on the work of Staats (2009, p. 136 f.f.).

Change Management

Percentage of change requests accepted

Formula

Percentage of accepted change requests

$$= \frac{Number\ of\ acceped\ change\ requests \cdot 100}{Number\ of\ received\ change\ requests}$$

Description of the KPI

The proportion of changes incorporated includes all accepted requirements that are incorporated into the project after the start of the project and thus change both the scope of work and the profitability. The requirements can be completely new, when modifications of existing requirements are available or even have an effect on already completed work results.

Origin of data

To calculate this key figure, a precise registration of incoming requests is required. All changes should be recorded, managed and marked with regard to their processing status across projects.

Evaluation

The percentage of accepted change requests can relate to an individual project, project groups, or the entire project portfolio. In addition, the collection can be detailed with regard to the requirement categories. The consideration of rejected requirements is also conceivable. The proportion of change requests accepted is relevant for performance and expense management, among other things. It is regarded as an indicator of the quality of the requirements. Rising values are signalising an increasing threat of not keeping the time schedule and project budget.

Change density during the reporting period

Formula

Change density (in changes per year)

$$= \frac{Number\ of\ acceped\ change\ requests}{year}$$

Description of KPI

The number of changes specifies the number of change requests that were implemented within an approved project. Appropriate target values with tolerance limits must be defined for each organization. Alternatively, you can enter the key figure as a volume of change requests.

Data Origin

The data for determining the number of changes comes from the change management records.

Evaluation

The number of changes is related to a single project, a project group or the entire project portfolio. In addition, a distinction can be made between approved and rejected change requests, the place of origin and the categories of requesters.
In general, change management is a central success factor for achieving goals in projects and an early indicator for meeting deadlines and budgets.

Number of changes during the project

Formula

Number of changes (in changes per project)

$$= \frac{Number\ of\ acceped\ change\ requests}{project}$$

Description of KPI

This key figure considers the number of changes made per project. Alternatively, the reference point can be a project group as well as a single project. It is also conceivable to consider the project portfolio average. The target values are organization-specific and, if necessary, product-specific.

Data Origin
All data for calculating the number of changes per project comes from Change Management, i.e. Configuration Management.

Evaluation
The key figure can be differentiated by change categories, project groups or individual projects and viewed accordingly. It is suitable as an early indicator of the intensity of change as an indicator of company stability.

Changes per project

Formula

Changes

$$= \frac{realized\ changes}{project}$$

Description of KPI
This key figure considers the number of changes made per project. Alternatively, the reference point can be a project group as well as a single project. It is also conceivable to consider the project portfolio average. The target values are organization-specific and, if necessary, product-specific.

Data Origin
All data for calculating the number of changes per project comes from Change Management, i.e. Configuration Management.

Evaluation

The key figure can be differentiated by change categories, project groups or individual projects and viewed accordingly. It is suitable as an early indicator of the intensity of change as an indicator of company stability.

Response Time

Formula

Response time (in hours / change request)

$$= \frac{\sum response\ time\ change\ requests}{number\ of\ change\ requests}$$

Description of KPI

The response time is the time span between the user entering a task and the time at which the first system reaction occurs. The response time must be precisely defined for each case with regard to start and end.

This key figure measures the average response time. This can be considered separately according to transaction groups, applications or application groups. Accordingly, the target values are determined transaction-specific.

Alternatively, the key figure can also be considered in terms of processing times.

Data Origin

The data for determining the response time is automatically recorded in monitoring systems. The data are often determined at centrally measurable points due to the high technical effort involved.

Evaluation

The response time is an important indicator from system operation. The response time behaviour correlates with customer and employee satisfaction. They reveal performance bottlenecks or problems in applications or infrastructure.

Data management of the business system

Rate of proposed changes

Formula

Rate of proposed changes (in change proposals per year)

$$= \frac{Number\ of\ change\ proposals\ submitted}{year}$$

Description of KPI
The proposed change rate reflects the number of proposed changes submitted during the reporting period. It is an indicator of the motivation and, if necessary, the need for changes.

Data Origin
The data is based on the number of change proposals submitted in the KM project business system and the change proposals of the users of the business system. You are to be investigated.

Evaluation
In the event of a decreasing rate of change proposals, the willingness to propose should be encouraged by appropriate instruments. In addition, employee motivation has to be increased and acceptance criteria for suggestions for improvement have to be examined.

Data management cost of business system per year

Formula

Data management cost (in $ per year)

$$= \frac{\sum workinghours\ datamanagement\ of\ businessystem * \frac{costs}{working\ hour}}{year}$$

Description of KPI

This key figure specifies the average data management costs for the business system during the year and therefore includes not only the direct data management costs but also the costs incurred for checking and looking at the business system of CM employees.

Data Origin

The amount of employee hours used to measure the annual data management costs for the business system is taken from employee reports from CM and from time recording in the sense of account assignment by employees. The personnel costs come from the personnel department.

Evaluation

The data management cost business system per year does not generally make any statements about the causes and the possible seasonal fluctuations. By the combined view with the data management cost per change proposal and the number of change proposals to the business system, you can increase the informative value of the key figure.

If the value of the data management business system increases per year, the number of changes received as well as the scope of the instructions in the business system must be checked and, if necessary, an idle time analysis of the employees supported by the data management of the business system must be carried out. This can be discussed within the employee appraisal interviews with regard to a under load. Structural changes in the structure of the business system must also be examined. If, on the other hand, the business system data management effort per year decreases, the above criteria must be examined accordingly.

Data management cost of business system per change proposal

Formula

Data management cost (in $ per change proposal)

$$= \frac{\sum workinghours\ datamanagement\ for\ the\ businessystem * \frac{costs}{working\ hour}}{number\ of\ change\ proposals}$$

Description of KPI

This key figure considers the average data management cost for the business system per proposed change.

Data Origin

The amount of employee hours for measuring the data management costs business system per change proposal is based on employee reports from CM and time recording in the sense of account assignment by employees. The personnel costs come from the personnel department.

Evaluation

The data management effort for the business system per improvement proposal can be improved visibly by considering the data management effort for the business system per year and the number of change proposals to the business system.

If the amount of maintenance required for a business system changes for each improvement proposal, the number of changes and instructions received in the business system and structural changes in the structure of the business system must be checked and employee appraisals conducted with regard to an over- or underload.

Processing time for change proposals

Formula

Processing time (in hour/change proposal)

$$= \frac{\sum Processing\ time\ change\ proposal}{number\ of\ change\ proposals}$$

Description of KPI

The processing time is the average time between opening and closing a change proposal to the business system. It therefore also includes interruptions caused by disruptions and waiting times.

Data Origin

The data for calculating this key figure comes from employee reports in the CM task area and from the account assignments of working time by employees.

Evaluation

The processing time for change proposals does not in principle specify the duration or the number of existing change proposals. An increasing or decreasing value of the key figure requires a cause analysis and employee interviews.

The processing time for change requests can be combined with the lead times of the change proposals.

Lead time for change proposals

Lead time I

Formula

Lead time I (in time units / units of measure)

$$= \frac{\sum Receipt\ of\ proposed\ change\ -\ decision\ on\ proposed\ change}{number\ of\ change\ proposals}$$

Description of KPI

Lead time I considers the average time from the receipt of change proposals to the business system until the decision on rejection or implementation. Both start and end must be precisely defined.

Alternatively, the key figure can also refer to all change proposals, both to the business system and to projects, to change proposals to certain project groups and to individual projects.

Data Origin

Employees must enter the data for determining lead time I as part of the task-related account assignment of working time.

Evaluation

Cycle time I makes no statements about the causes of its duration. These must therefore be analysed if the value of lead time I changes. In addition, employee meetings are to be held with regard to employee capacity utilization.
This key figure can be combined with lead time II and the processing time for change proposals.

Lead time II

Formula

Lead time II (in time units / units of measure)

$$= \frac{\sum Decision\ on\ proposed\ change\ -\ implementation\ of\ proposed\ change}{number\ of\ change\ proposals}$$

Description of KPI
Lead time II describes the average time from the decision to make the proposed changes to the business system until actual implementation. These points in time must be defined in concrete terms.
Like lead time I, this key figure can consider all change proposals, both to the business system and to projects, change proposals to specific project groups or to a specific project.

Data Origin
The data for calculating this key figure is recorded by the employees task-related time account assignment.

Evaluation
Note that lead time II only refers to the change requests to the business system that were accepted in CM. If the values of the lead time II change, an analysis of the causes and appraisals with regard to employee capacity utilization must be carried out.
This key figure can be considered in combination with lead time I and the processing time for change proposals.

Configuration Management Plan

Development costs Configuration Management Plan

Formula

Development costs Configuration Management Plan

$$= \frac{\sum workinghours \text{ development Configuration Management Plan } * \frac{costs}{workinghour}}{Number\ of\ CM\ plans}$$

Description of KPI

This key figure considers the costs incurred in drawing up a CM plan that conforms to customer wishes and operating requirements, based on a financial evaluation of the required working hours of the employees.

Data Origin

The employee hours for determining the development costs for a KM plan come from the employees working time account assignment. Personnel costs, on the other hand, are based on data from the human resources department.

Evaluation

This key figure can refer to a single CM plan, to CM plans of a specific project group, and to all the CM plans of the reporting period.

If the development costs change, the causes as well as the specifics of the CM plan and the number of subsequent necessary changes to the CM plan must be considered. Furthermore, the development costs for the CM plan must be set in connection with project key figures such as the special features of the project, the financial importance, the project duration and the quality of support.

Changes to the configuration management plan

Formula

Changes to the CM plan

$$= \frac{\sum Number\ of\ changes\ to\ \text{CM plan}}{Number\ of\ CM\ plans}$$

Description of KPI

This key figure determines the frequency with which a CM plan has changed after development or had to be adapted to the conditions or new requirements.

Data Origin

Changes to the CM plan are recorded by CM in accordance with company-specific documentation requirements. The number of CM plans can be determined using CM.

Evaluation

The changes to the CM plan do not generally provide any information about the causes and scope of these changes.

If the value of the key figure changes, the key figures that increase the informative value of the changes to the CM plan must be considered in particular. This primarily includes the project key figures. Furthermore, correlations must be established between the value of the changes to the CM plan and the scope and cause (internal, external) of the respective changes, as well as the scope of the CM plan in regard to its refinement in terms of development costs.

Maintenance costs of the Configuration Management Plan

Formula

Maintenance costs of the CM-Plan (in $)

$$= \sum (workinghours\ maintenance\ CM\ Plan\ * costs\ per\ workinghour)$$

Description of KPI

The maintenance cost of the CM plan considers the costs incurred for the development, the on-going consideration of its requirements, updates and the incorporation of changes.

Data Origin

The data for determining the maintenance costs of the CM plan comes from the working time account assignment of the employees and personnel costs from the human resources department.

Evaluation

The maintenance costs of the CM plan refers to a single CM plan, to CM plans of a specific project group, or all CM plans of the reporting period.
In general, project key figures such as the project support quality, the project personnel intensity, the project scope and the significance of the project as well as the key figures for the CM plan must be integrated into the analysis when the value of the maintenance costs of the CM plan changes.

7.4 Measuring the state of CM within your Organization (IPX, 2018)

State of CM within your Organization

- ✓ Eight topics
- ✓ Seven questions per topic
- ✓ 0 or 5 points per question
- ✓ Maximum points: 280

1. Configuration Management
2. Requirements Management
3. Change Management
4. Release Management
5. Data Management
6. Records Management
7. Dataset Control
8. Enabling Software

Process Efficiency of your Organization		
A	225 - 280	Core processes provide a competitive advantage. Intervention is minimal. Real improvements are robust.
B	170 - 225	Core processes have many strengths and areas needing improvement are recognized and being addressed.
C	110 - 170	Confidence in the CM2 principles and their application is growing as corrective action is declining.
D	55 - 110	The CM process has many weaknesses. The organization is deeply mired in corrective action.
E	0 - 55	The CM process is ineffective, there is no accountability. Firefighting is considered to be business as usual.

Self Assessment (5 = Yes, 0 = No)

	1) Configuration Management	Points Earned
1	Configuration management (CM) is a formally recognized function within your organization.	
2	The scope of CM includes all information that could impact safety, security, quality, schedule, cost, profit or the environment.	
3	The emphasis of CM is to accommodate change, keep requirements clear, concise and valid and ensure that results conform.	
4	Configuration requirements are maintained in baselines and updated with each change	
5	Each baseline includes both as-planned and as-released requirements and visibility of planned changes.	
6	Each baseline is closely coupled with a closed-loop change process that includes fast-track capability.	
7	Metrics are used to monitor performance of the configuration management process and guide continuous improvement efforts.	
	Total Points:	

	2) Requirements Management	Points Earned
1	A requirement is not a requirement unless it is captured on a tangible media, validated and released.	
2	Requirements must lead and results must conform.	
3	Each dataset is a requirement to its user and each user is responsible for achieving results that conform.	
4	All work is authorized and controlled with change objects.	
5	Results of work accomplished must conform to requirements specified on the change objects.	
6	Usage of deviations and waivers would be greatly reduced if it did not take so long to update or correct the requirements.	
7	Metrics are used to monitor performance of the requirements management process and guide continuous improvement efforts.	
	Total Points:	

Self Assessment (5 = Yes, 0 = No)

	3) Change Management	Points Earned
1	As-planned and as-released baselines, and all datasets contained in those baselines, are updated with one common change process.	
2	Each change goes through an analysis phase and, if approved, an implementation phase.	
3	Standardized change objects are used as templates to guide each change through each step of the process.	
4	Business decisions are separated from enterprise change assessments and implementation planning details?	
5	For changes categorized as fast-track, document creators may approve their own technical recommendations.	
6	All primary items and datasets impacted by a change are specified on the CN object.	
7	Metrics are used to monitor performance of the change management process and guide continuous improvement efforts.	
	Total Points:	

	4) Release Management	Points Earned
1	A new or revised dataset, once released, cannot be changed without proper CN authority.	
2	A dataset must be validated before it can be released.	
3	A dataset must be released before it can be used?	
4	Although release dates must support the earliest need dates, datasets are nevertheless released on a just-in-time basis.	
5	Baselines include both planned and actual release dates for new and revised datasets.	
6	Planned release dates are used to drive all development resources with one common set of priorities.	
7	Metrics are used to monitor performance of the release management process and guide continuous improvement efforts.	
	Total Points:	

Self Assessment (5 = Yes, 0 = No)

	5) Data Management	Points Earned
1	Each Physical item and each dataset has its own formally controlled metadata.	
2	Each physical items has a formally assigned identification number, name and description.	
3	Physical items that are not fully interchangeable are not allowed to carry the same identification number.	
4	Standardized and formally applied conventions are used to name each physical item and describe its attributes.	
5	Similarities and differences between the various physical items are derived from their names and descriptions.	
6	It is understood that resource effectiveness declines exponentially with a linear decline in the integrity of datasets used in-series.	
7	Metrics are used to monitor performance of the data management process and guide continuous improvement efforts.	
	Total Points:	

	6) Records Management	Points Earned
1	Forms used to authorize and control work are completed and retained as records of work accomplished.	
2	Each as-built item must conform to its as-built/as-modified record.	
3	Retained records include proof that the results of authorized and accomplished work did, in fact, conform to the requirements.	
4	Changes requiring traceability can be tracked to specific end-items via retained records.	
5	Old and new items are easily identified via retained records.	
6	Lot controlled items are traceable from their original source to their current location via retained records.	
7	Metrics are used to monitor performance of the records management process and guide continuous improvement efforts.	
	Total Points:	

The Results

	CM Categories	Points Earned
1	Configuration Management	
2	Requirements Management	
3	Change Management	
4	Release Management	
5	Data Management	
6	Records Management	
7	Dataset Control	
8	Enabling Software	
	Grand Total:	

Where is your Organization?		
A	225 - 280	Core processes provide a competitive advantage. Intervention is minimal. Real improvements are robust.
B	170 - 225	Core processes have many strengths and areas needing improvement are recognized and being addressed.
C	110 - 170	Confidence in the CM2 principles and their application is growing as corrective action is declining.
D	55 - 110	The CM process has many weaknesses. The organization is deeply mired in corrective action.
E	0 - 55	The CM process is ineffective, there is no accountability. Firefighting is considered to be business as usual.

Self Assessment (5 = Yes, 0 = No)

	7) Dataset Control	Points Earned
1	Released information is retained in secure repositories and accessible when needed.	
2	Individual dataset objects are identified by type, number and revision level.	
3	Dataset formats are standardized by dataset type.	
4	Rather than ownership by a single individual, each dataset is co-owned by its assigned creator and one or more users.	
5	The assigned creator is the one who best understands the higher-level requirements.	
6	Over 80% of all datasets are relatively simple and are co-owned by a creator and a single user.	
7	Metrics are used to monitor performance of the dataset and library control process and guide continuous improvement efforts.	
	Total Points:	

	8) Enabling Software Tools	Points Earned
1	Your organization understands the software functionality required to support baselines and the closed-loop change process.	
2	The strengths and weaknesses of existing software tools have been defined and agreed upon.	
3	Solutions for resolving the identified weaknesses have been agreed upon.	
4	Needed improvements in software functionality have been given the appropriate priority.	
5	Those who direct the software development and upgrade activities are IPE/CM2 certified.	
6	CM2 grads in your organization are ensuring that needed functionality is being achieved.	
7	Metrics are used to monitor performance of the enabling software tools and guide continuous improvement efforts.	
	Total Points:	

7.5 Analysis of the themes

7.5.1 Individuality

What I just wanted to point out, we have just introduced these score cards for the important suppliers. As you can see, there are no most important KPIs in this sense. These are the things we're recording right now. Of course, these are not mathematical KPIs. There are of course Score Cards (A-F), behind which of course the individual information stands. (Participant A)	KPI Individuality
If there was a typo correction, then of course it's something different than if the design was really nonsensical. (Participant A)	KPI Individuality
To measure the weighting, that is exactly the difficulty. You have the numbers. You already know how many open changes there are. Then you can compare with different MSNs (aircraft). The first 50 are difficult, then it gets better and better. There are fewer concessions, the curve goes down. (Participant A)	Individualisation of measurements
This can be used to determine how many percentage points were caused by the config. For example, this could be a maximum of 20 percent CM. (Participant A)	KPI Individuality
Especially at the beginning there is a lot of discussion between Airbus and the Suppliers. They say it's not in my contract to do CM. That will have to be renegotiated first. I can remember	Company Individualisation

the story about the manufacturer of slides who made a very simple window slide, and who was hard to educate about why he had to stay up to date. The supplier of a super simple product thought he could make ends meet without CM and didn't realise that he was classifying himself as a complex product. That is why the OEM, in this case Airbus, demanded a certain configuration standard. (Participant A)	
Some say we could make more profit if we delivered less quality, if we did less internally to maintain the high quality. (Participant A)	Product Individuality
Thus, the part of the configuration process that directly affects the customer, is essentially the change process, the customisation process and for all that there are surveys. This is a large number of KPIs that report status. One can't say there is a KPI where you can now say that CM was good or bad. (Participant A)	KPI Individuality
The more complicated the part or product that the suppliers we support become, the more they have to move towards full CM. The dependence is there absolutely. For those who deliver a very simple product ("Built to Print", we design the finished product), this is reduced to a few important points. (Participant A)	Product Individuality

They do very little reuse in shell construction and interior finishing, because they plan individually and are architecturally designed so that it is simply not worth doing. What they do however, is change management and that is to the point, because they have fixed-price contracts with their customers then tighten the specification and say, I am now delivering the ship. If the customer still has change requests, then he must pay extra for these. (Participant A)	Product Individuality
In aviation, for example, the ICAO structure is organized in chapters; in the rail sector, there are ISO standards, where there is a functional structure for trains. We have made projects in the field of ships and submarines, where there are also structures. In tank construction it is the so-called Gatel structure, i.e. also a standardized functional structure. This means that very many companies have functional structures from within their industries where they can structure the systems. (Participant B)	Product Individuality
So we really go on, we stay with a product from requirement to phase out, go through these configurations and try to analyse what the customer has already using in these configurations, what he needs, what he doesn't need. (Participant B)	Product Individuality

That doesn't mean every industry needs the same thing. (Participant B)	Company Individualisation
There are new business models. We may now be able to sell a blood diagnostic machine or an entire laboratory facility to customers who would not have been able to afford it before, because they had this one-time financial contribution but if I now charge via Services that is a completely new business model and that is another story. It is therefore also about presenting in the form of KPIs, there are new EBIT opportunities. New processes where I can generate an additional EBIT. (Participant B)	Product Individuality
It's therefore difficult to say they are the standard KPIs, there's a standard procedure as we find the customer specific KPIs, that's there, but CM is so enormously broad the data integration that it's most difficult to say there is this table. (Participant B)	KPI Individuality
Most of them have systems that are different in nature. Of course this depends on the size of the company as well as on the products they produce. The individual methods often differ considerably in scope but also in terms of content and the way in which they are carried out. Of course, the scope also depends on the complexity of the product or products, but not	Product Individuality

only with complicated products, some companies have relatively simple systems others very well elaborated systems, which produce essential results. (Participant D)	
It depends what you want. Do you want a big variety of process indicators and figures or do you want to have two or three informative and highly diagnostic process indicators, whose data you can collect continuously and consistently? (Participant G)	KPI Individuality
You only achieve comparability among different projects by thinking in percentage terms. 100% for example means "conditions are compiled" 110% means 10% over fulfilled 90% means 10% below your expectations or 10% over your budget. (Participant G)	Individualisation of measurements
That's the reason why I would first ask about the legal standards or normative requirements companies have to cope with. (Participant G)	Company Individualisation
I have, for example, the comparison of CM in space flight to CM in aviation. It's certainly two pairs of shoes. So, basically the topics are the same everywhere, but for example, I notice the CM we now do, we are not	Product Individuality

an OEM. We do maintenance with plus or minus a few modifications to it. However, now for example with the Ariane carrier rockets which we have manufactured ourselves the traceability is naturally important up to the last rivet. (Participant H)	
It always depends on how big the company is and what they are dealing with. I am convinced, I think CM is more and more important. (Participant H)	Company Individualisation
A few years ago, I noticed an imbalance between the factual necessity and the internal significance that CM had de facto assumed. (Participant M)	Company Individualisation
A clear distinction must be made between whether these complaints were discovered by the customer or whether they were established internally. (Participant M)	KPI Individuality
However, I do not know the exact cause of any deviation. I don't know if the deviation is CM relevant. (Participant M)	KPI Individuality

