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Supporting the Design of Management Control Systems in Engineering Companies from Management Cybernetics Perspective

Fatos Elezi

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	2.	Prof. Iris D. Tommelein, Ph. D., University of California, Berkeley / USA

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FOREWORD BY THE SUPERVISOR

As the environment is becoming more volatile and unpredictable, adaptability to environmental changes has become a top priority for engineering companies. Fluctuations of customer preferences, changing legislation, constant pressure from competitors, new technologies, all these represent some of the external influences that contemporary engineering companies need to deal with dynamically. Management Control Systems (MCS) are management systems that provide mechanisms for dealing with these changes by ensuring the attainment of strategic and operational goals despite the high environmental volatility. Hence, they play a vital role in the competitiveness of engineering companies and their proper design is essential for success in the market.

Although frameworks for understanding MCS exist, a systematical, method-based MCS design is still missing. This thesis takes a first step in this direction, by adopting a systemic view on MCS and by contemplating the complexity involved in MCS design. It recognizes that engineering companies are highly complex socio-technical systems, and that the design of MCS encompasses the planning, modeling and embedding of MCS into these systems. In order to tackle this complex task from systemic perspective, this thesis suggests three stages for MCS design: functional, social and organizational stage. The functional stage involves the modeling of necessary functional mechanisms that determine what needs to be accomplished. The social stage is concerned with the conceptualization of the functional mechanisms by means of social structures. The last stage, the organizational stage, involves the embodiment of the social structures into the organizational structures and their support with the right tools and incentives.

The thesis claims that it is essential for the contemporary MCS not only to ensure strategic goal achievement but also to provide the mechanisms for adapting these goals to environmental changes. For this purpose, the author of this thesis departs from the mainstream MCS research that considers MCS to be simple homeostatic regulators, and adopts a more holistic systemic perspective that uses Viable System Model as a canonical model for understanding the functional structures of MCS. Based on this premise, the author introduces a method that provides a systematic support for managers in engineering companies for designing MCS at the functional level. This method is applied and evaluated in three industrial case studies along three criteria: applicability, usefulness and usability of the method. In all these evaluation criteria, the method performed well and the added-value of the method in industrial settings is confirmed.

As a conclusion, it can be said that the thesis of Fatos Elezi opens a new perspective for understanding MCS and their design. This perspective is based on systems thinking, which provides a potential to address new challenges in MCS design that cannot be tackled with the existing theoretical frameworks. As such, this thesis represents a great academic and industrial contribution and paves the way for new and exciting research in the field of MCS.

Garching, March 2016

Prof. Dr.-Ing. Udo Lindemann

Institute of Product Development
Technical University of Munich

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Throughout my academic experience at the TUM, I came in contact with three academic organizations: the Design Society, the Institute of Electrical and Electronics Engineers (IEEE) and the American Society of Mechanical Engineers (ASME). I participated in numerous conferences organized by these organizations through the generous sponsorship of the Institute of Product Development. These conferences served as platforms for discussions with researchers and practitioners and as such provided a substantial contribution to the maturity of this thesis.

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Garching, March 2016 Fatos Elezi

The following publications are part of the work presented in this thesis:

Elezi, F.; Tschaut, R.; Bauer, W.; Chucholowski, N.; Maurer, M.: Integration of Strategic Flexibility into the Platform Development Process. In: ICoRD'15–Research into Design Across Boundaries, Volume 2, 2015. Springer p. 483-493. ISBN: 978-81-322-2228-6.

Steinhaeusser, T.; Elezi, F.; Tommelein, I. D.; Lindemann, U.: Management Cybernetics as a Theoretical Basis for Lean Construction Thinking. Lean Construction Journal, 2015.

Elezi, F.; Schmidt, M.; Tommelein, I. D.; Lindemann, U.: Analyzing Implementation of Lean Production Control with the Viable System Model. IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Kuala Lumpur, Malaysia, 2014.

Elezi, F.; Resch, D.; Tommelein, I. D.; Bauer, W.; Maurer, M.; Lindemann, U.: A Viable System Model Perspective on Variant Management based on a Structural Complexity Management Approach. Risk and change management in complex systems: Proceedings of the 16th International DSM Conference, Paris, France, 2014.