7.5.2 Complexity

Then try to evaluate, but when evaluating you are very quickly involved with the human component and feeling. It is difficult to say when it	EC1

could be or may be a configuration problem. (Participant A)	
The will to have a unified tool landscape from Airbus, or shall we say to reduce the many tools. (Participant A)	IC3, IC4 EC7, EC8
In the supplier organizations too, the whole issue has been underestimated because the development effort is so great. Especially due to the high proportion of customisation. (Participant A)	IC1, IC7 EC 3
The complexity of the supply chain is added, so as Heiko said, if everything could be done in one plant, from start to finish, it would be easier to do CM than if I had to involve risk share partners. (Participant A)	IC3
We have the customer, the end customer, the operator, the airline, we have the authorities; they are also a kind of customer. Or one has a strong connection, as we use CM also to satisfy the authorities to remain approved. (Participant A)	EC5
If we look at the suppliers of A350, they are risk sharing partners who also help develop the design, we can say that we have developed score cards for these different suppliers. (Participant A)	EC8
When it comes to late change, for example, the airlines have a factor from engineering that measures complexity with a kind of score	EC4

number. The airlines often have very special wishes which they express very late. (Participant A)	
This means that we not only manage a functional structure of the systems, but also all activities that arise in this development in this system engineering. (Participant B)	IC3
Many products are configurable, i.e. I have a customer order where I see what the customer actually wants. “As Should Be”, “As Planned” or “As Configured”, there are different terms. And then, of course, comes the “As Built”, which comes out of the supply chain, which is the generated hardware configured as to-be and then as-maintained with the lifecycle across the entire Operating and Maintenance. (Participant B)	EC4
The only thing that is clear is what I can really report and substantiate in structures, with all associative data, documents, article masters, structures, and everything that depends on them. (Participant B)	EC8
In the end it was a black zero instead of an EBIT from the project, because we didn't have Requirements Management under control and then had to do so much rework. We really try to make a ROI consideration on the basis of these findings. (Participant B)	EC1
Yes, and so there are still three results from a PLM Big Picture Workshop.	IC3

One is this huge map where really starting from requirements management up to phase out, all configurations are displayed with all IT systems and all the related processes. (Participant B)	
We have sales, we have system engineering, we have engineering, we have a supply chain, we have preparation activities, we have order fulfilment and we have all customer service. (Participant B)	IC3
That's an important thought, that one satisfies the individual silos, because every Chief Operation Officer or Chief Technology Officer or whoever has his goals, he has to satisfy them, but we also have to indiscriminately satisfy the whole process and a framework would have to contain both thoughts, otherwise we pursue the wrong goals and in the end we have no baseline added value. (Participant B)	
This means that it must always be borne in mind in these issues that we are sometimes talking about very long product life cycles and, that the products are used as hybrid by the customer. (Participant B)	EC2
Let's take Pilatus. It's relatively new, and for me it's amazing that for example the Kuwait Air Force didn't buy their training aircraft anymore. They say we don't need training aircraft, we need flight performance	IC4 EC7, EC8

and availability. That is, Pilatus had to offer you the entire operation, the total maintenance expenses and so on. Only now, of course, the problem is that I now need a lot of information about these flight diagnostic systems of these aircraft, because if the maintenance I have calculated is not correct, because the customer uses the aircraft incorrectly because, for example, the Kuwaiti army flies outside the flight envelope. (Participant B)	
Yes, now suddenly we have completely new possibilities. For example, we can directly store the production manufacturing information from CAD. When we have ten screws on one flange that need to be tightened where all have different torques. Now I can store this directly in the CAD and SAP knows I have a parts list item with quantity 10 (10 screws), but because I have now integrated it that way, I have actually stored the transformation matrix. (Participant B)	EC7
The main reason, of course, is always to make sure that an expensive system is worth the effort and where improvements can be introduced. In addition there are of course still legal demands from different sides that one must prove somewhere that the introduced system fulfils certain conditions. (Participant D)	IC5

One of the most important things especially in the aviation industry or in the supply industry is of course on time delivery, as punctual delivery is extremely important because otherwise the entire manufacturing process at other companies or other company departments are disrupted, which can lead to major problems. (Participant D)	IC6
There are legal requirements that we have to meet with regard to an aircraft. We must provide documentation confirming that the aircraft has been built in accordance with the definition. (Participant E)	EC5
We always measure the delivery reliability, we arrive on time and then there are still the quality indicators or the performance indicators that we show. We also measure how much work is left between the individual workstations. The remaining work can also be missing parts. The missing part situation is also measured. Since we have an industrial schedule and we have to clock, i.e. the components have to go from one building site to the next, you can't stop the running system somewhere. (Participant E)	EC7, EC6
For the A350, we have agreed various quality gates. Quality Gates from our supplier to us and the Quality Gate from us to St. Nazaire where we deliver Section 13, 14 and a Quality	EC6

Gate from us to the FAL. (Participant E)	
The decisive point however is whether the customer accepts the product immediately as part of a quality gate or whether it had to be corrected. Correction means entering the correction mode. The correction mode is a negative act because it reduces our profit. (Participant F)	EC1
The technology is not the problem but it is to understand what the customer actually wants, which is relatively complex to write down and in the feasibility report to point out all the difficulties, to point out all the risks, to make the large costs from this analysis understandable. (Participant F)	IC1
Not so long ago, we have defined KPIs (Key Performance Indicators) to measure our process. That's when we said we need to know how many corrections we have after a design freeze. That means when we look at the development process, we have a PDR (Preliminary Design Review), we then have a CDR (Critical Design Review) and then we have a Final Design Review before the prototype flies. (Participant H)	IC7
If you get involved from the beginning to establish an order baseline, and you can establish these are the requirements, the customer requirements, every time a fresh	IC1 EC3

change comes from outside or inside, you can hold up your hand and say, hey these are customer requirements and if the customer comes with a new requirement, you can request money, you have to charge money, so you get feedback back from the project itself and actually also for new projects, that added value is there, as you are involved from the beginning. (Participant H)	
[…] when we still had Ariane 4 payload fairings, they were riveted together with thousands of rivets and at one stage the rivet supplier came and said: hey, for the rivets in that batch the surface protection and the grease coating on the rivet head is wrong, a production defect. Then you had to be able to see which payload fairings that were in production, those already standing somewhere in Kourou on the launch pad that have been produced with this rivet batch. (Participant H)	EC1
Yes, it also depends on that there are several different perspectives of CM. There is the CM for the company and there is CM within a project and that is of course positioned totally differently. The CM for the enterprise focuses mainly on the company-specific processes, such as processes that are established, including HR processes, financial processes and everything under it. The project-specific ones are	IC3

really specific to the project technically. These are then already two points of view and often one concentrates only on the technology. You won't get the approval to produce a product if you can't ensure the quality system or the CM system is guaranteed. Yes, product liability is certainly also an issue. (Participant H)	
If a project goes through smoothly right from the beginning, of course there are always corresponding problems, but if these are of a technical nature, process-specific or organization-specific then CM definitely has a part to play in this occurrence. I don't think a project will go through smoothly if you don't have CM. I'm convinced of that. (Participant H)	IC3
That is primarily the reduction of rework, that is the ultimate goal. (Participant I)	
Especially companies in the aviation sector with high complexity and the associated risks have an increased interest in CM to make these risks manageable. With a good CM you can make all traceable. (Participant I)	EC1
Complexity of products of processes and procedures where you have to combine a lot. Especially for start-up companies, whose product becomes more complex, the importance of CM increases massively. For example, if they had only one product before, CM	IC1

wasn't that important. If, for example, the number of products and the variety of variants increase, the control of the design documentation becomes massively more complex. From my point of view, complexity is the most important criterion. Other important questions are how many external interfaces there are and how often the product is changed. (Participant J)	
[…] the Space Shuttle was a very complex machine and it was of course designed, built, and then tested by space specialists. (Participant L)	IC5
The idea was we needed to think that different parts don't work anymore, what can you do so that you can still accomplish the mission or if it develops too far into the area of failure or problems, then you have to know how to survive. (Participant L)	
Complex machines mean there are many ways for a complex machine to no longer function. (Participant L)	
The training was absolutely great. We trained with very lifelike equipment. For example, with the model of the telescope in water where we trained to simulate the weightless conditions, it was absolutely accurate like the telescope itself. (Participant L)	
For example, in my function as Head of Production Control for Helicopter Production, there were many customer options for the product that had to be	IC1 EC3

processed in close cooperation with CM. (Participant M)	
In general, I was mostly responsible for highly complex technical products involving many different configurations. (Participant M)	
The most important point I see is complaints about misconfigurations. (Participant M)	EC1
The time frame must be proportionate to the complexity of the change. (Participant M)	IC5

7.5.3 Potential

The customer has two ambitions. On the one hand he wants to have delivered a super quality and that speaks for CM, the customers know that too. On the other hand, he has the ambition in operation and in maintenance to be as simple as possible. (Participant A)	POT10, POT6 POT1 POT5
Yes, it depends on many complexity factors. Firstly, it depends on what I want to achieve with my CM. Do I only want customer satisfaction, or the ability to deliver different characteristics of a product at a glance. Or do I also have government requirements that I must meet and do I also want to control my profitability via CM. I want to use CM through the traceability of my product data to	POT3

understand whether I'm really on my target path, when I check my costs and my sales targets, etc. I want to be able to use CM to check whether I am really on my target path. (Participant A)	
Then of course what plays into our hands at the moment is the whole topic “Industry 4.0”, Internet of Things is not possible without CM. (Participant B)	POT8 POT9
The pressure to manage configurations in the context of industry 4.0 and Internet of Things will be much much bigger. (Participant B)	POT8 POT9
The topic of CM is therefore becoming increasingly important, not only because regulations are becoming increasingly stringent, but also because business models are turning around. (Participant B)	POT1
So it is really the case that we are now trying to implement a so-called Enterprise Development Manager at the companies, which is actually based exactly on a Development Configuration, which Requirement actually says, where the company is heading. (Participant B)	POT3
Another problem is we have customers who say we are being blown away in Europe with our cost structures by Asia and Latin American competition. We can only survive if we become premium in our field and this	POT7 Staying competitive

of course includes certain benefits etc. Others say we need to change our processes to batch size one. (Participant B)	
That means if we now want to use the product in a completely new way, we will stay with Pilatus, which no longer sells aircraft but only sells services. I have greater demands on the sensor technology, yes this must have been defined as requirements up front, because the sensor technology must be integrated into the product. Evaluation systems must be made available. Systems, where I now have to retrieve much more data, manage it and to evaluate it for these configurations, yes, someone has to create these software solutions. (Participant B)	POT1 POT5
There are also internal financial demands or financial reasons why one runs such systems. Reasons of environmental protection, reasons to be able to work out the future company strategy where inputs from the current production are needed. (Participant D)	POT2 POT1 POT3 POT8, POT9
It is also an important result that the scope of work can be simplified under certain circumstances, that processes can be streamlined and thus time, money and effort can be saved. One can save organizational effort. In any case, there are hardly any cases	Cost reduction & staying competitive

where this system would not lead to improvements. (Participant D)	
The main problem is that the material comes in, but is not exported in its raw condition, because it is used further. Here it must be proven exactly which titanium was used in which assembly, when it was purchased and where it was subsequently used. (Participant I)	POT1 Import-export Tax
At the beginning I have requirements for my product to be developed. After production, for example, I notice that the requirement has not been met. This implies a lack of CM and unforeseen costs for reworking or re-development. I'm losing time because of this. That would have to be recognised and that would be the potential I could realise through my CM. (Participant J)	POT4
The airline is paid for every concession. They consciously look for mistakes. There are also airlines that are short of cash. They look even more deliberately for mistakes to save money. That means the feedback is very direct. At the time of delivery, you are told that this and that are your mistakes, this and that you have to rework. (Participant A)	POT4
You have to rework those. That's a horror scenario. This is really a top-level requirement of CM and no reason for lower standard products. (Participant H)	POT4

That is primarily the reduction of rework, which is the ultimate goal. You can measure that, there is a white paper from CM2. There are formulas where you can see how the rework goes back. In general, you can say that the number of errors must be reduced and the number of improvements must be increased. (Participant I)	POT4
There are well-known examples such as Kaeser, which no longer sells its compressors, but simply sells compressed air in cubic meters to companies. The Kaeser compressors are serviced by Kaeser employees and of course when a compressor reports something back to Kaeser, I have to know exactly which configuration is on site, what happened, when the last time a field service employee was on site, and what he did. CM is really increasing in importance. It's independent of KPIs, it's clearly so. (Participant B)	POT10

7.6 Interview Guideline

A FRAMEWORK TO EVALUATE THE BENEFITS OF CONFIGURATION MANAGEMENT IN THE AEROSPACE INDUSTRY

INTERVIEW PARTNER	**Name:** _____
	Position: _____
	Company:_____
CONTENT	**Interview**
	Introduction and welcome
	Briefing: Topics Content
	Reasons for the selection of interview partners
	Ethics and confidentiality explanation
	Interview process (Asking questions)
	Clarification of ambiguities through in-depth questions
	Summary
	Acknowledgement and farewell
INTERVIEW METHOD	Semi-structured personal interviews, supported by interview guideline and auxiliary material (interview guideline, voice recorder, camera, timer, pen and paper)
INTERVIEWER	Manuel Maier

Table 7-1: Interview Guideline (before the pilot study)

A FRAMEWORK TO EVALUATE THE BENEFITS OF CONFIGURATION MANAGEMENT IN THE AEROSPACE INDUSTRY

INTERVIEW PARTNER	**Name:** _____
	Position: _____
	Company:_____
CONTENT	**Interview**
	Introduction and welcome
	Ethics and confidentiality explanation
	Briefing: Topics Content
	Reasons for the selection of interview partners
	Interview process (Asking questions)
	Clarification of ambiguities through in-depth questions
	Summary
	Acknowledgement and farewell
INTERVIEW METHOD	Semi-structured personal interviews, supported by interview guideline and auxiliary material (interview guideline, voice recorder, camera, timer, pen and paper)
INTERVIEWER	Manuel Maier

Table 7-2: Interview Guideline (after the pilot study)

7.7 Depth of the Structure

Every single interview has its typical depth of its structure. The volume of structure has to be derived from the parameters of the state of knowledge, the subject area and the group of interviewed persons.

Three basic types can be differentiated:

a. The interview of low profile structure
b. The interview of semi structured profile
c. The interview of strongly structured profile

The case where an interview has no structure at all can be excluded, because every human communication, just because of the fact that at least two individuals are participating, at least have a rudimentary structure.

7.7.1 The Interview of low profile structure

It normally develops its own dynamic and so has the tendency to develop into width and depth. For this reason it also is termed as an „in-depth“ or „intensive“ interview. A guideline for the interview may be used in a rudimentary form. It so pre-forms only the aim of the interview and various groups of topics.

7.7.2 The interview of partly structured profile

In the partly structured interview the person doing the interview can make use of a variety of pre-formulated key questions. Their sequence however is not determined. It is always possible to integrate new matters coming up during the course of the interview. Depending on the situation prepared special questions can be included into the interview.

7.7.3 The Interview of strongly structured profile

The strongly structured interview is based on a questionnaire, which exactly defines the content, number and sequence of questions as well as the verbal formulation. It also has pre-categorized the possible answers. For these reasons the strongly structured interview largely corresponds to the standardized interview.

7.8 Standardization

The criteria for classification of the structural depth is complemented and superimposed by the criteria of standardization, i.e. specifying and unifying the details of the proceeding.

7.8.1 The strongly (or fully) standardized Interview

In the fully standardized interview, the quantitative aspect of the data collection comes to fruition.

„Quantitative procedures are such procedures in which empiric observations on few chosen features systematically are documented by numerical values and are collected on a numerically broad basis.“ (Brosius, Haas, & Koschel, 2012)

The tools of the strongly structured interview are closed questions with various categories of answers. In the simplest case a binary yes-no dichotomy can be applied but also alternatives of higher value. For reasons of symmetry the positive and negative optional answers should be in balance- (example: „very bad – bad – more or less bad / more or less good – good- very good).

The advantage of the strongly structured interview is the density of data (generation of lots of data in a very short amount of time) but also the comparability of the information collected during the interview.

7.8.2 The non-standardized Interview

The non-standardized interview serves the exploratory analysis of facts but also the investigation and screening of complex systems of reference as well as value systems. Due to its flexibility it can deliver important additional information, which might be lost in a strongly standardized interview.

The non-standardized interview also is a preferred option in cases where the frequency, distribution and the comparability of the answers is not possible or is not the primary aim of the evaluation.

7.9 Overview chart: Forms of the qualified interview acc. to Lamnek (2005)

Methodological assumption	Types of interviews					
	Narrative interview	Episodic Interview	Problem-centred Interview	Focused Interview	In Depth interview	Receptive Interview
Openness	absolute	wide	wide	limited	marginal	absolute
Communication	narrative	narrative aim-oriented interrogative	aim-oriented interrogative	guideline	interrogative narrative	narrative observing
Process-conformance	given	given	given	limited	given	given
Flexibility	high	relatively high	relatively high	relatively high	relatively high	high
Explication	yes	yes	yes	yes	yes	yes
Theoretical requirements	relative without concept	concept exists	concept exists	extensive concept	concept exists	relative without concept; only preliminary under-standing
Hypothesis	generation	generation, examination	generation, examination	more ex-amination as well Gener-ation	more ex-amination as well Generation	generation, examination
Perspective of the interviewed	given	given	given	limited	limited	absolute

Table 7-3: Forms of the Qualified Interview acc. to Lamnek (2005)

7.10 Qualification Profile of the Interview

Independently of the chosen interview design, the data collected in the interview as well as the insight gained through it should satisfy at least the general criteria of economy. These requirements consist of the following:
The information gained shall be:

a) Undistorted (authentic)
b) Intersubjectively comprehensible
c) In principle reproducible (reliable)

An approximate approach to these targets should be strived for by way of a methodically-reflexive method.

7.11 The chosen interview design

Initially it was planned to combine a strongly standardized / structured form of interview with a partially structured guideline based interview. In a more advanced planning phase and after the first preliminary talks with the interview partners, it became apparent, however, that its strict, continuous standardization was not conducive to the targeted gain of knowledge. Since it is not a matter of a uniform rigid application of a CM system, it was necessary to leave room for the description of further problems, experiences and desiderata beyond a basic canon of common questions. An interview design was therefore required which, following an introductory common discussion basis, made it possible to gain an individual form depending on the company and interview partner. A partially structured interview with narrative elements is suitable for this purpose. Because it offers like no other interview type the possibility to find out attitudes, value propositions, opinions, personal experience and evaluations etc. – types of information which by way of a formalised questioning system conceived a priori cannot be depicted in its full amount in an authentic form.

7.12 Theory of Measurement

7.12.1 Introduction

CM is a practical activity that has a high impact on empirical relationships. Both the theoretical understanding and the practical use CM, require the collection and evaluation of numerical-quantitative data about relevant variables. The collection and evaluation are *measurement processes*. Measurement processes are described in a basic and standardized way by *measurement theory*. In the everyday life measurement processes always take place without much thought. But without a fundamental consideration of a) which mental acts are necessary and b) which conditions of validity have to be fulfilled, the measurement lacks a sound basis. There is a high risk to create data phantoms without a real value. Even a non-numerical relational quantification represents an enormous challenge for a fundamental attempt at explanation, as can be shown by a simple example Figure 7-1.

The seemingly trivial task of determining the relative length of the following two lines involves a number of concealed categorical rules which require a systematic clarification.

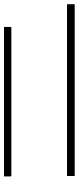

Figure 7-1: Example of a Relational Quantification (case a)

The process of comparison requires mental acts of imagination that the naïve consciousness is not even aware of. Primary in this case, is the virtual drawing of two orthogonal lines for comparison, which are necessary, even if their length may tend toward zero. That this is the case becomes clearer if the two lines being compared can no longer be viewed with (supposedly!) “one glance” for example, they have lengths of 17,50 km and 17,56 km and are at a distance of 45 m apart. (Figure 7-2)

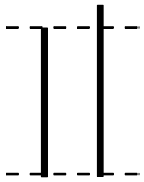

Figure 7-2: Example of a Relational Quantification (case b)

The naive consciousness is inclined to say that it is very obvious that the right hand line is longer than the left hand line. However, is what is declared as “greater than” really invisible? It is not visible and it could not be so, because it is not a sensual quality rather as a *relation* of a non-sensual nature. To express this rational in this case it is at least necessary that there is: a) movement, b) thetical acts and c) memories to the thetical acts, which finally results in d) a synthetic judgement which uses the recognised comparative relations of the contents.
The “greater than” statement is therefore in reality based on a construct of mental operations, which normally are below the threshold of consciousness. As we progress from such a bivalent comparison relation to a numerical scale of measurement, further categorical determinations come into play.
First of all we have the *measure* - the *unit*. However, since the measurement process records the number of repetitions of this unit, we also have the parameter of *multiplicity*. As, this is a multiple of the same unit of measurement the category of *identity* is additionally needed. This, in turn, is inconceivable without it complimentary concept of non-identicalness i. e. a *difference*.
Thus in the discussions of the philosophical problems of measurement theory it will be enough to pay attention to the more formal aspects.
This thesis focuses on the qualitative framework conditions, which are based upon quantitative measurements. A brief look at the theoretical measurement

requirements structure is nevertheless necessary, since qualitative statements are not viable without the numerical foundation of reliably measured KPIs.