Bauer, W.; Chucholowski, N.; Elezi, F.; Lindemann, U.; Maurer, M.: Zyklenorientiertes Modul- und Plattformdenken - Ein Leitfaden für Praktiker. Maurer, M.; Lindemann, U.; Eigenverlag 2014. ISBN: 978-3-00-048286-1

Maurer, M.; Bauer, W.; Elezi, F.; Chucholowski, N.: Methodik zur Erstellung zyklengerechter Modul- und Plattformstrategien. In: Vogel-Heuser, B. et al. (Eds.): Innovationsprozesse zyklenorientiert managen. Springer Vieweg 2014, p. 139-154. ISBN: 978-3-662-44931-8.

Schmidt, M.; Elezi, F.; Berghede, K.; Tommelein, I. D.; Lindemann, U.: Supporting Organizational Design Towards Lean With The Viable System Model. In: The Proceedings of the 22nd Annual Conference of the International Group for Lean Construction, Oslo, Norway, 2014.

Schmidt, M.; Elezi, F.; Tommelein, I. D.; Lindemann, U.: Towards recursive plan-do-check-act cycles for continuous improvement. In: 2014 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Kuala Lumpur, Malaysia, 2014.

Elezi, F.; Maier, T. G.; Lindemann, U.: Engineering change management challenges and management cybernetics. In: 2013 IEEE International Systems Conference (SysCon), Orlando, 2013. ISBN: 978-1-4673-3107-4.

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Elezi, F.; Sharafi, A.; Mirson, A.; Wolf, P.; Krcmar, H.; Lindemann, U.: A Knowledge Discovery in Databases (KDD) Approach for Extracting Causes of Iterations in Engineering Change Orders. In: Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2011), Washington DC, USA, 2011.

CONTENTS

List of Abbreviations

ACE	Allied Concurrent Engineering
ADA	Americans with Disabilities Act
BIM	Building Information Modelling
BiQ	Built-in Quality
BUR	Business Unit Refrigerator
CBC	California Building Code
CI	Continuous Improvement
CONWIP	Constant Work in Progress
CSH	Critical Systems Heuristics
CT	Computer Tomography
DCS	Diagnostic Control System
ECM	Engineering Change Management
ICS	Interactive Control System
IFOA	Integrated Form of Agreement
IOR	Inspector of Record
IPD	Integrated Project Delivery
JIT	Just-in-Time
KPI	Key Performance Indicator
LCS	Lean Control System
LPS	Last Planner® System
MACS	Modular Architecture Control System
MCS	Management Control Systems
MIS	Management Information Systems
MoU	Memorandum of Understanding
OEM	Original Equipment Manufacturer
OSHPD	Office of Statewide Health Planning and Development
RAM	Responsibility Assignment Matrix
RFI	Request for Information
SSM	Soft Systems Methodology
TPS	Toyota Production System
TQM	Total Quality Management
VM	Variant Management

1. Introduction

Chapter one provides the theoretical underpinning and the research position of this thesis. The first part presents the motivation for this research and introduces the problem to be addressed. Based on the motivation and the problem description, the objective of the thesis as well as the research questions are formulated. In addition, the research methodology adopted for this work is presented. At the end of the chapter, an overview of the structure of the thesis is provided.