7.12.2 What is ‘measuring’?

Measuring is the basic form of gaining empirical knowledge by assigning numbers to objects or to their characteristics. A well known dictum of Campbell which became popular later through Stevens is as follows: “Measurement consists in the assignment of numerals to things or properties.” (Campbell & Jeffreys, 1938) (Cf. Stevens 1946, 1962, 1968) However is the assignment of numbers to objects a necessary but not sufficient condition of the numerical principal. As not every linking of numbers to things is a measurement, rather the assignment of numbers to objects, subjects or events according to certain rules. Also (Stevens, 1946) called on the existence of rules as a definiens of measurement when he said: “Measurement in its broadest sense, is defined as the assignment of numerals to objects or events according to rules”. According to this viewpoint Campbell adds that the assignment of numbers can not be achieved arbitrarily, thus rules or laws have to be defined and used which he calls “laws of measurement”. (Campbell, 1920) So he continues from the above mentioned position. “But not every assignment of numerals is a measurement. A street is not measured when numerals are assigned to the houses in it; a dyer does not measure his colours when he assigns numerals to the in his catalogue. To understand in what circumstances the assignment of numerals is measurement, we must ask what is the significance of numerals as distinct from other symbols, such as hieroglyphics or the letter of our alphabet.”(Campbell & Jeffreys, 1938) However not every correlation of numbers and things has a measuring character. Another example Campbell uses is the assignment of telephone numbers to a certain household. (Campbell, 1928)

It is not the task of measurement to state characteristics or to introduce any order for an ensemble of data just because for its own sake. Every measurement, as measurement needs a direct link to reality on which basis for a research object a quantitative statement about its empirical characteristic has to be created. In other words the measurement determines which intensity a certain

characteristic linked with a measured object has. For this character and condition has to appear in a fixed previous defined relationship.

7.12.3 Measuring Theories – Classification

There are different types of measuring theories which are use different definitions for the term “measuring”. In the history of the measuring theory the representational paradigm has prevailed as the dominant. As Joel Michell (1986) shows there are alternative measuring theoretical models in the following: “There are at least two others, the operational and the classical.” This methodical trichometry is also agreed by Hand (1996).

For a well-founded and consistent theory of CM it has to be determined which model has to be the basis for the measurement procedure.

Therefore a short outline of the three mentioned paradigm follows.

a) Classical Theory of Measurement.
   The classical theory of measurement defines the old theory of the hard measurement according to a physical pattern. This model of understanding about measuring processes can be traced back historically to Aristotle and Euklid. The measurements of this type should give answers to the question “How much?”. Therefore this approach is exclusively quantitative oriented. It observes only variables whose characteristic can be arranged and added together. The measurement on this basis is the determination of the exact numerical relations between values of quantitative variables.

b) Operational Theory of Measurement.
   The operational approach tries to avoid the ontological contact problem between the measured subject and the external world which are seen as independent. For this model it is sufficient that exactly defined measuring operations are consistently applied. The meaningfulness will be generated and acquired by definitions. With this, an acceptable measurement is made by every precisely specified operation which produces a number. The father of the “operational thinking” Percy Bridgman has to be mentioned. From him came the fundamental idea that a variable which has to be measured and its involved measurement operations be used as

synonyms. The procedures are absolutely constitutive for the creation of the measuring values; each receiving from these their validity, without recourse to any “conformity”. Bridgman (1927) affirms to this method a considerable clarifying potential insofar the operationalisation of these questions contribute to their preciseness and transparency. This is valid for different disciplines of science. He states:

> “I believe that many of the questions asked about social […] subjects will be found to be meaningless when examined from the point of view of operations. It would doubtless conduce greatly to clarity of thought if the operational mode of thinking were adopted in all fields of inquiry as well as in the physical.” (Bridgman, 1927)

c) Representational Measuring Theory

Contrary to the operational measuring theory it is a basic assumption of the representational measuring theory that the results of measuring reflect actual underlying reality, consequently the name. It is the fundamental concept of this approach that “measurement is (or should be) a process of assigning numbers to objects in such way that interesting qualitative empirical relations among the objects are reflected in the numbers themselves, as well as important properties of the number system.” (Townsend & Ashby, 1984)

In contrast to the classical measuring theory it has to be declared additionally, that not variables or attributes by themselves but objects as the owners of the attributes are in the centre of interest.

For the model of representational measuring theory there are always two structure or relation systems: an empirical and a numerical. These have to exist in a defined *relationship* to each other to allow meaningful measurements. The relationship from the mathematical point of view is a mapping and is such that the empirical relation system may be converted preserving the structure of a numerical relation system. Instead of the term relation system, the term relative may also be used.

The structured preserved mapping between the empirical and numerical relative system represents a homomorphism. To show homomorphy means that the data is represented on a scale according to the empirical structure of the investigated phenomenon. Only with this homomorphism is it possible to allocate an object an unambiguous value. The homomorphism is only able to unambiguously allocate one object with

one number. The number, on the contrary, is not unambiguously retraceable to the object because multiple objects can receive the same number. (The last point is found in isomorphism, a special form of homomorphism, where a one to one allocation exists which is not necessary for a measurement.)

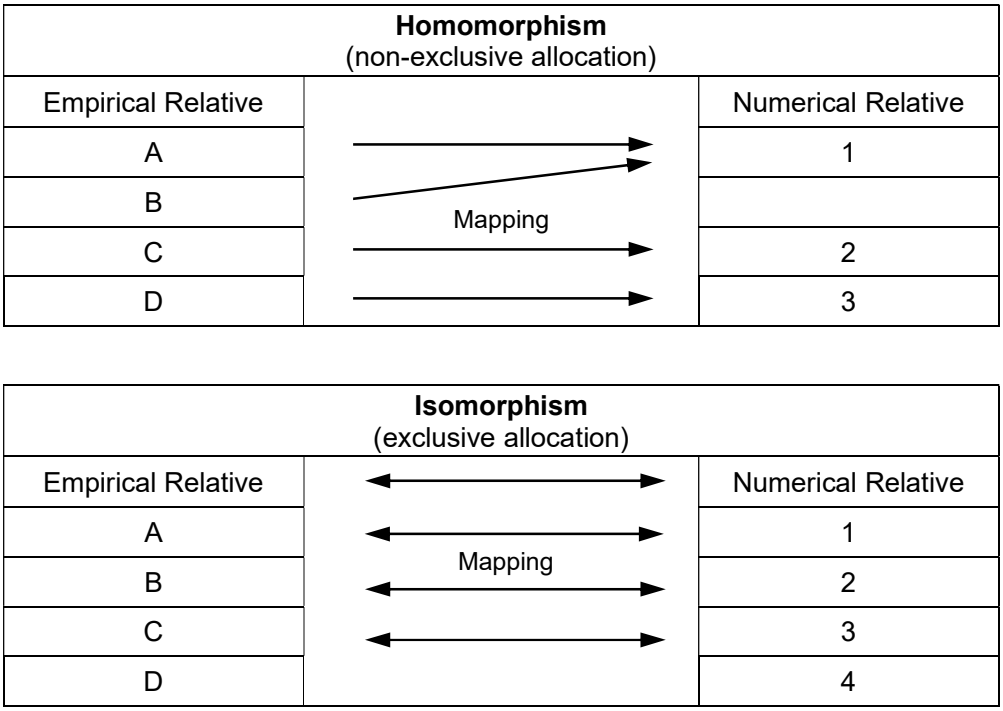

Figure 7-3: Homomorphism and Isomorphism

This mathematical procedure is used in the accepted measurement theory, introduced by (Stevens, 1946) and (Stevens, 1951) and developed by (Krantz, 1967), (Luce, Krantz, Suppes, & Tversky, 1990) and (Suppes, 2014). The fundamental principle can be formalised according to (Saint-Mont, 2011):

For the further reification of the termini technici it has to be taken into consideration.

α) Characteristics of the empirical relative

- An empirical relative is a set of objects and the observable relations between the objects.
- There are two different types of relations: the equivalent relation and the order relation.
- An equivalent relation means that the degree of intensity of a characteristic feature by different relata in relation to a specific characteristic, are the same, or equivalent.
- An order relation means the degree of intensity of a characteristic feature by different relata are of different levels. Therefore the measured objects may be ranked in order.

β) Characteristics of the numerical relative

- A numerical relative is created by a set of numbers and their defined correlations to each other.
- The following correlations can be differentiated: Equality relation (=) and greater-less relation (>)
- If a numerical relative results in a homomorphic mapping, it is called a scale.

γ) What is mapping

- A mapping according the measurement theory is an allocation of numbers and objects.
- It is important that every object (empirical relative) exactly one number (numerical relative) is allocated
- The allocation rule is called mapping.
- If the relations between the measured objects are represented by the relations between the allocated numbers then it is said to be a homomorphic mapping (see above).

MEASUREMENT THEORY		
Classical	Representational	Operational
Finding	*Alocation from numbers to objects*	
Preexistent relations	to model their relations	according to a specified measuring procedure
if a character is measurable		The measuring process defines the character
depends if it is quantitative	can be predicated if the corresponding representationtheorem exists	
Hypothesis and investigation of an underlying reality		Operations in the focus
one single type of scale	Type of scale is dependent	
	from the uniqueness of the scale	*from the intended purpose*
No limitations when using statistical procedures	*Relyibility of statistical procedures is linked to the criterion of empirical meaningfulness*	*No limitations when using statistical procedures*

Table 7-4: Summary presentation of the classification possibilities of Measuring Theories

7.12.4 Scales

7.12.4.1 Scale generation

As described above, a valid homomorphy mapping results in the generation of scales. The following must to be taken into account, every intact mathematical theory of measuring has to be able to cope with change of the scale used, in other words this means to be able to handle a change of units. In the mathematical view this leads to so called *transformations.*
The demand for independence according to one specific scale corresponds with the fact that the observed relations in the measuring process are meaningful and are representable on different scales without the loss of information.

7.12.4.2 Dignity of scales and variable measuring properties

Generally scales are constructible of different informative values, which depending upon the different areas of application has specific legitimacy. According to the type of the characteristic or in other words which rule could be followed during its measurement allows distinguishing different stages of the scalability, which have influence in the following classification of *measurement level* or the *dignity of scales*.
The dignity of scales has to be adequate for measuring the characteristics of the measured object and is an essential requirement of a functional CM framework. Because the appraisal of the value CM could have for a company has to be based not on arbitrary attributes, it has to be based on empirically gained measurements as the determination of the dignity of scales for gaining quantitative measurement values of significant KPIs is absolutely necessary. Generally during measurement procedures, as in our case, not all the measured objects apparent empirical relations are interesting, but just the intensity (this means strength or degree of the feature) of a specially measured characteristic. The measured characteristic is the characteristic whose intensity should be determined by the measurement. These shapes of characteristic are of changing nature – variable – this means they are different strong shaped by different objects, persons, situations or during time. This could be dichotomy, categorical or continual variables. These three types of variable have to be considered in the CM problematic.

As it can be seen in the following investigation the problem definition is impeded in this case because sometimes in CM there is no directly measurable “hard” variables, thus also such which are lying more in the covered area. In contrary to the manifest variables the latent variables are just indirect and with less measurable certainty, (for example, the attitude of a person towards homosexuality.) The existence of latent variables – for example during the problematic of the intercultural themes – leads unavoidable to a certain weakness of the factual and prognostic informative value of the framework; thus it does not result principally out of an deficient failure, but out of the systematical boarders with are in the nature itself.

7.12.4.3 General characteristics to the suitability dignity of scale

The today established classification in nominal-, ordinal-, interval- and ratio scale was suggested by Stevens (1946). Later they added to these four types the absolute scale (Stevens, 1951) and log interval scale (Stevens, 1957).
The mentioned types of scale form at the same time a hierarchy of scales. This results because the to the scales allocated mathematical transformations are special cases to the lower standing levels of scales in comparison to the higher standing levels. In addition the lower standing levels of scales are richer in information about the empirical world. (Saint-Mont, 2011)

6. Log-Interval Scale
5. Absolute Scale
4. Ratio Scale
3. Interval Scale
2. Ordinal Scale
1. Nominal Scale

Because of the four main types of levels of scales the following dichotomy is used above.
Nominal and ordinal scaled characteristics are also named *categorical*. Interval and ratio scale are combined to the *cardinal scale*. Characteristics of this scale are named *metric*.

Generally the level of scale gives no information if a variable is discreet or steady. In the practical world however nominal and ordinal scaled characteristics are mostly discreet and metric scaled characteristics mostly steady.

It follows a short overview of the different level of scales to the purpose of the suitability test for measuring related to CM. A deeper mathematical derivation and discussion is not part of this thesis, because this would be too extensive within the scope of application related task of this thesis.

An important methodological advice has to be given at that point; by not following this not repairable logical-metrological confusions would appear. Before the question which special scale should be used in the special case, for the framework the following fundamental distinction has to be made:

1. What is measured *with* CM? (Measuring is a functional part of it.)

2. What is measured *on* the CM?

On the first scientific question CM is used as *measuring tool*.
On the second scientific question thus CM is *measuring object* respective *measuring parameter*.

7.12.4.4 Nominal Scale

The name comes from lat. nomen ‘name’ and greek onama; pl.:nomina also nomen.
A characteristic variable scales nominal if their possible shape can be differentiated but have not a natural ranking. The measuring process exists on the perception if the shape of a characteristic is equivalent or different within different objects. Requirement is a classification system of categories, thus every investigated unit can be allocated one to one to a category (exact). Nota bene: because of the missing of a ranking the notation ‘-scale’ (from lat. scalae ‘ladder’, ‘stair’) is not adequate in this case.
The allocation of the numbers, this means the numerical relative to the respective shape of characteristics happens on this scale level arbitrary. The allocated numbers are serving only as names or labels, so they can be replaced with any other numbers or symbols without any problems because its numerical meaning is not used. Accordingly it makes no sense to offset the single measuring values with each other. Because the only possible structure keeping

transformation are on this scale level renaming, through this every category gets a new category allocated one to one. Also if the categories can be coded through numbers (it is talked form nominal numbers, Example: profession$_1$, profession$_2$, …), are mathematical operations with this codes not meaningful, for example a division ‘locksmith/confectioner’.
Statistical meaningful is just the calculation of the modal value, this means the worth which appears mostly.

Examples see Table 7-6 on page 371.

Problematic:
The generation of categories has to be legitimated in special cases and is not beyond all doubt. It could be the appearance that there are ‘naturally’ predefined divisions, for example the dichotomous categorizing ‘female/male’. Thus are these really a priory valid? In the attached example form the modern point of view it would be possible to attach a third value for the variable: the trans sexuality.
Economical industrial processes are following entirely certain structurally imbedded laws; at the same time they are human artifacts, which have not the ‘hardness’ and invariance like natural laws. There is the categorization in nominal categories even more problematic.

7.12.4.5 Ordinal Scale

Ordinal scale contains more data than nominal scale. The ordinal scale contains nominal scale as subsets.
An ordinal scale sorts variables with different shapes among them exists a ranking order. Ordinal scaled variables contains nominal information as well as information about the ranking (order) of the variable values.
Requirement for application is that at least exists a weak ranking order in the empirical relative, that it is possible ascertain empirically if an object or a person possess a weaker, stronger or equal characteristic shape like another object or person.
With this the shape of characteristic can be easily differentiated and can be compared in a ranking list. Consequently the numbers express an order (for example: 1 = weak, 2 = medium, 3 = strong). The objet which is dominating

according the criterion gets a larger number assigned. The shape of characteristic of the empirical relative will be presented with the help of a trichotomy, which contains the values ‘larger’, ‘smaller’ or equal. These values will be mapped on related numbers in the numerical relative.
This means if the shapes of characteristics (categories) are named with (order) numbers they are chosen in the way that the ranking of the numbers corresponds to the ranking of the shapes. With other words an observation respectively an object or a person with a higher grade possess also a higher shape on the observed characteristic as an observation with a lower grade.
An ordinal scale can therefore be transformed as required as long as the ranking of the scale values stays equal. More than the ranking of the scale values is not expressed by an ordinal scale.
As an ordinal scale allows the put the objects in order therefore sometimes it is also named as ranking scale.

Formal conditions and specifications
In addition to the conditions to the construction to a nominal scale the construction of an ordinal scale requires the fulfillment of two addition formal conditions:

Trichotomy:
It is valid either a larger than b, or b larger than a, or a is the same as b.

Transitivity:
If a is larger than b and b larger than c, than a has to be larger than c.

The founded frequencies of an ordinal scale could be even brought in a ranking. To the *distances* of the categories to each other no statement can be done. Here is a significant limit in the expressiveness of ordinal scales. (Example: In a car race there can be awarded a 1^{st}, 2^{nd} or 3^{rd} rank. In this case it is not of importance if the winner was one hour or one minute faster than the second.)
As well as for the nominal scale it is also valid for the ordinal scale: Also if categories are coded by numbers mathematical operations with this numbers are not senseful. This is grounded in the fact that the numbers do not realise a

numerical value thus represent a categorical determination. Therefore it makes no sense to calculate the mean value. It has no semantic attributable meaning for example if you divide the quotient ‘major/ lieutenant’ within a military ordinal scale. Statistical senseful is by contrast the calculation of the median or the determination of frequency of occurrence.

Examples see Table 7-6 on page 371.

7.12.4.6 Interval Scale

The interval scale contains ordinal and nominal characteristics, thus is in one characteristic by far superior.
On the level of the interval scale begins in addition to the characteristics of the ordinal scale, the possibility to determinate exactly the intervals between the different shapes of characteristics. This means to have *intervals* between the different shapes of characteristics, this means to have *quantitative* statements. This scale counts to the metrical measuring level, because the shapes of this scale level can be presented quantitatively with the help of numbers.
Was it a requirement for the validity of the ordinal scale, is that the different shapes characteristics can be differentiated and brought in a line with intervals, so it is here the case that these differentiations can be brought in a line with specifiable this means exact quantifiable distances. It is also not just the difference by itself empirically determined or its rank, thus the quantity of the difference between different shapes of a characteristic. For this purpose the objects are mapped on an interval scale numerical in this case, that according to the allocated numbers various large differences between different objects can be detected. In other words the inequality of the characteristics can be quantified through the formation of difference, for example for dates through the expression ‘three years earlier’. By this the zero point (‘A.D’) and the distance of the classes/units (years or moons) is though determined arbitrary.
On this scale level a unit will be defined that for example during a measurement it can be not only determined if a person achieved a better result than another but in addition with how many points. This is given through the fact, that the same distances between the measuring values reflect the same distances between the shapes of characteristics.

As on this scale level the determination of the measuring unit is freely chosen, as with the zero point, in the measuring process the size of the difference between the measuring values can be determined, thus not relationship between the measuring values. The measuring value zero is determined arbitrary and therefore does not state, that a characteristic is not there. Arbitrary defined zero points like for example the degree Celsius temperature scale does not count here as natural zero point, while the zero point of the kelvin temperature scale, which corresponds with the absolute zero point, is a natural zero point.
The range on information, which can be gained on this scale dignity can be clarified on the following examples. On each day A, B and C the temperature will be measured on a certain time in grad Celsius. It delivers a measuring sequence the values:

A	B	C
20°C	30°C	40°C

It can be stated, that the distance of the measured temperatures between the days A/B and B/C is exactly 10°C each. In contrast it is not allowed, to follow on this scale level, that on day C it was the double temperature than on day A. Because 0°C is not the natural zero point of the temperature. (This becomes obvious if you transform Celsius Values in Kelvin or Fahrenheit.) However a permitted statement can be constructed through ratio formation of the differences (A-B)/(A-C) For the above mentioned measuring sequence this delivers the (trivial) value 1. For an additional measuring sequence

A	B	C
15°C	7°C	12°

the resulting value is 8/3 =2,66. This allows the scale conform expression: ‘The temperature difference between day A and B is according the factor 2,66 larger than the temperature between day A and C.’
Every interval scale is designed so that the raking of the difference between numbers is the same that the ranking of the differences of the shapes of characteristics between the corresponding objects.

Another example for the application for interval based measuring systems are the lines of longitudes of the geodesy. Also here no natural cero point of measuring exists; and there cannot be any. The actual zero point is the result of a historical fortuity. From this results: If you move the longitudes about a fixed value *x,* so the distances (measured in longitudes) between the places do not change.

It would also be possible to change the unit, for example by means of an aspect ratio of two. Apparently the distance between the two places *A* and *B* are doubled. Thus that all other distances (between all places on the surface of the earth) have been doubled, the validity of the statements remains unaffected. To put it graphically, by applying this stretching factor, the earth is covered solely with a net of longitudes twice as fine. By this the basic distance relations between the places stays valid.

Like seen additionally to the comparison of quantities (like by the ordinal scale) differences and sums form interval scaled characteristics are senseful, because the distances between the different shapes of the characteristics are exactly defined. Therefore the calculation of the average is statistically sensful. Because of the missing of the (absolute) cero point the multiplication is not a senseful operation for interval based characteristics. Generally it can be said: By using interval scales those transformations are allowed which besides the ranking of the measuring results also lead the relations of the intervals between the measuring values invariant.

Examples see Table 7-6 on page 371.

7.12.4.7 Proportion Scale (= Ratio Scale)

The proportion scale also called ratio scale or relation scale is the highest scale level in the statistic. It is a metrical scale. Moreover the proportion scale is the most known scale which is used besides other things for the measuring of the length.

The up to now presented scale types were selectable. This limitation gives the following requirements to the scale:

The shapes of characteristics can be differentiated, brought in a line with definable spacings and there is a natural zero point thus the unit is arbitrary. On

the one hand the size of the difference between the shapes of characteristics have to be empirical definable and on the other hand there is a substantively significant zero point. Statements about empirical relationships: the mathematical relation between two numbers corresponds to the full extent to the empirical relations of the allocated objects, if the used scale has a not changeable beginning- or reference point, thus begins with zero.

For the proportion scale the following characteristic elements are valid:

- Shapes of characteristics will be expressed as number
- For the numerical value a natural zero point exists and
- The measurement unit is defined arbitrary

The following table shows some examples for the natural zero point with proportion scaled temperature, time, weight, price, speed and length measurement.

Charcteristic	**Zero Point**
Temperature in Kelvin	Absolute zero point
Period of time	Zero period
Mas	Zero mass
Price	Free
Velocity	Zero velocity, (stoppage)
Percentage	0%
Distance	Zero distance

Table 7-5: Examples for the natural zero point

As by proportion scales the numbers reflect the intensity of the shapes of characteristics, to the accepted statements belong also relation values in percent. Only with the scale level the operations multiplication and division are senseful and allowed.

Summarising:

With characteristics, which are measured on a proportional scale the following operations are possible:

- Comparison on identity (Nominal scale level)
- Size Comparison (Ordinal scale level)
- Addition, subtraction (Interval scale level)
- Multiplication, division (proportion scale level)

Examples see Table 7-6 on page 371.

7.12.4.8 Absolute Scale

In addition to the proportion scale there is even a more restrictive scale type, the absolute scale. It is the most explicit of all available scales.

On an absolute scale shapes of characteristics will be captured, for which the following requirements are valid:

- The shapes of characteristics are expressed as numbers,
- For the numerical value a natural zero point exists and
- The measuring unit is no more arbitrary (like in the proportional scale), thus given naturally (this means in the further sense “single objects”). Therefore this is a natural unit.

Absolute scales are therefore clearly specified. For them just transformations of identity are allowed. Absolute scales are always used, if frequencies are apprehended.

Example:

Quantity of the members of a certain group. This means this scale type handles the number of units or items. So for example for the characteristic ‘Quantity of inhabitants in a country‘ the number of the inhabitants is the natural amount with the natural zero point ‘no inhabitants’.

	Nominal	**Ordinal**	**Interval**	**Rational**
Order according to	categories, types	ranks	measuring points	measuring points
Common dimension	—	yes	yes	yes
Defined unit	├—	—	yes	yes
relations between them	—	yes	yes	yes
equidistance	—	—	yes	yes
Meaningful sequence	—	yes	yes	yes
zero-point	—	—	arbitrarily	naturally
purpose	sorting	Classification of the difference	Measurement of degree of expression	Measurement of degree of expression
examples	account numbers shirt numbers at football religious affiliation gender blood type	school grades wind strengths ranks in competitions, sales successes, military rank	IQ, Celsius-temperature, longitudes	length, weight, time, Kelvin-temperature, blood pressure, age, pulse
data level Mathematical operations	categorical equality, inequality	ordinal equality, inequality, greater than, less than	metric equality, inequality, greater than, less than, addition, subtraction	metric equality, inequality, greater than, less than, addition, sub-traction, multi-plication, division

Table 7-6: Overview of the different scales

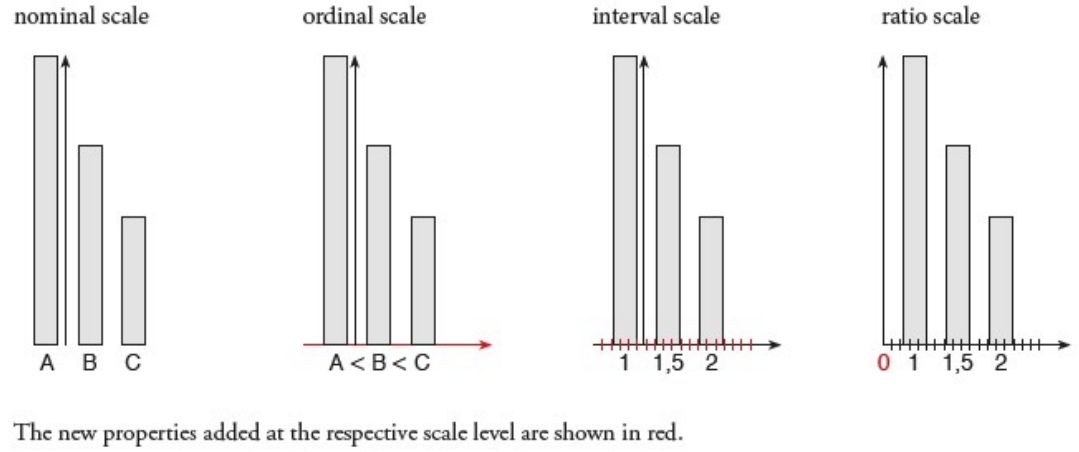

Figure 7-4: Systematics of scales

7.12.5 Reflection on the limits of empirical measurements

This broadly outlined measurement theory provides the tools, which the present work must also make use of as an empirical study. A critical reflection must be undertaken on the extent to which this tool can actually be used and to what extent it delivers reliable results.

'We tend to give the data - regardless of where they come from - an advance on objectivity,' warns (Jaenecke, 2018). Therefore, not only the data themselves, but also their collection and their methodology must be questioned as to their validity. The question of empirical relevance as it was mentioned before is firstly reflected within the measurement theory itself, as Saint-Mont (Saint-Mont, 2011) clearly points out in his study:

"The measurement theory strongly warns against reading more into data than it actually contains. The subtle point here is that, mathematically seen, measured values are nothing else than numbers, with which it is possible to calculate almost arbitrarily. The measurement theory limits this freedom substantially, since it shows that many formally well-defined operations are not meaningful from the content point of view."

In addition, the fundamental question of the reference to reality of measurement-technical and statistical methods arises. This includes a complex of further questions:

a) The problems of *reproducibility*, *comparability*, *objectivity*, which are particularly clearly reflected in the phenomenon of critical measurement interactions, i.e. reactivity. Every measuring implies a contact with reality. Therefore, measuring is never completely free of influence. Already prior to the well-known quantum-theoretical phenomenon that due to the uncertainty principle there is a fundamental limit for microphysical measurements, independent of the accuracy of the instruments. Fundamental measurement limits are also known in the field of classical physics. In principle, each measurement is an interaction, i.e. a mutual influence of at least two systems on *each* other. The contact of the observer which happens during the measuring process with the help of the used measuring device provokes a reaction of the measured system. These measurement interactions inevitably generate an influence on the measured object by the measurement itself. These changes to the measured object leads to measurement errors or better inaccuracies as the results diverge from the values that would exist in reality without measurement.

An example known from electrical engineering is the so-called feedback deviation (according to DIN 1319-1), which results from the internal consumption of the measuring instrument through its measuring connections. This means that the open circuit voltage of a real voltage source cannot be measured exactly with real measuring instruments.

The critical principle of reactivity applies analogously to non-physical measurements, especially where there are points of contact with human scientific methods, and must be taken into account accordingly.

b) The topic of problematic characteristics that cannot be assigned to exactly one scale level in the established handling. An example of an unclear yet frequently applied approach is the formation of averages in school grades coded as digits, although they actually represent an ordinally scaled characteristic, because they are defined in fixed terms (for example in Germany from ‘very good’ to ‘unsatisfactory’).

Another example can be found at Saint-Mont, which illustrates the problem of intransitivity. In the animal kingdom there are hack orders in some populations in which intermediate triplets or multiplets can be found. This means that there are a certain number of individuals within the total group who ‘hack’ each other

according to the pattern A>B>C>A. This ‘illogicalness’ goes beyond the schema, which is actually odinal scaled

c) The enormous problem field of ‘soft’ measured variables, depending on the respective type of science. Strictly spoken, only physics has hard measured variables, defined in the International System of Units (SI). These enable fundamental, direct measurement – for example when determining length, mass or temperature. Other sciences do not meet these requirements. In the human sciences, for example, ratio scales are of only marginal importance, since most of the measurements do not show a natural zero point. In the social sciences and economics, direct measurement is also excluded in many cases, since the constructs under consideration are often complex, multidimensional and in particular not directly observable. The pragmatic solution in these cases is the consideration of corresponding indicators that are assumed to be legally related to the latent variable of interest.

In the non-scientific disciplines, for example, instead of desirable quantification, classification is often de facto only possible at nominal or ordinal scale level. Unfortunately, in his extensive study Saint-Mont (2011) has to complain: "In many areas of economics and social sciences, figures are handled as if they were at (at least) interval scale level.

d) The referred difficulties culminate in the problem of the mathematisability of empirical relations. The question of whether the high degree of abstraction and mathematisation of established measurement theory is applicable and expedient cannot be conclusively decided here. But a work such as this one is at least obliged to call for a corresponding awareness of the problem. In this sense, Saint-Mont expresses his concern that "the current measurement theory is only accessible to a scientist who is truly experienced in mathematics. It is as impressive as any mountain that can only be conquered with extreme effort, but at the same time it is as rugged and barren as a high mountain. (Pfanzagl, 1968, p. 9) explicitly warned over four decades ago: 'A close relationship to applications is necessary, because otherwise the theory of measurement becomes rather fruitless [....]‹« For these reasons, the present paper does not include a mathematical-formal superstructure. The focus is clearly on applicability and not on an axiomatic foundation; as Saint-Mont stresses elsewhere, the dictum of Velleman and Wilkinson (1993, p. 68) applies: "'Axiomatic measurement theory is mathematics rather than science', thus unassailable and often empirically irrelevant at the same time. For the sake of this empirical relevance, the framework to be presented is not a theoretical end in itself, but is intended to provide decision-makers with a

robust tool for business management decision-making. The well-being of both the workforce and the company as a whole can therefore depend to a large extent on its efficiency. One of the requirements for the values elaborated by the framework is that they are hard, binding and robust. Accordingly, the interviewees were asked specifically about such hard parameters.

7.13 Derivation of the QDI

$$\text{QDI} = \frac{\text{Degree of Implementation}_{\text{actual}}\ (\text{DIA})}{\text{Degree of Implementation}_{\text{target}}\ (\text{DIT})} = \frac{65\ \%}{65\ \%} = 1$$

$$\text{QDI} = \frac{\text{Degree of Implementation}_{\text{actual}}}{\text{Degree of Implementation}_{\text{target}}} = \frac{35\ \%}{65\ \%} = 0{,}54$$

$$\text{QDI} = \frac{\text{Degree of Implementation}_{\text{actual}}}{\text{Degree of Implementation}_{\text{target}}} = \frac{75\ \%}{65\ \%} = 1{,}15$$

QDI = 1 the target value is reached

QDI < 1 CM implementation insufficient

QDI > 1 CM implementation oversized

How is the target and actual value of the degree of implementation in each case investigated?

QDI: is *calculated*
DIA: is *calculated* from *measuring values*
DIT: is determined by estimates and judgements based on empirical experience

7.14 Mathematical foundations for the framework

The values of the determination elements form a ratio scale in the cases where the quotient of the type $\frac{benefit - costs}{benefit}$ results in a real value.

(between 0 and 1)

The determination elements, whose assessment is purely subjective (e.g. because they refer to future unknown situations), form only an ordinal scale.
To enable a combination of these different DE, a number between 0 and 1 must be found in a subjective way (intuition, experience, etc.).
This means that a "pseudo-ratio scale" is generated. Of course, the accuracy is not improved if you evaluate a situation with points from 0 to 5 or with numbers 0, 0, 0.2, 0.4,...1.0 is irrelevant.

Any fine subdivisions are only theoretically conceivable, in reality one will have to limit oneself to a few values in order not to pretend an accuracy that does not exist. The uncertainty in the assessment of future developments cannot be eliminated. The contribution to knowledge is here the possibility to include sharp statements such as $\frac{benefit - costs}{benefit}$ and vague estimates of the future together in a model. The weighting factors allow the tailoring to the individual company according to its structure. They represent the significance of individual characteristics of a particular company and its relations with its surroundings.

Benefits = Gross benefits (e.g. additional sales)

Benefits - Costs = Net benefits

The quotient of net utility and gross utility returns a value less than or equal to 1. By specifying 0 if cost>= gross utility it is ensured that no negative value appears. Thus the size lies within the interval [0,1].

Interpretation 0→0%
1→100%

For the less interesting case gross benefit = cost = 0 set Q(..)=0

7.15 Derivation of the DIA

7.15.1 Configuration Management (CM)

$$V(CM_i) = N(CM_i)$$

Have to be determined by CM experts, who know the company to be evaluated in detail.
Formally this results in the following general formula.

$$\text{Influencing Value} = IV(CM_i) = N(CM_i) \cdot \varepsilon_i$$

ε_i = Weighting Factor for the Configuration Management CM_i

$$\sum_{i=1}^{7} \varepsilon_i = 1$$

$V(CM_1)$ = Configuration management (CM) is a formally recognised function within your organization.

$V(CM_2)$ = The scope of CM includes all information that could impact safety, security, quality, schedule, cost, profit or the environment.

$V(CM_3)$ = The emphasis of CM is to accommodate change, keep requirements clear, concise and valid and ensure that results conform.

$V(CM_4)$ = Configuration requirements are maintained in baselines and updated with each change.

$V(CM_5)$ = Each baseline includes both as-planned and as-released requirements and visibility of planned changes.

$V(CM_6)$ = Each baseline is closely coupled with a closed-loop change process that includes fast-track capability.

$V(CM_7)$ = Metrics are used to monitor performance of the configuration management process and guide continuous improvement efforts.

$$IV(CM) = \sum_{i=1}^{7} V(CM_i) \cdot \varepsilon_i$$

7.15.2 Requirements Management (RM)

$$V(RM_i) = N(RM_i)$$

Have to be determined by CM experts, who know the company to be evaluated in detail.
Formally this results in the following general formula.

$$IV(RM_i) = N(RM_i) \cdot \zeta_i$$

ζ_i = Weighting Factor for the Requirements Management RM_i

$$\sum_{i=1}^{7} \zeta_i = 1$$

$V(RM_1)$ = A requirement is not a requirement unless it is captured on a tangible media, validated and released.
$V(RM_2)$ = Requirements must lead and results must conform.

$V(RM_3)$ = Each dataset is a requirement to its user and each user is responsible for achieving results that conform.

$V(RM_4)$ = All work is authorized and controlled with change objects.

$V(RM_5)$ = Results of work accomplished must conform to requirements specified on the change objects.

$V(RM_6)$ = Usage of deviations and waivers would be greatly reduced if it did not take so long to update or correct the requirements.

$V(RM_7)$ = Metrics are used to monitor performance of the requirements management process and guide continuous improvement efforts.

$$IV(RM) = \sum_{i=1}^{7} V(RM_i) \cdot \zeta_i$$

7.15.3 Change Management (CHM)

$$\mathrm{V(CHM_i) = N(CHM_i)}$$

Have to be determined by CM experts, who know the company to be evaluated in detail.

Formally this results in the following general formula.

$$\mathrm{IV(CHM_i) = N(CHM_i) \cdot \eta_i}$$

η_i = Weighting Factor for the Change Management CHM_i

$$\sum_{i=1}^{7} \eta_i = 1$$

$V(CHM_1)$ = As-planned and as-released baselines, and all datasets contained in those baselines, are updated with one common change process.

$V(CHM_2)$ = Each change goes through an analysis phase and, if approved, an implementation phase.

$V(CHM_3)$ = Standardized change objects are used as templates to guide each change through each step of the process.

$V(CHM_4)$ = Business decisions are separated from enterprise change assessments and implementation planning details.

$V(CHM_5)$ = For changes categorized as fast-track, document creators may approve their own technical recommendations.

$V(CHM_6)$ = All primary items and datasets impacted by a change are specified on the CN object.

$V(CHM_7)$ = Metrics are used to monitor performance of the change management process and guide continuous improvement efforts.

$$IV(CHM) = \sum_{i=1}^{7} V(CHM_i) \cdot \eta_i$$

7.15.4 Release Management (RLM)

$$V(RLM_i) = N(RLM_i)$$

Have to be determined by CM experts, who know the company to be evaluated in detail.

Formally this results in the following general formula.

$$IV(RLM_i) = N(RLM_i) \cdot \theta_i$$

θ_i = Weighting Factor for the Release Management RLM_i

$$\sum_{i=1}^{7} \theta_i = 1$$

$V(RLM_1)$ = A new or revised dataset, once released, cannot be changed without proper CN authority.

$V(RLM_2)$ = A dataset must be validated before it can be released.

$V(RLM_3)$ = A dataset must be released before it can be used.

$V(RLM_4)$ = Although release dates must support the earliest need dates, datasets are nevertheless released on a just-in-time basis.

$V(RLM_5)$ = Baselines include both planned and actual release dates for new and revised datasets.

$V(RLM_6)$ = Planned release dates are used to drive all development resources with one common set of priorities.

$V(RLM_7)$ = Metrics are used to monitor performance of the release management process and guide continuous improvement efforts.

$$IV(RLM) = \sum_{i=1}^{7} V(RLM_i) \cdot \theta_i$$

7.15.5 Data Mangement (DM)

$V(DM_i) = N(DM_i)$

Have to be determined by CM experts, who know the company to be evaluated in detail.

Formally this results in the following general formula.

$$IV(DM_i) = N(DM_i) \cdot \rho$$

ρ_i = Weighting Factor for the Data Mangement DM_i

$$\sum_{i=1}^{7} \rho_i = 1$$

$V(DM_1)$ = Each Physical item and each dataset has its own formally controlled metadata.

$V(DM_2)$ = Each physical items have a formally assigned identification number, name and description.

$V(DM_3)$ = Physical items that are not fully interchangeable are not allowed to carry the same identification number.

$V(DM_4)$ = Standardized and formally applied conventions are used to name each physical item and describe its attributes.

$V(DM_5)$ = Similarities and differences between the various physical items are derived from their names and descriptions.

$V(DM_6)$ = It is understood that resource effectiveness declines exponentially with a linear decline in the integrity of datasets used in-series.

$V(DM_7)$ = Metrics are used to monitor performance of the data management process and guide continuous improvement efforts.

$$IV(DM) = \sum_{i=1}^{7} V(DM_i) \cdot \rho_i$$

7.15.6 Records Management (RCM)

$$V(RCM_i) = N(RCM_i)$$

Have to be determined by CM experts, who know the company to be evaluated in detail.

Formally this results in the following general formula.

$$IV(RCM_i) = N(RCM_i) \cdot \kappa_i$$

κ_i = Weighting Factor for the Records Management RCM_i

$$\sum_{i=1}^{7} \kappa_i = 1$$

$V(RCM_1)$ = Forms used to authorize and control work are completed and retained as records of work accomplished.

$V(RCM_2)$ = Each as-built item must conform to its as-built/as-modified record.

$V(RCM_3)$ = Retained records include proof that the results of authorized and accomplished work did, in fact, conform to the requirements.

$V(RCM_4)$ = Changes requiring traceability can be tracked to specific end-items via retained records.

$V(RCM_5)$ = Old and new items are easily identified via retained records.

$V(RCM_6)$ = Lot controlled items are traceable from their original source to their current location via retained records.

$V(RCM_7)$ = Metrics are used to monitor performance of the records management process and guide continuous improvement efforts.

$$IV(RCM) = \sum_{i=1}^{7} V(RCM_i) \cdot \kappa_i$$

7.15.7 Dataset Control (DC)

$$V(DC_i) = N(DC_i)$$

Have to be determined by CM experts, who know the company to be evaluated in detail.

Formally this results in the following general formula.

$$IV(DC_i) = N(DC_i) \cdot \lambda_i$$

λ_i = Weighting Factor for the Dataset Control RCM_i

$$\sum_{i=1}^{7} \lambda_i = 1$$

$V(DC_1)$ = Released information is retained in secure repositories and accessible when needed.

$V(DC_2)$ = Individual dataset objects are identified by type, number and revision level.

$V(DC_3)$ = Dataset formats are standardized by dataset type.

$V(DC_4)$ = Rather than ownership by a single individual, each dataset is co-owned by its assigned creator and one or more users.

$V(DC_5)$ = The assigned creator is the one who best understands the higher-level requirements.

$V(DC_6)$ = Over 80% of all datasets are relatively simple and are co-owned by a creator and a single user.

$V(DC_7)$ = Metrics are used to monitor performance of the dataset and library control process and guide continuous improvement efforts.

$$IV(DC) = \sum_{i=1}^{7} V(DC_i) \cdot \lambda_i$$

7.15.8 Enabling Software Tools (EST)

$$V(EST_i) = N(EST_i)$$

Have to be determined by CM experts, who know the company to be evaluated in detail.

Formally this results in the following general formula.

$$IV(EST_i) = N(EST_i) \cdot \mu_i$$

μ_i = Weighting Factor for the Enabling Software Tools EST_i

$$\sum_{i=1}^{7} \mu_i = 1$$

$V(EST_1)$ = Your organization understands the software functionality required to support baselines and the closed-loop change process.

$V(EST_2)$ = The strengths and weaknesses of existing software tools have been defined and agreed upon.

$V(EST_3)$ = Solutions for resolving the identified weaknesses have been agreed upon.

$V(EST_4)$ = Needed improvements in software functionality have been given the appropriate priority.

$V(EST_5)$ = Those who direct the software development and upgrade activities are IPE/CM2 certified.

$V(EST_6)$ = CM2 grads in your organization are ensuring that needed functionality is being achieved.

$V(EST_7)$ = Metrics are used to monitor performance of the enabling software tools and guide continuous improvement efforts.

$$IV(EST) = \sum_{i=1}^{7} V(EST_i) \cdot \mu_i$$

7.15.9 Determination of the DIA from IVs of the chapter DIA

ν_i = Weighting Factor for the Determination of the DIA.

$$\sum_{i=1}^{8} \nu_i = 1$$

$$\mathrm{DIA} = \mathrm{IV(CM)} \cdot \nu_1 + \mathrm{IV(RM)} \cdot \nu_2 + \mathrm{IV(CHM)} \cdot \nu_3 + \mathrm{IV(RLM)} \cdot \nu_4 + \mathrm{IV(DM)} \cdot \nu_5 + \mathrm{IV(RCM)} \cdot \nu_6 + \mathrm{IV(DC)} \cdot \nu_7 + \mathrm{IV(EST)} \cdot \nu_8$$

7.16 Derivation of the DIT

7.16.1 External Complexity

The *external complexity* is determined by the respective company environment, for example by suppliers, customers or authorities. These external influences cannot be directly influenced, but have a direct impact on daily work.

The different determination elements (DE) have different weightings depending on the type of company or industry. For the mathematical illustration of this fact it is therefore necessary to have the various single complexities (EC_i). (which determine the content of the determination elements) to assign a corresponding weighting factor α_i.

$$N(EC_i) = Q(EC_i) \text{ für } i = 1, 2, \dots 8$$

$Q(EC_i)$ is the quotient $\frac{current\ costs\ related\ to\ EC_i}{maximum\ allowed\ costs}$

If $\frac{current\ costs\ related\ to\ EC_i}{maximum\ allowed\ costs} > 1$ so set $Q(EC_i) = 1$

Formally this results in the following general formula.

$$IV(EC_i) = Q(EC_i) \cdot \alpha_i$$

α_i = Weighting Factor for the single complexity EC_i

$$\sum_{i=1}^{8} \alpha_i = 1$$

Determination elements of external complexity in this thesis are:

EC_1: Suppliers Quality fluctuations

Data Origin:
Quality Department or Procurement

Under this point, the quality evaluation of the supplier is carried out. Usually, this function is located in the quality department or in the procurement department.

Formula:

$$Q(EC_1) = \frac{current\ costs\ of\ adaptation\ per\ time\ unit}{maximum\ allowed\ costs\ of\ adaptation\ per\ time\ unit\ defined\ by\ the\ involved\ company}$$

The numerator shows the current adjustment costs per time unit incurred by Supplier Quality Fluctuations. The denominator indicates the maximum allowable adjustment expenditure per unit of time that will be accepted by management to complete the business activity.

Configuration Management provides the suppliers with all the data and information required for production. It contains the drawing validities, the modification validities and the change control. Quality fluctuations in supplies are an indication that data quality and communication are not at the level they should be. This results in considerable additional costs for both companies (supplier and goods recipient), have a negative impact on earnings. High-quality configuration management counteracts these costs.

Evaluation:
The traceability and identifiability of parts or services is ensured by Configuration Management. The higher the suppliers quality fluctuation, the more important it is to use Configuration Management at a high level to maintain an overview and prove product conformity to the authorities. This is particularly important when many or complex parts are used in the end product to be produced. For example, 5000 and more individual parts are installed in individual sections of aircraft structures, many of which are safety-critical. The most important parts are additionally serialized. The aircraft section built by the aircraft structure manufacturer is an independent CA (constituent assembly) consisting of many subordinate parts, some of which are also serialized. The serial number of the CA is different from the serial number of the aircraft (MSN) in which the CA is installed. This means that different serial number systems are used and combined. These must be mastered for themselves and the resulting

combination. The complexity increases massively with the size and number of serial number systems.

EC_2: Fluctuation in customers demand

Data Origin:
Programme and Planning Department

This point is understood as quantity-based order adjustment by the customer. This means the quantity to be produced or the resulting quantitative fluctuation as well as the change of the end customer with a combined configuration change.

Formula:

$$Q(EC_2) = \frac{current\ costs\ caused\ for\ fluctuation\ in\ customers\ demand\ per\ time\ unit}{maximum\ allowed\ costs\ for\ fluctuation\ in\ customers\ demand\ per\ time\ unit\ defined\ by\ the\ involved\ company}$$

Evaluation:
Changes in customer demands are taking place faster and faster. This leads to a significantly higher complexity for the company as a whole and for CM in particular. In general, this leads to the conclusion that product life cycles are becoming shorter and shorter. Since this thesis is a global investigation in the field of aerospace, there are very different customer groups along the entire product lifecycle. In the aerospace industry, strategic decisions by end customers (airlines and aerospace operators) play a major role. Here are two examples: In recent decades, the aviation industry has been faced with the question of which long-haul transport system will prevail. On the one hand, there is the point-to-point system in which smaller twin-engine long-haul aircraft fly directly between two destinations. One example is the Delta Airlines flight between Stuttgart and Atlanta, which has taken place since 1986. Usually, one of the two destinations is a secondary airport. On the other hand, there is the so-

called hub system. Two hubs are operated by large four-engine long-haul aircraft. These hubs are often neither the starting point nor the destination, which means that air passengers often arrive at the first hub airport with short-haul and medium-haul aircraft and then travel on to their final destination at the second hub airport. One example is the Munich-Dubai route, which Emirates has been operating with the Airbus A380 for years. Ultimately, the point-to-point system has prevailed due to passenger comfort, since no annoying changeover is necessary. In this case, it is the end-user who is responsible for ensuring that the airlines have reviewed and changed their strategy. This ultimately led to a massive drop in demand for large four-engine long-haul aircraft. Finally, Airbus took the consequences and will stop A380 production. The right strategy was to rely on modern twin-engine long-haul aircraft in time. Airbus did this with the A350. In order to implement such a highly complex international project as quickly as possible, very advanced CM methods are required. For this reason, the responsible Configuration Manager for the A350 program was interviewed for this thesis.

Space travel is also on the move at the moment. There are strong adaptations of customer requirements based on more advanced technologies and new strategies. One example is SaceX, which has developed recyclable rockets using revolutionary control techniques. This development also has a massive influence on customer behaviour, with payload prices falling massively. The entire product lifecycle becomes longer and this leads to higher complexity and presents the CM with new challenges. In order to take this development into account, experts from space industry and even an astronaut were interviewed.

EC_3: Customer specific adaptations (Customising)

Data Origin:
Configuration Management

Formula:

$$Q(EC_3) = \frac{current\ costs\ caused\ for\ customer\ specific\ adaptions\ per\ time\ unit}{maximum\ allowed\ costs\ for\ customer\ specific\ adaptions\ per\ time\ unit\ defined\ by\ the\ involved\ company}$$

Evaluation:

An exposed factor in external complexity is the degree of individualisation on the part of the customer. Depending on the number of possible degrees of individualization, the complexity increases steeply. The more customization options available, the more important the functionality of the underlying Configuration Management. In individual cases, the possibilities of variation of the mathematical tool of combinatorics need to be determined.

EC_4: Rate of change of production requirements by customers

Data Orgin:

Industiral Engineering

Formula:

$$Q(EC_4) = \frac{current\ costs\ caused\ for\ chang\ \ of\ production\ requirements\ by\ customers\ per\ time\ unit}{maximum\ allowed\ costs\ change\ of\ production\ requirements\ by\ customers\ per\ time\ unit\ defined\ by\ the\ involved\ company}$$

EC_5: Rate of change of production requirements by authorities

Data Origin:

Industiral Engineering

Formula:

$$Q(EC_5) = \frac{current\ costs\ caused\ for\ change\ of\ production\ requirements\ by\ authorities\ per\ time\ unit}{maximum\ allowed\ costs\ for\ change\ of\ production\ requirements\ by\ authorities\ per\ time\ unitdefined\ by\ the\ involved\ company}$$

EC_6: Fluctuations in delivery times of suppliers

Data Origin:
Procurement

Formula:

$$Q(EC_6) = \frac{current\ costs\ caused\ by\ fluctuations\ in\ delivery\ times\ of\ suppliers\ per\ time\ unit}{maximum\ allowed\ costs\ by\ fluctuations\ in\ delivery\ times\ of\ suppliers\ per\ time\ unit\ defined\ by\ the\ involved\ company}$$

EC_7: Exchange of information with the customer

The measurement of the changed information is limited in this thesis to modified documents. The reason for this limitation is the high complexity of the information flow. The social exchange of information, such as meetings, formal and informal types of communication, is not to be underestimated. However, the decisive information is documented and exchanged in written form. For this reason, the procedure makes sense to limit itself to the written exchange of information.

Data Origin:
Programme Department

Formula:

$$Q(EC_7) = \frac{current\ costs\ caused\ by\ fluctuations\ in\ exchange\ of\ information\ with\ the\ customer}{maximum\ allowed\ costs\ by\ fluctuations\ in\ exchange\ of\ information\ with\ the\ customer\ defined\ by\ the\ involved\ company}$$

EC_8: Exchange of information with the supplier

The measurement of the changed information is limited in this thesis to modified documents. The reason for this limitation is the high complexity of the information flow. The social exchange of information, such as meetings, formal and informal types of communication, is not to be underestimated. However, the decisive

information is documented and exchanged in written form. For this reason, the procedure makes sense to limit itself to the written exchange of information.

Data Origin:

Procurement

$$Q(EC_8) = \frac{current\ costs\ caused\ by\ fluctuations\ in\ exchange\ of\ information\ with\ the\ supplier}{maximum\ allowed\ costs\ by\ fluctuations\ in\ exchang\ \ of\ information\ with\ the\ supplier\ defined\ by\ the\ involved\ company}$$

$$IV(EC) = \sum_{i=1}^{8} N(EC_i) \cdot \alpha_i$$

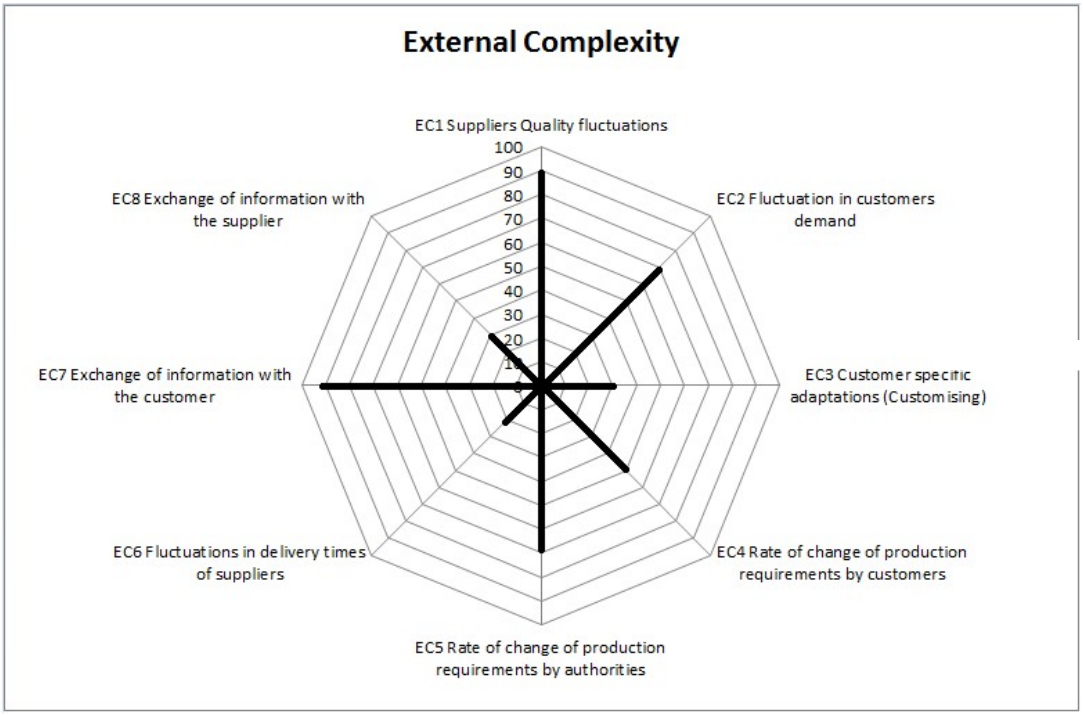

Figure 7-5: External Complexity based on $Q(EC_i)$ presented with data of a sample company (The length of the bars represent $Q(EC_i)$)

	EC_1	EC_2	EC_3	EC_4	EC_5	EC_6	EC_7	EC_8
$Q(EC_i)$	0,9	0,7	0,32	0,5	0,7	0,22	0,91	0,30
α_i	0,1	0,1	0,2	0,1	0,05	0,1	0,2	0,15
$IV(EC_i)$	0,09	0,07	0,064	0,05	0,035	0,022	0,182	0,045

Table 7-7: EC_i as a function of $Q(EC_i)$ and $IV(EC_i)$

The next graph shows the Influence Values combining the $Q_{(ECi)}$ with the weighting factors as a product.

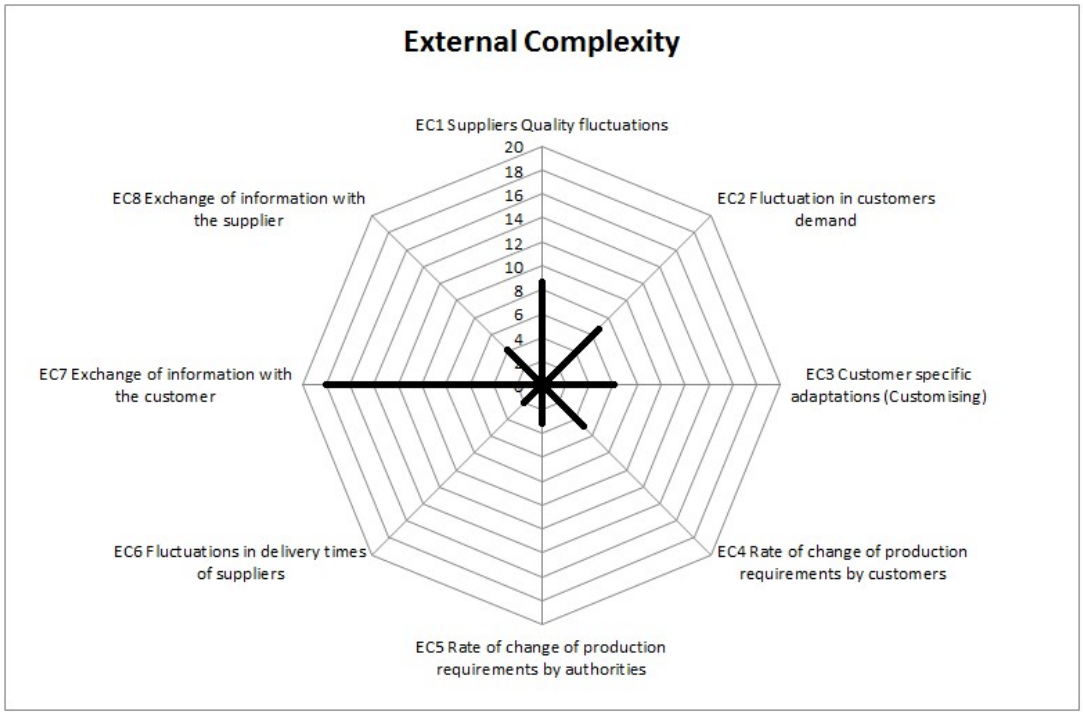

Figure 7-6: External Complextiy based on influencing values $IV(EC_i) = Q(EC_i) \cdot \alpha_i$ presented with data of a sample company (The length of the bars represent $IV(EC_i)$)

7.16.2 Internal Complexity

The *internal complexity* of a company is determined by various factors. Important influencing factors are the organizational structure, processes and especially the complexity of the products.

The different determination elements (DE) have different weightings depending on the type of company or industry. For the mathematical illustration of this fact it is therefore necessary to have the various single complexities (IC_i). (which determine the content of the determination elements) to assign a corresponding weighting factor α_i.

$$N(EC_i) = Q(EC_i) \text{ for } i = 1, 2, \ldots 7$$

$Q(IC_i)$ is the quotient $\frac{current\ costs\ related\ to\ EC_i}{maximum\ allowed\ costs}$

If $\frac{current\ costs\ related\ to\ IC_i}{maximum\ allowed\ costs} > 1$ so set $Q(IC_i) = 1$

Formally this results in the following general formula.

$$IV(EC_i) = Q(IC_i) \cdot \beta_i$$

β_i = Weighting Factor for the single complexity IC_i

$$\sum_{i=1}^{8} \beta_i = 1$$

IC_1: Diversity of product range:

Data Origin:
Sales Department

There are thousands of different product variations in aircraft structures. Not all variations are similar or specified by time intervals. The more variance is in the production process the more complex is the production.

The variant diversity is increasing enormously during the last decades. There are a lot of different reasons for a rising variant diversity. The offering of a modified short and medium distance aircraft to serve long range routes is an example to follow individual customer wishes. This brings a lot of individual options which are managed with the help of MODs.
Regional requirements in globalized markets which could be for example water absorbers at the rear aft fuselage of aircraft is another example of variant diversity.

Other reason for a large diversity of product range could be:

- Realizing market potential
- Addressing different purchasing groups
- Increasing customer loyalty
- Differentiation in the market and avoidance of price wars
- Creation of market entry barriers

Many drivers lead continuously to more and more variants. The speed of this growth is increasing extremely, especially in the aerospace industry.

Formula:

$$Q(IC_1) = \frac{current\ costs\ for\ diversity\ of\ product\ range}{maximum\ allowed\ costs\ for\ diversity\ of\ product\ range\ defined\ by\ the\ involved\ company}$$

IC_2: Multidisciplinarity:

Data Origin:
Program Department

Formula:

$$Q(IC_2) = \frac{current\ costs\ for\ multidisciplinarity}{maximum\ allowed\ costs\ for\ multidisciplinarity\ defined\ by\ the\ involved\ company}$$

Evaluation:
The aerospace industry is highly characterised by the phenomenon of multidisciplinarity. The concept of multidisciplinarity is constituted by the fact that several disciplines work in parallel on an overarching complex task. This requirement profile is present in all companies which (a) develop/manufacture a multi-layered structured product, (b) consequently have a corresponding size and depth of operation and (c) therefore employ highly specialised experts in different specialist departments. These criteria are particularly true for the aerospace industry. In order to manufacture the highly complex products, different specialist departments must cooperate, even though their experts have little or no points of contact with regard to content. In the case of a technical

product, an a priori interdisciplinary approach is de facto not meaningful or pragmatically feasible, since it is not really possible to create a uniform conceptual framework structure that is sufficiently cognitively accessible to all parties involved due to the extensive scope and disparity of the specialized areas of competence. Clearly defined, highly specialized subtasks in the high-tech sector require the indispensable expertise of specialization, which eo ipso diametrically opposes the integrative style of thinking. In other words, the parallel processing of parallel sub-processes is a necessity due to the high technical standard and degree of complexity.

For the successful integration of the sub-processes into a final overall process, not only an additive synthesis of the work results of different departments is necessary (especially since the processes are very dynamic due to the high technical and economic development pressure), but a continuous structural integration on a superimposed control level. This is the domain of CM.

Examples:

Development of a complex international aircraft project using the Airbus A350 is an example. This example clearly illustrates how the requirement for the interaction of different disciplines presented by the concept of multidisciplinarity can be expressed in reality. Since the A350 is one of the largest aircraft projects of recent years in Europe, this project was given special consideration in this thesis by including an interview from this programme. With the A350, new composite materials play an important role, which have been used for the first time in such a high degree of detail. This has a significant impact on both the materials department and the strength department. New avionics applications and engine technologies have also been introduced. Also, the fact that it is a long-range aircraft capable of flying extreme distances non-stop has created requirements for development that can only be met by integrating a wide range of disciplines. For example, the necessary enlargement of the fuselage cross-section had an influence on almost all disciplines.

IC_3: Variety of applicable processes

Data Origin:

Program Department

Formula:

$$Q(IC_3) = \frac{\text{current costs for variety of applicable processes}}{\text{maximum allowed costs for variety of applicable processes defined by the involved company}}$$

IC_4: Exchange of information between different business units

Data Origin:

Program Department

Formula

$$Q(IC_4) = \frac{current\ costs\ for\ exchange\ of\ information\ between\ different\ business\ units}{maximum\ allowed\ costs\ for\ exchange\ of\ information\ between\ different\ business\ units\ defined\ by\ the\ involved\ company}$$

IC_5: Period of product development

Data Origin:

Planning Department

Formula:

$$Q(IC_5) = \frac{current\ costs\ for\ period\ of\ product\ development}{maximum\ allowed\ costs\ for\ period\ of\ product\ development\ defined\ by\ the\ involved\ company}$$

IC_6: Period of production

Data Origin:

Planning Department

Formula

$$\mathrm{Q}(\mathrm{IC}_6) = \frac{current\ costs\ for\ period\ of\ production}{\substack{maximum\ allowed\ costs\ for\ period\ of\ production \\ defined\ by\ the\ involved\ company}}$$

IC_7: Parallelisation of development and production

Data Origin:

Planning Department

Formula

$$\mathrm{Q}(\mathrm{IC}_7) = \frac{current\ costs\ for\ parallelisation\ of\ development\ and\ production}{\substack{maximum\ allowed\ costs\ for\ parallelisation\ of\ development\ and\ production \\ defined\ by\ the\ involved\ company}}$$

$$IV(IC) = \sum_{i=1}^{7} N(IC_i) \cdot \beta_i$$

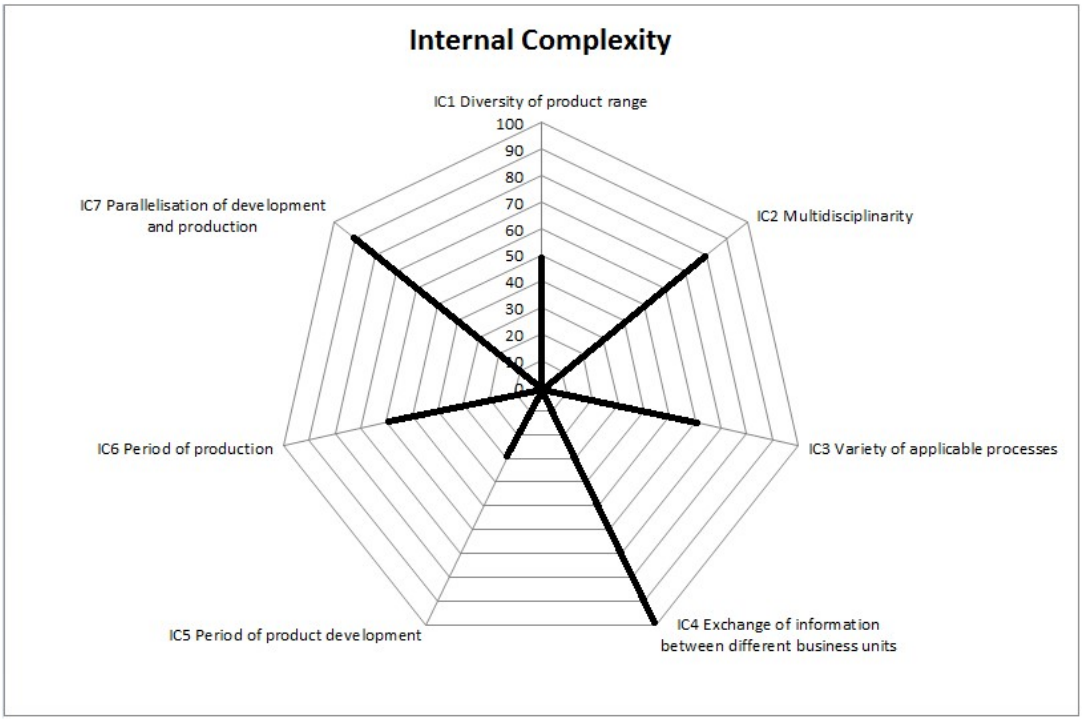

Figure 7-7: Internal Complexity based on $Q(IC_i)$ presented with the data of a sample company (The length of the bars represent $Q(IC_i)$)

	IC_1	IC_2	IC_3	IC_4	IC_5	IC_6	IC_7
$Q(IC_i)$	0,5	0,8	0,62	1,0	0,3	0,6	0,91
β_i	0,2	0,0	0,1	0,2	0,1	0,3	0,1
$IV(IC_i)$	0,1	0,0	0,062	0,2	0,03	0,18	0,091

Table 7-8: IC_i as a function of $Q(IC_i)$ and IV (IV_i)

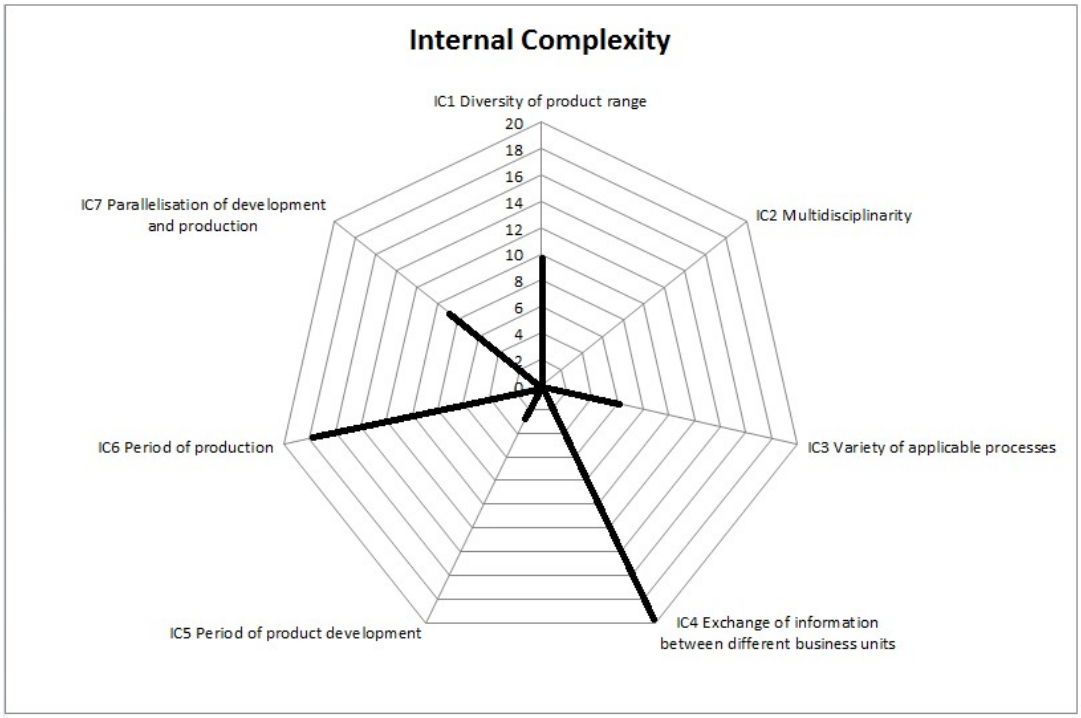

Figure 7-8: Internal Complextiy based on influencing values $IV(IC_i) = Q(IC_i) \cdot \beta_i$ presented with the data of a sample company (The length of the bars represent $IV(IC_i)$)

7.16.3 Potential

With regard to potential, it should be noted that the individual potential targets (POT_i) relate to feasibility, while the weighting factors represent the significance of the category concerned within this company.

In order to compare subjective assessments with calculable quotients based on concrete data, the following expression is defined:

$$N(POT_i) = \begin{cases} Q(POT_i) \text{ if for the individual determination element } POT_i \text{ a quotient exists} \\ V(POT_i) \text{ if there is only one subjective assessment in levels} \end{cases}$$

Für i = 1, 2, … 10

$V(POT_i)$ is a number between 0 and 1 given by experts by subjective assessment, e.g. in five steps.

$Q(POT_i)$ is the quotient $\frac{benefit - costs}{benefit}$

Benefits = Gross benefits (e.g. additional sales)

Benefits - Costs = Net benefits

For the less interesting case $\text{gross benefit} = \text{cost} = 0$ set $Q(POT_i)=0$

The different determination elements (DE) have different weightings depending on the type of company or industry. For the mathematical illustration of this fact it is therefore necessary to have the various single complexities (POT_i). (which determine the content of the determination elements) to assign a corresponding weighting factor γ_i.

Formally this results in the following general formula.

$$\mathrm{IV}(\mathrm{POT_i}) = \mathrm{N}(\mathrm{POT_i}) \cdot \gamma_i$$

γ_i = Weighting Factor for the single complexity POTi

$$\sum_{i=1}^{10} \gamma_i = 1$$

Determination elements of external complexity in this thesis are:

$\mathrm{POT_1}$: Generation of new business models

$$\mathrm{V}(\mathrm{POT1}) = \mathrm{N}(\mathrm{POT1})$$

$\mathrm{POT_2}$: Cooperation between different locations of a company

$\mathrm{POT_3}$: Overview in a company

$\mathrm{POT_1}$ –$\mathrm{POT_3}$: Define significance by a number between 0 and 1 through information from experts

$\mathrm{POT_4}$: Reduction of rework

$$\mathrm{Q}(\mathrm{POT_4}) = \mathrm{N}(\mathrm{POT_4})$$

$$\mathrm{Q}(\mathrm{POT_4}) = \begin{cases} \frac{benefit\ of\ rework - costs\ of\ rework}{benefit\ of\ rework} & if\ benefit > costs \\ 0 & if\ benefit \leq costs \\ 0 & if\ benefit = 0 \end{cases}$$

With regard to the current situation

POT_5: Finding new customers

POT_6: Delivering services over the whole product lifecycle

POT_7: Ensuring the individualisation of a product

POT_8: Enabling industry 4.0

POT_9: Enabling internet of things

POT_{10}: Enabling new services for customers

POT_5 – POT_{10}: Define significance by a number between 0 and 1 through information from experts.

The result of the evaluations of the interviews has shown that there are already several consulting firms that act as external service providers and record the current status of configuration management in companies. The generation of these data and the subsequent evaluation requires highly specialized expert knowledge. A comprehensive market overview and as much experience as possible are beneficial for this activity. For these reasons as well as in particular to counteract an internal blindness of the company, the appeal of an external consultant is highly recommended, who has the appropriate routine to apply the necessary tools such as the adequate presented here.

$$IV(POT) = \sum_{i=1}^{7} N(POT_i) \cdot \gamma_i$$

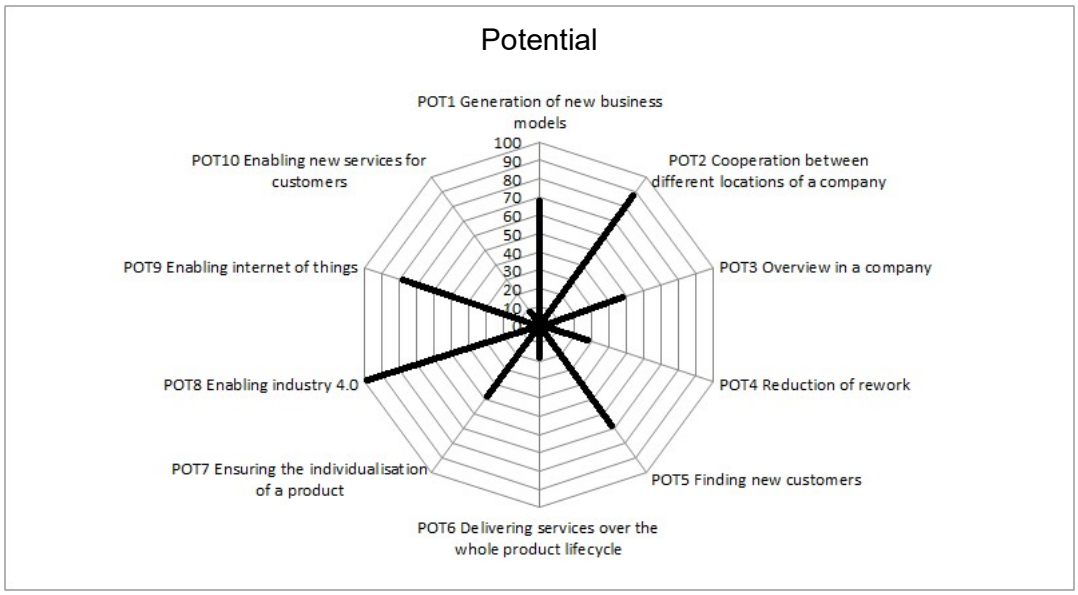

Figure 7-9: Potential based on $N(POT_i)$ presented with data of a sample company (The length of the bars represent $N(POT_i)$)

	POT_1	POT_2	POT_3	POT_4	POT_5	POT_6	POT_7	POT_8	POT_9	POT_{10}
$N(POT_i)$	0,7	0,9	0,5	0,3	0,7	0,2	0,5	1,0	0,8	0,1
γ_i	0,1	0,1	0,2	0,1	0,05	0,0	0,05	0,1	0,2	0,1
$IV(POT_i)$	0,07	0,09	0,1	0,03	0,035	0,0	0,0275	0,1	0,16	0,01

Table 7-9: POT_i as a function of $N(POT_i)$ and $IV(POT_i)$

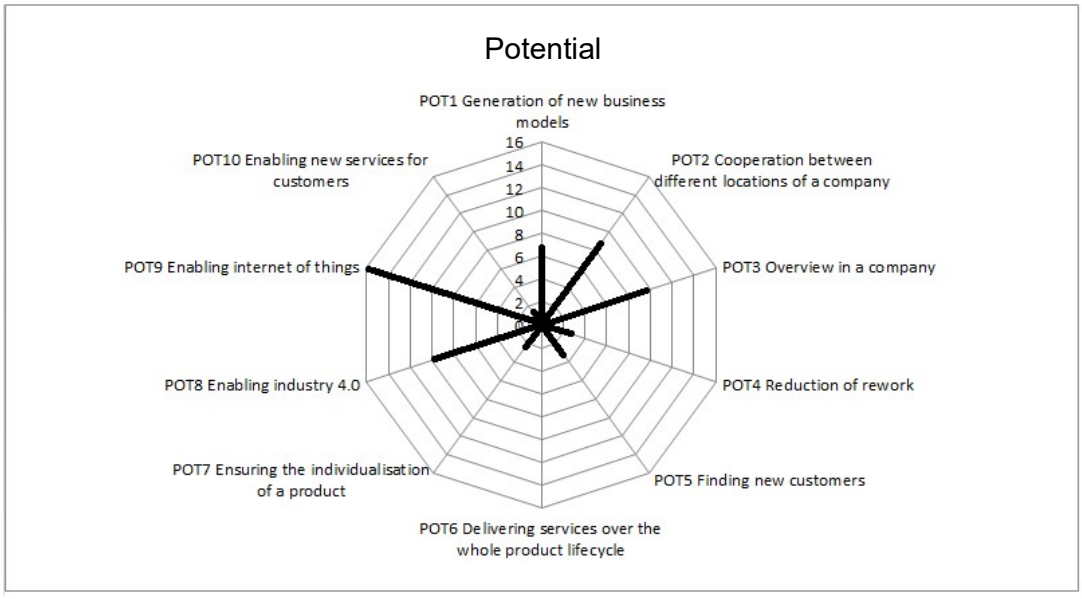

Figure 7-10: Potential based on influencing values $IV(POT_i) = N(POT_i) \cdot \gamma_i$ presented with data of a sample company (The length of the bars represent $IV(POT_i)$)

7.16.4 Determination of the DIT from IVs of the chapter DIT

ξ_i = Weighting Factor for the Determination of the DIT.

$$\sum_{i=1}^{3} \xi_i = 1$$

$$\mathrm{DIT} = \mathrm{IV(EC)} \bullet \xi_1 + \mathrm{IV(IC)} \bullet \xi_2 + \mathrm{IV(POT)} \bullet \xi_3$$

7.16.5 The problem of prognosis

Problem Exposure
It has been said above that the evaluation of the future potential of a company makes particularly ambitious demands and requires demanding competencies. Why is that? It is so, because when dealing with the future we are not dealing with a possibly exuberant, but in principle nevertheless finite number of *facts* (as with the present), but with an unmanageable number of *possibilities*, the field of which fans out all the more, the more distant that future is, into which the searching gaze is correct.

This results in a host of problems on different, i.e. theoretical as well as practical levels, which cannot even approximately be solved in this study; nevertheless, they must - not only for academic interest but also for reasons of real economic practicability of the frameworks - at least be addressed as tasks of capital difficulty that cannot be overlooked.
So the question arises: What is the inner quality of the future qua its futurity? Two essential aspects can be distinguished in a very rough distinction (beside a multiplicity further):

- First, the "technical" aspect of the predictability of the future.
- Second, the anthropological aspect of anticipation and appropriation for the future

The two aspects have a lot of coherent facts inherent in them, which apart from more general philosophical and fundamental-physical questions of the kind, whether being in time or vice versa is time in being, show concrete meaning in questions of concrete meaning.

7.16.6 The technical aspect of the predictability of the future

7.16.6.1 The Physical Paradigm

The common exemplary model for scientific predictions of the future is the physical system. Scientific predictions of the classical kind are made in their operative core in a mathematical way by quantitatively calculating a future state of a defined observation and measurement field (system) on the basis of existing facts. This means that it is a kind of linear extension of the present insofar as current parameters of the system are extrapolated to a future point in time. This procedure is basically deterministic. (Apart of the problems of quantum theory.) From initial conditions, subsequent effects are causally derived.
Along with the mathematical procedure is the formation and application of a physical model. The German physicist and philosopher Heinrich Herz aptly describes the principle of physical predictions:

> "We make ourselves inner illusory images or symbols of the outer objects, namely we make them of such a kind that the logical [denknotwendig] consequences of the pictures which are necessary for the knot are always the pictures of the consequences of the depicted objects which are necessary for nature". (Hertz, 1894, p. 1)

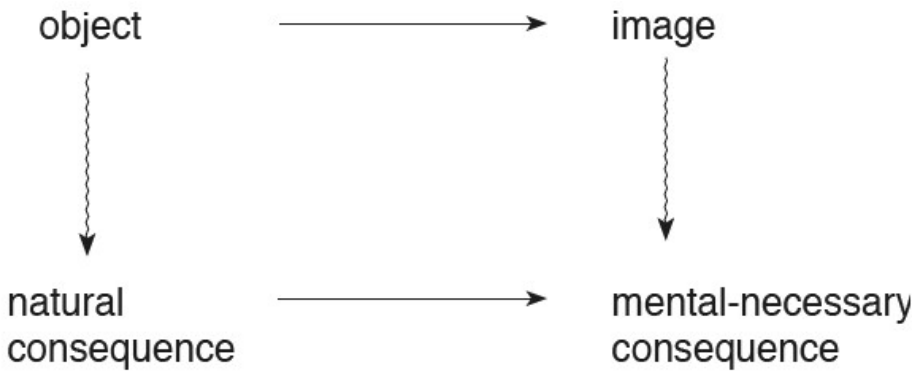

Figure 7-11: Parallelism of physical predictions according to Heinrich Hertz

This controlled parallelism is necessary, because when making a physical prediction (in sensu stricto) it is not possible to operate with the physical object itself, because for this the *real* process would have to be run through in *real time*. This is possible in principle. But then it would not be a prediction, but an experiment that could only serve to verify a prediction! Thus, the necessary sequences of given initial states are projected into the future on the basis of physical laws and the corresponding resulting states are described

mathematically. Which role mathematics plays in this is to be considered in more detail.

The world consists of innumerable conditional relationships. Every physical object, especially the quantum-physical one, has a possibility or probability horizon, i.e. its own probability of how it could interact with another object. This is the 'future' of the object. At the time when such an event actually occurs, the relevant conditional relationships collapse (and generate new ones) into a fact. The conditional is fixed and reduced to fact. In the language of classical metaphysics: potency became an act. This is, so to speak, the mechanism of time. Nevertheless, – when looked at in depth – the question remains *how* this mechanism is structured in detail. This is classical physical understanding no question which pure mathematics can solve. For it is not primarily a question of abstract quantities, but of *forces*. The situation is of course different in the quantum-physical model when it regards the decay of particles as a 'spontaneous' process, the concrete location of which on the time line cannot be further justified *in individual cases*. Meanwhile, the understanding of time formation as the fundamental collapse of conditional relationships also applies here; although apart from the recording by probability calculation, no further reason for the collapse in the individual case is asked for. Nevertheless, modelling of physical forces for prognostic statements (in the sense of Hertz; see above) is basically necessary here as well. In this respect, our image of future reality, including the future expectations concerning it, has always been (pre-)interpreted.

Decisive in the process of development of the temporal is the distinction in conditional relationships and existential statements. To the extent that the former are represented by mathematics by means of formal isomorphisms, this alone does not permit any existential statements. The latter only arise when, within the framework of the mathematically calculable physical model conceptions of fundamental forces of nature, empirically controlled perceptions are encountered. Therefore mathematics can only determine the possible by its formalism alone, not yet its binding appearance in reality.

In principle, such an approach is based on the interpretation model of the world as a machine. A classic example could be how a future solar eclipse can be precisely predicted in a thousand years by means of celestial mechanics (mathematical formulas + models of qualitative forces; here gravitation and

centrifugal forces). The same degree of precision and certainty is not achievable for the expected development line of a company.

7.16.6.2 The birth of the possible from the factual.

The history books are getting thicker and thicker. What does this fact mean? It means that with the perpetual passing of time more and more facts and events begin to exist. The inventory of the world, the set of its facts *is growing*. The systematic description of this fact is called Growing Block Theory. (Tooley, 1997)

Carl Friedrich von Weizsäcker (1980) describes this connection with the following words:

> “The past does not pass, thus the set of facts grows; the present of the future is its possibility founded in facts; thus the set of possibilities grows.” (von Weizsäcker, 1980, p. 236)

Elsewhere, when he writes, he explains this in more detail:

> “Present possibilities are always based on present facts (formation of a star is possible by the factual existence of a gas nebula; formation of a crystal by the factual existence of a melt flow; formation of numerous living beings by the factual existence of protozoa; etc.). If now the past does not pass away, but is "stored" in the present facts, then the set of the facts grows and with it the set of the currently founded possibilities. But if the number of possibilities grows, the emergence of new forms is to be expected.” (von Weizsäcker, 1991, p. 34f)

Through already existing facts a stock is built up, from whose material new possibilities are imradiated, which in turn provide the potential for new formations. This universal connection also applies to human artefacts; naturally also to economic artefacts: The more complex a company or organisation is, the greater its potential, i.e. the number of opportunities to be expected. Nota bene, this also applies to negative development opportunities, i.e. degenerative deteriorations. To put it colloquially, the more structures there are and the more they interlock operatively, the more they can go wrong. A structural wealth of

initial conditions means an abundant pool of further development opportunities, but also a ballast of possible undesirable developments. With the complexity of the given structure, the number of future sources of error also increases. The richness of factual complexity is therefore Janus-faced with regard to its future development. This makes an efficient application of CM all the more important.

7.16.6.3 The Determinism Problem

From everyday experience we know that there is an essential structural asymmetry between the past and the future: The past is “finished”, “tangible”; it is known or at least fundamentally knowable. The past is unchangeable, fixed with an iron hand, filed in the register of world history. The future is – despite all efforts regarding prediction and planning – ultimately unknown. It is true, as described above, that with its unforeseeable possibilities it is based on the foundation of factuality that has already coagulated into the past. Nevertheless, we are not granted any long-term and secure forecasts for the future. At best, we can guess, but we can't possibly know what's going to happen. Evidence, records, certificates, documents exist of the past; not of the future. One distinguishes these qualities by speaking of the *isolation* of the past and the *openness* of the future.

A flawless determinist, however, who would orientate himself on the mechanistic world view of classical physics of the nineteenth century, would claim that there is no asymmetry between past and future. He would concede that it is impossible for us to predict the future in detail due to a lack of knowledge of all initial conditions and due to a lack of computing power. But basically, he'd think that was possible. Lukasiewicz (1970) is describing this point of view vividly.

> “The determinist looks at events taking place in the world as if they where a film drama produced in same cinematographic studio in the universe. We are in the middle of the performance and do not know its ending, although each of us is not only a spectator but also an actor in the drama. But the ending is there, it exists from the beginning of the performance.”
> (Lukasiewicz, 1970, p. 113)

First of all, this should be noted semantically: If the future were strictly deterministically calculable, – would it be a future? In this case it would 'actually' already be present (no longer pending), albeit beyond the current empirical horizon of perception. Because all the necessary realities would already have been there – determinated. The reality 'film' of the world events to stay with the picture of the above quotation is then already finished. This means that all events up to the end of the world are already completely and irreversibly fixed. Thus the significant difference between past and future is blurred beyond recognition.
Regardless of the fact that the determinism of classical physics was broken by the probability prediction of quantum theory, it must be noted that the theoretical construct of determinism contradicts the factual experience of free will.
As a valid status quo, the facts of the respective present undoubtedly form the foundation on which future development is based. The question arises, however, whether the latter takes place (exclusively) in the mode of necessity or whether it permits degrees of freedom. To put it differently: Although the number of determinants increases with the accumulation of past determinants, the question still arises as to whether out of this set of growing possibilities
a) The facts lying in the future are actually deterministically to be derived from the present facts; or whether:
b) a causally not derivable 'randomness' transfers the possibilities from the realm of potentiality in an unpredictable way into factuality (quantum physical background); or whether finally:
c) man, through free acts of will, can contribute to *what* possibilities can be updated from the field of available potentiality.

That the future is open means that it is simply undecided what course our world will take. A probable event is the case only in some, but not all possible, thus conceivable, world courses. Not everything can be derived mathematically and/or causally from the present initial conditions. Therefore, even statements of a formal nature that refer to contingents of events in the future cannot correspond with the facts, precisely because these facts do not yet exist. Statements about conditional probability ratios do not in themselves lead to existential statements.
Also the prediction of a solar eclipse taking place in distant future is subject to conditional restrictions. It will occur in the predicted manner *if* no cosmic

catastrophe occurs in the solar system. No man can guarantee *that* this will be so.
Anthropologically speaking, the free will of the mind rising above the bare necessity of nature must be seen as the inescapable postulate of practical reason. Because only if and when it is not already clear in advance what will happen in the future, i.e. only if we can choose between real alternatives, can we see ourselves as genuinely acting and thus responsible originators of our actions. This results in an unavoidable individual residual risk for entrepreneurial action from a practical economic point of view.

7.16.6.4 The anthropological aspect of anticipation and appropriation for the future

a) The limits of the physical paradigm
If within physics mathematics alone cannot decide on the face of the future (because, as seen, mathematics must always be mathematical description of *something*), then this applies to predictions of the future beyond the physical a fortiori.

Prognostic statements about the future are not examples of arithmetic. Such statements include a large number of parameters that are hardly or not at all scientifically detectable and are therefore of a soft nature. In other words, they can only depict plausibilities or probabilities that do not result primarily from a lack of knowledge of hard facts available in principle for the purpose of a prognostic extrapolation, but result from a multidimensional constitution through constituents that are a priori inaccessible to quantifying calculability.
In addition, with regard to the very limited validity of the physical paradigm, in physics we are always dealing with artificially isolated subsystems. (With the exception of astrophysics, where statements are also made about the future development of the universe as a whole. However, these statements are highly speculative of a high degree of abstraction and de facto not verifiable experimentally.) However, the subject of this research is not an isolated subsystem, since a large number of external factors must be considered in every analysis of a company and its development potential. In this respect, the physical paradigm of predictability falls short for several reasons.

b) The construct character of time

As elementary as it may be, time as a structural structure is always a construct. This can already be seen in the time models of physics and even more so in the non-scientific fields of research. Also and precisely where temporal development is the explicit topic par excellence, in historical science, time as its primary medium of research is not to be presupposed in the sense of a factum brutum, but is itself to be historicized. This means that the respective past and future are already subject to interpretations, which therefore have to be reconstructed. Transferred to the topic dealt with here: Only the self-conception from the company history requires the decision and determination as well as application of a binding narrative in order to achieve a corresponding external image and customer perception. In an exposed way, the constructive character shows itself in the further future, i.e. the future in the narrower sense. Past expectations for the future can only be understood from a multilateral, even more so: multidimensional approach. This already requires a holistic approach. This makes it all the more obvious that the current future has a special *draft character*, which is of decisive importance within the framework developed for assessing the development potential of a company. The user of the framework has to deal with a projective component, which clearly exceeds the mere projection of the already existing into nearby future scenarios, because it has a considerably fictitious part. The question is not: what will develop from the company with natural necessity, but: where *should* it develop into? This means that the objective development tendency from the factual situation (structural, technical, organizational, personnel, economic) is countered at the intersection of the present by creative intentions that are postulatively placed in the future.

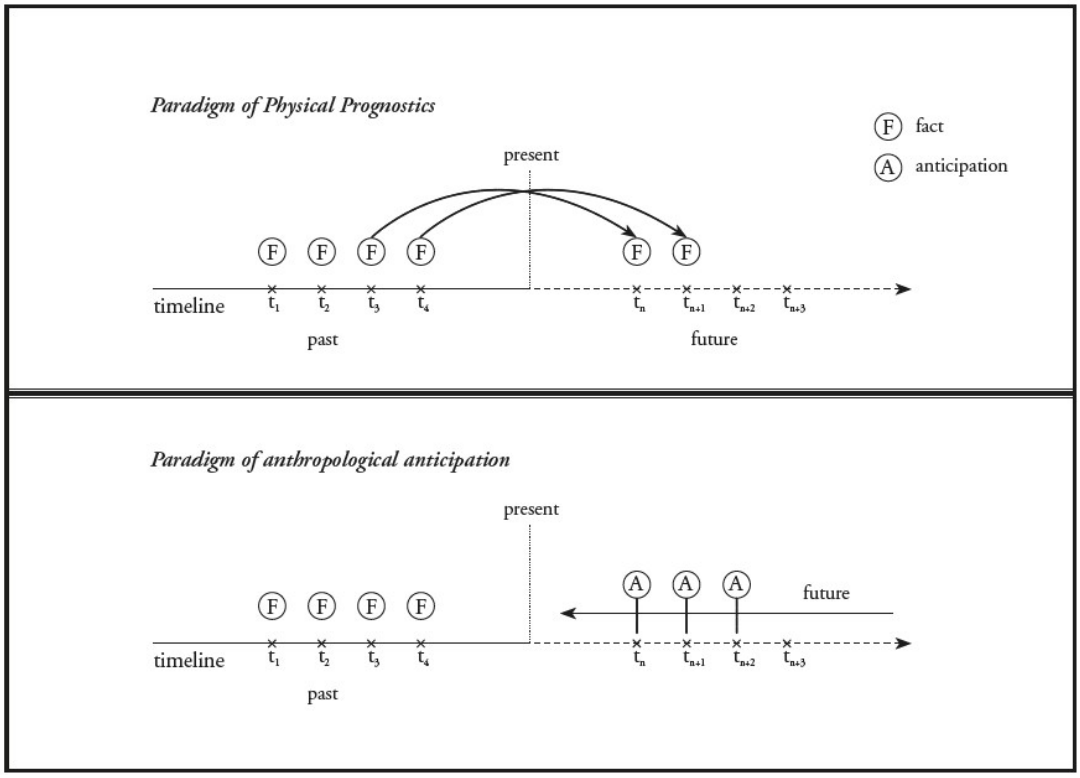

Figure 7-12: Comparison of different designs of futurity

Just as every individual human being must take his future into his own hands for the purpose and in the active execution of self-constitution and construction, every company and every organisation is called upon to engage in such a process. This is not possible without a temporary, methodical release from the present situation in order to anticipate the future. This requires a mood of curiosity, openness and energetic creative will on the part of those responsible. This ability of 'being ahead' ('Sich-vorweg-Seins' to talk with Heideggers words) is not given to every person.

7.16.6.5 The modern experience of futurity

The modernity experience of the contemporary human being is shaped by the state of being of a 'network society'. Typical of these is the phenomenon of global simultaneity. Due to the comprehensive technical possibilities of telecommunications, any information is instantaneous at almost any point in the world. On the other hand, this is accompanied by the fact that the so-called 'facts' tend to be both more questionable and more difficult to verify, and that actually verified facts have an ever-shorter actuality span and consequently a

shrinking length of stay in consciousness. Information is becoming more and more short-lived. On this fragile basis, the future will become less and less predictable, or increasingly short-term. All this more and more fragments the formerly intact connected time experience. As the German sociologist and political scientist Hartmut Rosa (2017) points out, there is an increasing acceleration in several respects with all the associated uncertainties. He distinguishes between a technical acceleration, an acceleration of the pace of life and an acceleration of social and cultural rates of change. For modern man, these processes cause an increasing desynchronization of everyday time, lifetime and historical time.

The quality of the future has therefore been strongly deformed over the past decades. It occurs more “short-term”, is more complex, consequently less predictable, consequently less predictable in length and depth. This manifests itself psychologically as a feeling of increasing insecurity.

In a globalised world there are many imponderables: global economic fluctuations and slumps, local crises with supra-regional effects, natural disasters, political developments and upheavals, wars, migration flows etc. etc... Social and economic systems are sometimes extremely sensitive to such unpredictable situations. In this respect, the management of a company can only ever be carried out subject to postulated but uncertain stability.

Stock exchange trading is a striking example of the economic risk potential of uncertain future expectations. The development of the stock market is to a large extent characterised by the expectations of the stock market with regard to forthcoming events in the near future. It can quickly be confirmed, among other things, that the anticipated future has not occurred in this way.

Leading a company successfully into the future in a time of rapid change is not an easy task. This requires a proven future orientation. How we deal with the future varies from person to person. The type of psychological future orientation depends, among other things, on mentality, temperament, socialisation, level of education and many other factors.

It makes an essential difference for a company whether it is run by a technocrat with profound expertise but no ideas, or by a visionary like Steve Jobs. If the one relies on solid but unimaginative perpetuation of the given one, then this one dares imaginative designs for the future. The soft skills required for this include qualities such as entrepreneurial courage, innovative thinking, intuition,

toughness, interdisciplinarity, but also an instinct for what is feasible and marketable. Ultimately, complementary strategies / competencies are always necessary for success in entrepreneurial future planning: It is also necessary to discard old encrustations with risk appetite, just as it is necessary, on the other hand, to adhere conservatively to valuation. In order to avoid a proliferation of visionary imagination, it must be grounded compensatively through the provision of solid pragmatics. It is rare that these complementary distortions or abilities are united in a single executive in personal union. If this is not the case, suitable persons in the leading team must complement each other to navigate the ship over rough waters into a good future. In any case, it is extremely difficult to formally consider these enormously important factors in a framework. This task can only ever succeed to a limited extent.
Through a more uncertain future the importance of CM is growing as explained before in an abstract way.

The work carried out in this chapter cushioned the inductive extraction of the core concepts from the empirical data of the interviews and thus placed them on a sound theoretical foundation. Following the elaboration of the framework itself.

7.17 Main disciplines (functions) of CM

Historically CM is divided into the CM Processes represented in **Fehler! Verweisquelle konnte nicht gefunden werden.** with the correlating typical CM Activities.

CM Processes	Typical CM Activities
CM PLANNING & MANAGEMENT Selection, tailoring, guidance & assessment	• Define application environment • Select tools, techniques and methods suitable for the environment • Plan implementation • Integrate CM within enterprise defined processes • Prepare procedures • Perform training • Measure performance
CONFIGURATION IDENTIFICATION Attributes, identifiers & baselines	• Define product structure and select sub-elements to be managed • Assign unique identifiers • Select configuration document types & formats • Define product attributes, interfaces, details in configuration documentation • Conduct review and coordination of configuration documentation and if required, obtain customer review and approval • Establish release process; release configuration documentation, authorising use • Baseline configuration documentation for internal design control and, as applicable, for customer configuration change management • Assign serial and lot numbers, as necessary to differentiate individual units and groups of units, respectively • Ensure marking or labelling of products and documentation with applicable identifiers enabling correlation between the product, configuration documentation and associated data.

CM Processes	Typical CM Activities
CONFIGURATION CHANGE MANAGEMENT Manage changes	• Identify need for change or variance • Document each request for change or variance and assign identifiers • Evaluate each change and variance, coordinating with affected areas of responsibility • Classify each request and establish effectivity • Disposition each request, obtaining required approvals • Plan change implementation • Implement change and verify re-established consistency of product, documentation, operation and maintenance information, services and training
CONFIGURATION STATUS ACCOUNTING CM information & status	• Identify and customise information requirements • Implement information system • Capture and report information about: • Product configuration status • Configuration documentation • Current baselines • Historic baselines • Change requests • Change notices • Variances • Warranty data/history • Replacements by maintenance action • Configuration verification and audit status/action item closeout • Provide availability and retrievability of data consistent with needs of the various users
CONFIGURATION VERIFICATION & AUDIT Verify performance & consistency	• Verify product within normal course of process flow • Assure consistency of release information and production/modification information • Conduct formal audit when required

CM Processes	Typical CM Activities
	• Review performance requirements, test plans, results, other evidence to determine product performs as specified, warranted & advertised • Perform physical inspection of product and design information: assure accuracy, consistency & conformance with acceptable practice • Record discrepancies: review to close out or determine action; record action items • Track action items to closure via status accounting
CM OF DIGITAL DATA Assure data integrity	• Apply identification rules to document representations and files • Use business rules based on data status for change management and archiving of data • Maintain data-product relationships • Apply disciplined version control • Assure accurate data transmittal • Provide controlled access
Note: Some activities are not applicable in every application environment.	

Table 7-10: CM Processes (ANSI/EIA-649, 1998, p. 10)

7.18 CM and Industry 4.0 - An Outlook

How will future production and service processes be structured? The answer to this question determines which practical value is to be assigned to CM in general and to the framework developed here in particular.

7.18.1 Sequence of industrial revolutions – an overview

First industrial revolution

The beginning of the first industrial revolution can be located in 1784, with the introduction of mechanical looms. These were first developed into weaving machines by means of wooden punched card controls and later by means of circulating ribbons.

In general terms, the muscle power of humans and animals was replaced by water and steam power in mechanical production plants. Hydropower was the first primary energy source. Then the steam engines were used.

Second industrial revolution

The beginning of the second industrial revolution is set in the year 1870. Due to the first use of assembly lines in the US (in the slaughterhouses of Cincinnati) using electric drives.

General characteristics of the second revolution are electrical energy and assembly lines.

Third Industrial Revolution

The third industrial revolution began in 1969 with the first programmable logic controllers from the US company Modicon (type Modicon 084). This marked a breakthrough in both industrial electronics and information technology, leading to mass automation of production processes.

The general characteristic of the third revolution is the use of information technologies for industrial production.

Fourth Industrial Revolution 'Industry 4.0'

The so-called fourth stage of the industrial revolution is also referred to as "Industry 4.0", which refers to the version numbering common for software products. This name is derived from the Research Union of the German Federal

Government and a project of the same name in the High Tech Strategy of the Federal Government. (Bundesregierung), (BMBF), (Forschungsunion)

The questionable German word creation ‘Industry 4.0’ has subsequently spread to other language areas as well. Similar initiatives have been launched in other countries. In America, for example, the ‘Industrial Internet Consortium’ (ICC) was founded in March 2014 by AT&T, Cisco, General Electric, IBM and Intel. In Japan, a similar initiative was founded by large companies, the ‘Industrial Value-Chain Initiative’ (IVI).

The usefulness of the term ‘Industry 4.0’ for the quality of such initiatives can, of course, be doubted. For industrialization stages marked by the first, second and third industrial revolutions can be clearly identified from a retrospective view. This means that there is a historically sound basis. In contrast, the figure ‘4.0’ is intended to establish an artificial relationship to these previous revolutions and thus insinuate that the current dynamics of change have the same depth of meaning and reach. With what right does this happen within a not yet completed and finally transparent development process? Accordingly, the term ‘Industry 4.0’ is also criticized on various occasions.

Rainer Draht, for example, notes: “Remarkable is the fact that an industrial revolution is being proclaimed for the first time even before it has taken place.” (Draht) Another author Wolfgang Halang criticizes the term as “impudent and dubious” (Halang & Unger, 2014) It would make more sense (albeit less spectacularly and senselessly formulated) to label the intended change, for example, as a “second phase of digitization” as Hartmut Hirsch-Krainsen does. (Hirsch-Kreinsen, Ittermann, & Niehaus, 2015) The arbitrary proclamation of a new age seems presumptuous and not very target-oriented, even counterproductive. Stefan Bornemann formulates his objections with the worB: “Can one proclaim an industrial revolution? Is the development of ‘Industry 4.0’ at all about an industrial revolution in the classical sense? And if you already proclaim it and turn it into an initiative, it actually demands development. A lot of criticism collects around the term ‘industry 4.0’. This concerns both the choice of the term and the classification as an industrial revolution [...]”. (Bornemann, 2016) Ultimately, it may be added, it is a marketing gag, but not a scientifically justifiable and exploitable classification.

De facto, for the development trend that is to be indicated by the unfortunate designation ‘Industry 4.0’, it is not the computer that is the central technology, but the Internet with its resulting possibilities. This needs to be further investigated. Whatever the term ‘Industry 4.0’ as such may be, a new phase of digitisation can be observed for the year 2012 with the development and use of so-called cyber-physical systems (CPS). Further components will be added in order to constitute the full form of the new type of industrialization.

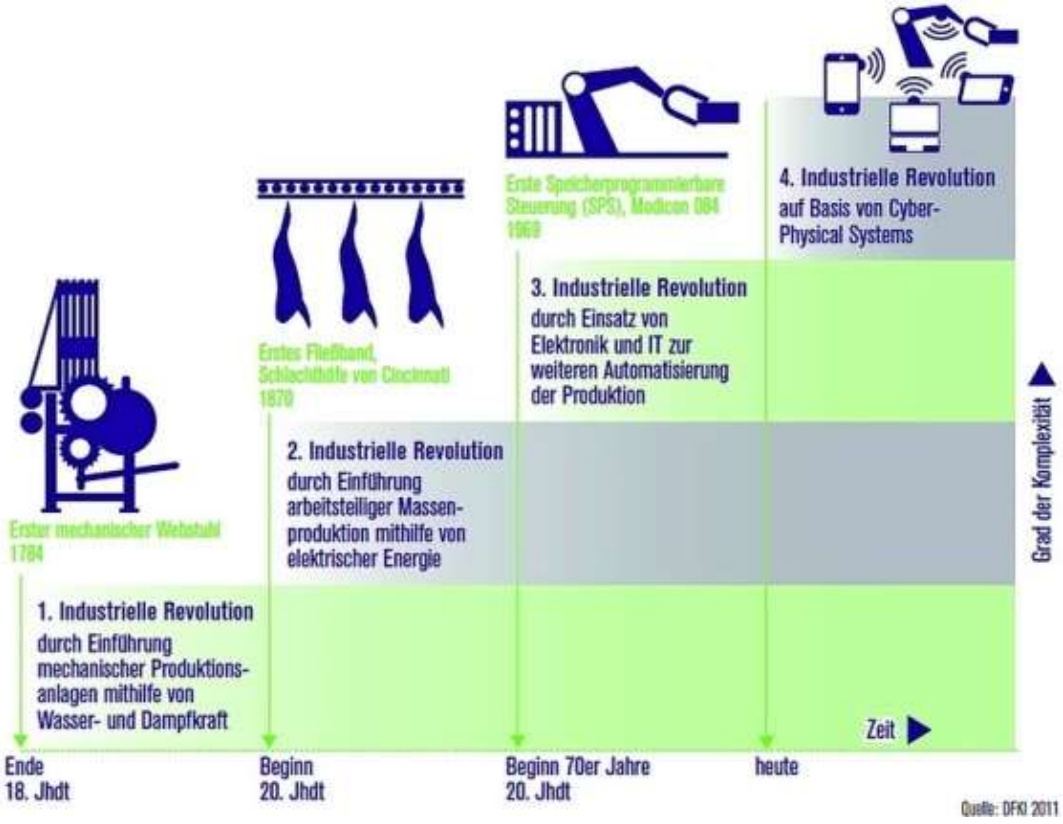

Figure 7-13: Overview of the industrial revolutions (DFKI, 2011)

It is therefore not merely a matter of a comprehensive digitalisation of the industrial revolution. Rather, it is a matter of interlocking these with modern information, network and communication technology to such an extent that *self-organised* production processes can be achieved as far as possible. With the idea of ‘Industry 4.0’, it is not enough for manufacturing processes to be computer-controlled; the objective is for people, machines, plants, logistics and products to communicate and cooperate directly with one another. As a result, it is no longer just *one* production step that is optimized, but the *entire* value chain. This means that the momentum of ‘Industry 4.0’ encompasses all phases of the life cycle of a product ─, starting with its conceptual brainstorming through its

development, production, use and maintenance to recycling at the end of its existence.

As will be shown below, the various aspects of “Industry 4.0” are in themselves highly complex. This **complexity** is further potentiated by their additional close interdisciplinary interlocking. Due to the high information density in the Smart Factory, variability ranges of the product design up to the extreme case of complete **individualization** are possible in production. These outstanding characteristics and possibilities of ‘Industry 4.0’ form an enormous **potential** of development capabilities and directions. ‘Industry 4.0’ is thus characterized by exactly those core terms that are at the centre of the Configuration Management Framework presented here: Individualization, complexity, potential. Together, they form a force-locked point of attack that can be used to meet the extremely complex requirements of configuration management. The significant properties of the new industrialization stage are thus mapped genuinely by the framework. This results in its grip in practical application. The Contribution to Knowledge of this thesis is based on this overall structure and will be explained in more detail on the following pages.

7.18.2 Smart Factory

In the implementation of the new degree of industrialization ‘4.0’, the “Smart Factrory” is regarded as the epitome of networked production over the entire life cycle. (In the US, there is talk of ‘Smart Manufacturing’. There is an industry association, the ‘Smart Manufacturing Leadership Coalition’ (SMLC), which is dedicated to the promotion of this idea.) In this new type of factory, the human being is to become the conductor of the production, while the production organizes itself according to its specifications. This means nothing less than that the extremely complex systems of a ‘Smart Factory’ have to perform situational self-control, -optimization, -configuration, -reallocation and finally self-diagnosis. This means that machines, materials, blanks and resources network and communicates with each other. This makes production more efficient, more flexible, more individual and faster. Furthermore, resource efficiency increases and the involvement of customers and business partners in the business and value creation processes can ─ and must ─ be drastically increased. This requires various high-performance tools, such as above all:

- Cyber Physical Systems (CPS)

- Internet of Things (IoT)
- Augmented Intelligence (AI)

7.18.3 Cyber physical systems

As already mentioned, the introduction of cyberphysical systems marks a discernible break in production technology. These systems represent a connection of physical objects and processes with virtual objects and processes by linking these two worlds via open, partly global and always interconnected information networks. Basically, physical and virtual objects/processes were already coupled in the third industrial revolution. What is different about CPS, however, is the fact that in this case the coupling takes place via the Internet. The Internet is no longer just a medium that provides content primarily for people; it also serves as a channel for the exchange of information between things. This aspect is called the ‘Internet of Things’. This results in a whole new quality of engineering.

7.18.4 Internet of Things

Very early, in 1999, Kevin Ashton (a co-founder and former director of the Massachusetts Institute of Technology (MIT) Auto-ID Center) created the term ‘Internet of Things’ (IoT). (Chui, 2010) It refers to an information technology networked system of autonomously interacting objects and processes. This means that physical objects self-organize and connect to a comprehensive connection, which is represented by a virtual structure. Physical-causal relationships and virtual, logical information relationships interpenetrate and influence each other. For this to succeed, it is necessary that part systems and subsystems of all orders of magnitude are provided with appropriate environmental intelligence. This makes it possible to detect states in the environment of the correspondingly equipped objects via sensors and at the same time to initiate (partially) autonomous action by means of actuator components. The latter can be electronic (e.g. switching relays) or mechanical (e.g. valves or pneumatic cylinders).

The smooth interaction between different technology areas is therefore crucial for success. These include mechatronics, sensors and actuators, power supply, data transmission, -storage, -safety, etc.

7.18.5 Standardisation

A complete standardization is to be aimed at if CPS and IoT are to succeed. The often still widespread proprietary systems that have to be developed and managed by certain manufacturers set fatal barriers for communication and integration. Proprietary systems are high-tech islands that work completely isolated despite their high performance. Only through open standards can the devices themselves be comprehensively and directly networked (instead of via so-called middleware), regardless of whether their current location is at the manufacturing site of business partners or the end customer. It also has to be irrelevant whether it is a question of networking everyday objects or a direct networking of production machines with each other (‘machine-to-machine’ or M2M for short). The aim is an informative penetration of the entire value-added process, i.e. beyond the industrial production, so that even after the delivery of a product to the customer a close contact from the manufacturer to the product remains and a real-time analysis for the purpose of maintenance up to the final step of recycling is guaranteed. Open standards also help to integrate standards-compliant equipment from any third party manufacturer. Another advantage is that data can be read out or the devices controlled without detailed knowledge of the hardware. In all of this lies an important source of optimizations, accelerations and not least monetary savings, for which a correspondingly optimized configuration management provides the appropriate tools.
All these processes generate vast amounts of data. Thus emerges the extremely urgent problem of how to deal with this exuberant quantity of information.

7.18.6 Augmented Intelligence (AI)

Business is based on data. With increasing amount and quality of data, they have the potential to push the business. But how can this be achieved? As described above, the volume of data exceeds by far the possibility of direct human evaluation. This ‘Big Data Environment’ offers ideal application conditions for the use of Augmented Intelligence. Machines can analyse the huge amounts

of data that can no longer be directly captured by humans on behalf of predefined, intelligent algorithms and thus deliver results as the basis for human action. So in order to cope with the flood of data, artificial intelligence must be combined with human intelligence. In the future, this can no longer be done in such a way that a person evaluates the data conventionally in front of the output terminal of a classic PC. In the medium and long term, new interfaces, Brain-Computer Interfaces (BCI) and processors developed for neural networks (Neural Network Processor, NNP) are necessary for the successful establishment of Augmented Intelligence.

7.18.7 Advantages of 'Industry 4.0' technology

The advantages of the so-called Smart Factory are basically advantageously applicable for every production process: For complex large-scale technological or scientific machines up to unspectacular use in everyday life. The benefits that Configuration Management brings to mastering these demanding tasks can be seen on a large scale in one of the most complex machines ever built, the Space Shuttle (as participant L pointed out in the interview) and on a small scale in medium-sized and small companies. While the latter by their very nature have smaller capacities than larger companies, they do not need to evolve at a slower pace in order to compete technologically and economically on the market. In the future, this will not be possible without Smart Manufacturing and ─ this controlling ─ Configuration Management that works effectively in the background. But when Configuration Management is used as an organizational and control tool, the processes and structures of the so-called 'Industry 4.0' offer a whole bundle of advantages and potentials:

- Product differentiation
  Through the 'Industry 4.0' the production of small quantities (i.e. rapidly decreasing lot sizes up to lot size one) can become profitable, i.e. individual production at the cost of series production can be achieved. Participant B pointed this aspect already out in the interview by saying: "[…] we need to change our processes to batch size one." Due to these individual "custom-made" products, individual customer wishes can be fulfilled. That means that such customer-centric solutions bring producer and consumer closer together. Customers can help design their own

products according to their wishes. Conversely, these individualization options mean a greater variety of variants.

- On-demand production
  Just-in-time strategies allow many products to be manufactured at short notice on demand or according to actual needs. This eliminates the need for warehousing.
  The smart factory can also react faster and more precisely to trends, tastes and the needs of the sales market.

- Flexibilisation
  The globalization of all business and production processes requires ever shorter response times and enormous flexibility in process control. Digital networking allows the necessary steps to be better coordinated for all business partners and the production steps to be better utilized. This is significantly supported by the modularization of future production lines, which must also be controlled by Configuration Management.

- Optimized decision making
  With suitable configuration management processes and smart monitoring processes ─ including Augmented Intelligence also in the Big Data environment ─, the value chain can be made transparent throughout. Decision processes can be controlled and optimized almost in real time.

- Resource productivity and efficiency
  The characteristics of ‘Industry 4.0’ described above mean that productivity and efficiency during the process can be optimized in almost real time.

- Competitiveness as a high-wage location.
  There are significant differences in the forms of production between Asia and Europe. Asian countries are clearly leaders in low-cost mass production. In Europe, on the other hand, there is an increasing trend towards leadership in individual production and the production of small series within the framework of ‘Industry 4.0’. Configuration Management, which is individually tailored to the respective company on the basis of the

presented framework, can therefore also offer international advantages on the world market. Participant B confirms from his wealth of experience that the European economy will only be able to survive in the face of Far Eastern competition through the advantages of the targeted use of CM, if he says: “[…]we have customers who say we are being blown away in Europe with our cost structures by Asia and Latin American competition. We can only survive if we become premium in our field and this of course includes certain benefits etc.”

- Optimized logistics
  Logistics also receives an enormous boost from the comprehensive networking:
  - Intelligent algorithms calculate ideal delivery routes that are adapted to the effects of unforeseeable disruptions, such as traffic jams, in real time.
  - Machines report independently when they need new consumables or maintenance/repair.
  - Smart networking enables an optimal flow of data in all logistical processes.

- Resource-conserving environmental service branch
  Using highly developed sensor technology, the products are accompanied throughout their entire life cycle. Already in the design and construction phase, engineering is determined in which way the materials used can be recycled after a continuous life cycle.

- Expenses
  The advantages mentioned so far accumulate to an increased cost transparency. The continuous flow of information makes it possible at any time to track which costs are incurred at which point in the production or value-added process. The prerequisite for this is that the processes are clearly defined in theory and function smoothly in practice. It is the domain of Configuration Management to guarantee this.

The following advantages are of secondary importance:

- Value creation potential through new services
  It is obvious that the profound changes brought about by smart production will lead to the development of new services in the IT and high-tech sectors.

- Demographic-sensitive working hours
  Due to the increased flexibility, the work processes in the workforce can also be made more variable. It is easier to adapt production to the possibilities of the workforce than it is in the comparatively rigid processes of conventional production. Configuration Management is therefore not only of economic importance but also has socio-political and social aspects.

- Work-life balance
  The aforementioned aspect can basically be broken down even further, so that the increased flexibility and variability of production can be constructively mapped to the work processes. This makes it easier to adapt the company to the needs of the workforce in such a way that a higher degree of work-life balance can be guaranteed.

The variety of these advantages, which can only be summarized here, shows what a rich field of application possibilities opens up for smart production. An indispensable basic prerequisite for this is a consolidation of all processes through a configuration management system, which in its own conceptual design is also designed for critical self-reflection. This means that the highly sensitive processes of the smart industry require configuration management that ─ to put it bluntly ─ looks over the shoulder in an enlightened manner and is therefore tailored precisely to the company and its needs. To have provided an effective reference framework for this is the contribution of this work.

7.18.8 Fields of application of ‘Industry 4.0’ technology

The fields of application of ‘Industry 4.0’ are, as indicated by the advantages just presented, extremely diverse. Basically, it can be used everywhere. Of course,

those areas are particularly predestined in which highly developed complex technological systems are used or which are particularly data-intensive.
Such areas of need include mobility. health, energy supply or air-conditioning technology.

- Mobility and traffic engineering
  An enormous application potential lies in worldwide traffic engineering. This essentially includes the navigation of all types of means of transport and the optimised organisation and monitoring of traffic flows. A challenge of a very special kind, not least due to the inclusion of the highly sensitive safety aspect, is the development of self-navigating systems. This applies to aviation as well as to shipping and automobile traffic. For the latter, a major task is the development of Car-to-X Communication. This involves the networking of vehicles with each other or with the transport infrastructure via information networks. The minimum requirement here is that critical and dangerous situations are indicated to the driver at an early stage in order to be able to react in good time. A further step is that the braking system is addressed directly in order to bring the vehicle to a standstill immediately without the intervention of the driver. In the long run, the vision is for cars to drive completely autonomously. (The driver is no longer an active driver of the vehicle but only a passenger).
  The same applies to shipping and aviation.

- Logistics
  The optimisation of logistics is closely linked to the previous point. It includes the totality of the spatial transport of persons and goods. The Internet of Things provides the technological basis for this. In the future, deliveries of goods will manoeuvre themselves independently through the supply chain to the end consumer. They intervene themselves in the solution of unforeseen problems and decide autonomously on further processing.

- Health Telematics: E-Health Systems
  The new technology also offers outstanding opportunities in the fields of medicine and health care. Electronic devices and means of

communication provide medical care (including prevention, diagnosis, treatment, remote monitoring) as well as health care management via the Internet. This makes it possible, for example, for health-relevant data to be recorded online and simultaneously forwarded to a treating physician. This ensures that patients can also be medically monitored and treated in their familiar home environment. A further possibility is the virtual participation of surgeons or highly specialized doctors in a spatially distant operation.

- House and building technology
  In an intelligent house, appliances (e.g. refrigerator, washing machine, coffee machine, telephone, TV system) and building/house systems (e.g. heating, lighting, ventilation) are networked. All implemented instances can be controlled or mutually regulated via PC, Smart Phone app or tablet. (The open window automatically throttles the heating.) The aim of this form of application is primarily to increase comfort for the user, but also to optimise energy consumption.

- Power supply
  So-called ‘Smart Grids’ are intelligent power grids which serve as a combination of decentralised units for the coordinated generation, storage and distribution of energy. A central control system optimally coordinates the components of these units so that the consumers can be supplied with electricity in line with demand and in a cost- and energy-efficient manner. These structures are programmed to compensate power fluctuations ─ preferably due to fluctuating renewable energies ─ in the grid.

7.18.9 Compliance and Risk Management

Basically, the more complex a structure is, the more susceptible it is. This is for two reasons: First, the more structural elements a structure contains, the more structural elements can fail. Secondly, the more interfaces there are between the individual structural elements with their increasing number, the more of these interfaces can be functional fail. All this follows analytically directly from the structure itself. This means that the more complex a structure is, the more it

tends to become susceptible from its inner structural integrity. This is an *internal* hazard potential.
In addition, there is an *external* risk potential that also increases with the degree of complexity. This means that the more complex a structure is, the more points of attack it offers in order to be disavowed from the outside. This applies a fortiori to highly networked systems designed (as explained previously) to communicate with the outside world according to open standards.

In the case of potential hazards, countermeasures must be taken to prevent functional deficits in the structure or even its complete collapse. This is not possible with complex systems without the use of Configuration Management. Configuration Management is internally designed to act in a structure-preserving way.

The undesired influence of a production system from outside can occur in different ways and intensities. For example through:

- Sabotage as deliberate manipulation from control information to deliberate miscontrol of machines or processes. In ‘Industry 4.0’ it is basically possible from anywhere.

- Espionage to take advantage of competitors by the secretly and illegally acquired knowledge about new products, new production processes on the market. This also includes spying out machine configuration data. This, too, can in principle be done from anywhere in the world due to networking.

- Quality defects: The complexity of the smart factory also means that more legitimate employees and cooperation partners can access the production tools. This also allows unauthorised influence on quality assurance, for example by deliberately ignoring test routines. A proof of quality under the conditions of ‘Industry 4.0’ has thus become considerably more complex.

- Liability: In addition, there are greater compliance and liability risks of a company producing on a smarter basis. Increasingly, laws and treaties

require additional security measures to ensure compliance and implementation.

- Dependence: In addition, a reliable, sufficiently powerful and redundantly secured Internet connection is required.

All this leads to the need for an appropriately thought-out and expanded risk strategy. This is based on a security assessment including all sensitive data from IT. After the hypothetical damage is first estimated in the corresponding models, experts assess how likely it is that this case will occur, in particular due to the networking of the systems. The results are plotted on a risk matrix according to loss amount and probability of occurrence. Such a risk analysis should be carried out at least annually in the dynamic sectors of 'Industry 4.0'.

Configuration Management is also the adequate control tool for this on the entrepreneurial meta-level of risk management, beyond the direct process control in day-to-day operations.

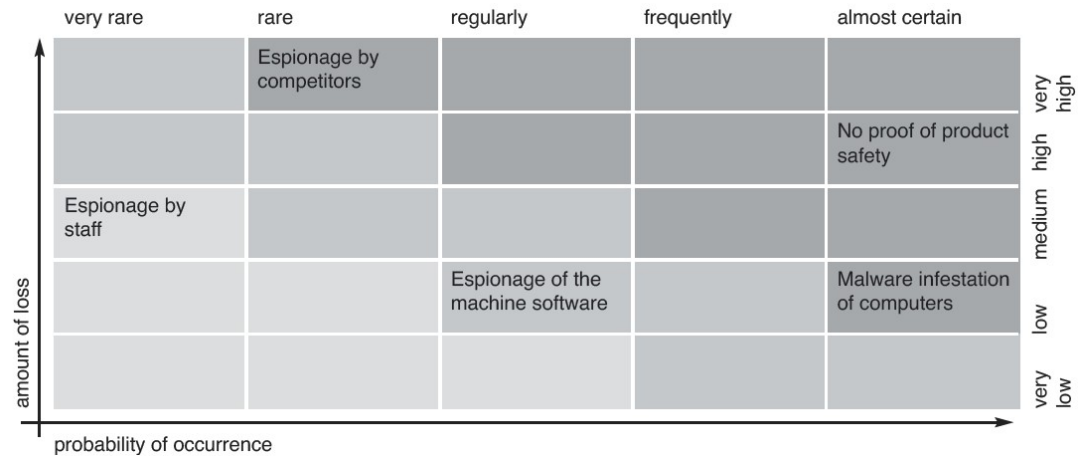

Figure 7-14: Example for a risk matrix

7.19 The value of CM for the smart industry

Networked production successively affects all areas of the economy. In the previous section, the enormous range of some selected application cases was exemplarily demonstrated. These are fields of application which are also reflected in the aviation industry, for example in the energy supply of the production facilities.

In the historical progression from the first to the so-called fourth industrial revolution, the importance of CM instruments is growing increasingly, ─ initially rather linear, currently rather exponential. (This would be a topic for a relevant academic investigation in computer science.) Accordingly, participant B emphasizes from the extensive experience of his consulting activities that the importance of CM in 'Industry 4.0' tends to increase enormously: "[…] the pressure to manage configurations in the context of 'Industry 4.0' and "Inte'net of Things' will be much much bigger." The evidence is obvious that all these extremely complex and demanding procedures of the so-called 'Industry 4.0' require a general control instrument. This is given by CM. CM makes the target-oriented control, review and evaluative safeguarding of such deeply structured and comprehensively networked processes manageable. It is *the tool* for obtaining an essential overall view. This statement is confirmed in an interview with Participant B when he notes that "[...] the whole topic Industry 4.0, Internet of Things is not possible without CM."

In modern industry, the coordination of an overabundance of components and systems with each other is the decisive main topic. The interdisciplinary interaction between different technology areas such as electronics, sensors and actuators, energy supply, data transmission, data security, etc. must be mastered. This places the most extreme demands on those responsible. Therefore, CM for smart production has a crucial importance over success and failure.

Complete process orientation is decisive for smart production. The entrepreneur looks at the totality of all processes in the entire production and service chain. The level of the requirement potential is defined and evident by the fact that for the totality of the processes at any time all involved plants, devices, networks and persons with their rights and mutual relations to each other are exactly conceptualized and mapped on the software side; namely in such a way that also corresponding branches for alternative reactions to unforeseen events are sensibly implemented. These structures must become identifiable, formable,

linkable and verifiable. Participant B also makes this demand in an interview when he says: “This means that we not only manage a functional structure of the systems, but also all activities that arise in this development in system engineering.” It is precisely the proprium of CM's line of vision and thrust to perceive, analyse and control structures in their functional context. However, it would be a fatal mistake to uniformly superimpose CM in its basic form on smart processes in a dumb act of unreflected application. Because the processes or rather their structures are self-dynamized. This has a consequence which can hardly be overestimated in its range. Because in dynamic production and management environments, their control instrument must also be dynamic. This was elaborated in the present study by (a) demonstrating extensively that not every company needs the same level of CM in scope and depth; and (b) providing a theoretical framework for factually and temporally variable individualization in an intensive way through the three key categories complexity, individualization and potential. The contribution of this work is therefore a double one.

In other words, it is necessary to understand processes from the underlying structures. In the smart industry, these structures themselves are dynamic and variable. To impose a fixed, unchangeable CM tool on these process structures would ultimately mean their sclerotisation. Consequently, in order to develop adequate effectiveness, the CM must be related to these process structures; it must itself be dynamic and variably applicable. *How* this should be done in individual cases can be determined by the individualization matrix of the framework presented here. It describes in a metasystemic way the dynamic adjustment of the CM apparatus to the individual company requirements (this is illustrated in the graphic x by the two different orders).

In the age of smart production, the CM applied to it must itself be smart. Everything else would be a functional anachronism. Both production processes and CM must be at the same level of rank and development. For this purpose, it was necessary to analyse CM in a more in-depth way, i.e. progressive compared to its classical application, by three dimensions, which together span a three-dimensional determination space. In this space, the specific coordinates of a company are defined on the basis of the three dimensions complexity, individualisation and potential, whereby an individual localisation is carried out on the basis of the scope and type of its appropriate CM application. This is the

contribution of the presented thesis that with the help of this three-dimensional framework a tailor-made application of CM for the individual requirements of an individual company is made possible.

The original category of all processes and requirements described is *information*. Nothing happens without information. With the idea of smart production (alias 'industry 4.0') the phenomenon of a complete 'informatisation' is given. The multidimensional connections merge to a uniform information space of highest potency. There, all initially disparate individual information must be bundled into an integrative synopsis, which enables reliable (albeit constantly updated) answers to questions, such as:

- What do you do with the permanent and ubiquitous data available in paralyzing amounts?
- How and why do systems control themselves?
- How can security and stability be guaranteed (even in highly sensitive, security-relevant areas)?
- Who makes the countless decisions in real time? And on what basis?

Decision-making situations become highly complex within the context of 'Industry 4.0'. The technical collection and analysis of the data is already a tricky task, and yet it is only a first step in an even more comprehensive and challenging process of making and representing far-reaching business decisions. Digitalisation and networking in itself has nothing to do with intelligence, decision-making authority or even entrepreneurial ethos. Data is not yet information. Information is not yet knowledge. Knowledge is not a decision yet.

It makes sense to distinguish four levels in the management of a company:

- *Descriptive level*: Key question: *What* happens?
- *Diagnostic level*: Key question: *Why* does what occur happen?
- *Predicative level*: Key question: What *will/should* happen?
- *Prescriptive level*: Key question: *How* and *for what purpose* is the goal achieved and controlled?

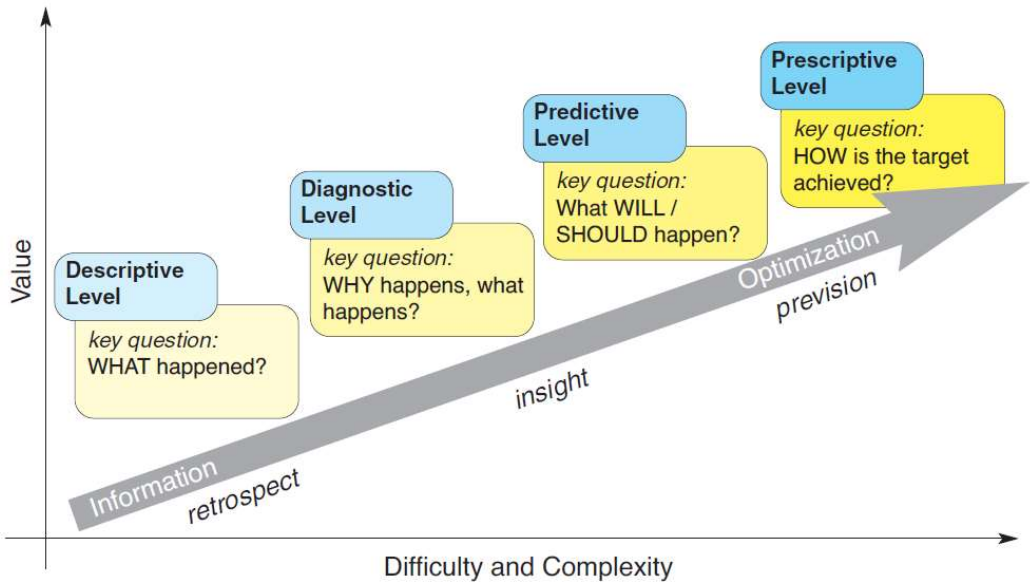

Figure 7-15: Structuring the Management of the Company with the Involvement of the Timeline.

Only when these stages have been completed (which, incidentally, must not be done once, but cyclically) has the decision-maker approached an entirely understanding of data. The requirement of such a holistic view and course of action is characteristic for the smart industrial form. Without a fine-tuned individualized CM, as presented here, such an indispensable overview effect cannot be achieved. Those who don't have an overview clearly see too little. To strive for this continuously is not only an imperative of economic reason, thus also an ethical requirement of responsible entrepreneurial action.