1.1 Motivation

Since the industrial revolution, the environment in which engineering companies operate has changed significantly. At the beginning, these companies operated in relatively stable market conditions. In the meantime, increased competition through globalization, changing customer demands and legislations are just some factors that drove the dynamics of the environment to higher levels [DAFT et al. 2011, p. 8]. Today, the high dynamics and turbulence have generated a lot of challenges, but also opportunities for engineering companies. On one hand, the companies which stay rigid and unresponsive to these changes are predestined to fail and perish. On the other hand, the companies which are able to adapt to changes gain sustainable competitive advantage, which is reflected in growing market share and higher profitability [EISENHARDT & MARTIN 2000, p. 1106]. As HAECKEL observed, adaptability to changes has come to be increasingly valued in recent years, and the terms flexibility, agility, and responsiveness appear frequently in business discussions today [HAECKEL 2013, p. 3]. He further states that in order to become adaptive "(…) an organization must have a fundamentally new structure, it must manage information in a particular way, it must be managed as a system, and its leaders and employees must commit themselves to very different behaviors and responsibilities" [HAECKEL 2013, p. 3, 4]. Relating to engineering companies, SANCHEZ states that the ability to respond to environmental and market changes depends not only on inherent flexibility of the firm's resources, but also on the firm's ability to apply those resources to different alternatives [SANCHEZ 1995, p. 135]. This means that the engineering companies need not only flexible resources, but also adequate processes that help operationalize these flexible resources. In strategy literature, more specifically, the resource based view, these two competences are termed as dynamic capabilities. EISENHARDT & MARTIN define the dynamic capabilities as "(…) firm's processes that use resources – specifically the processes to integrate, reconfigure, gain and release resources to match and even create market change. Dynamic capabilities thus are the organizational and strategic routines by which firms achieve new resource configurations as markets emerge, collide, split, evolve, and die" [EISENHARDT & MARTIN 2000, p. 1107]. The resource based view defines dynamic capabilities to a wide range of resources, processes and capabilities and the empirical studies have primarily addressed firm- or industry-specific processes pertinent to dynamic capabilities based on case studies [WANG & AHMED 2007, p. 2]. Hence, the resource based view is regarded as a highly theoretical view and does not provide any concrete support to managers on how to develop and maintain the dynamic capabilities [MCCARTHY &

GORDON 2010, PRIEM & BUTLER 2001]. As a consequence, a new perspective is sought for obtaining insights on the dynamic capabilities in engineering companies. This new perspective is provided by the organizational theory, more precisely - the contingency theory.

The contingency theory as the core explanatory theory of organizational structure, regards management as means to balance internal needs and adapt to environmental changes. One central mean for the adaptability of organizations, according to this theory, are management control systems (MCS). The contingency based research has approached the study of management control systems (MCS) assuming that managers act with an intent to adapt their organizations to changes in contingencies (certain environmental factors – note by the author) in order to attain fit and enhanced performance [CHENHALL 2003, p. 160]. MCS are systems employed by managers to ensure that the strategic goals of their organization are achieved or changed when it is required [MERCHANT & VAN DER STEDE 2012, p. 5]. As such, MCS are seen as tools for leveraging the organizational behavior necessary for dynamic capabilities [MCCARTHY & GORDON 2010, p. 15]. In MCS literature, there are several frameworks for MCS design that describe this leverage (see for example [MERCHANT & VAN DER STEDE 2012, SIMONS 1995, FISHER 1995]). These frameworks have a strong impact on the research of MCS but unfortunately are of lesser importance to practitioners in the field. The reasons are manifold, but the most important one is that they do not provide systematic guidelines on how the MCS should be designed, but rather give design considerations that are merely abstract. In addition, the existing MCS frameworks focused on description of single MCS [MALMI & BROWN 2008, p. 287]. This does not represent the reality, as usually several MCS are implemented in engineering companies that interact with each other.

In order to overcome these problems, a systemic perspective on MCS design can be employed. The field of cybernetics as a science of control and coordination is especially rich with theoretical background for self-regulating feedback systems. Its offspring, management cybernetics, was established by transferring the cybernetic theory into the context of management and organizations. In his seminal work "Cybernetics and Management", BEER states that cybernetics is the science of control, whereas the management is the profession of control [BEER 1959, p. 239]. As a consequence, management systems, including MCS, are subjects of cybernetic principles. Management cybernetics studies the ability of systems to survive in changing environments in meta-systemic sense. There is a well-established model as a result of these studies, the viable system model (VSM), that incorporates all the functions and communication channels that the organizations should integrate for adaptation to environmental changes.

In order to contribute to the research of MCS in engineering management, and at the same time to support the managers of engineering companies in designing their MCS, this thesis project includes the study of systems theory and management cybernetics, particularly different systemic paradigms and the VSM. FEYERABEND states that for important discoveries, unconventional routes should be taken [FEYERABEND 1993, p. 120]. In this spirit, this thesis takes a different research route than other studies in this field. The research presented in this thesis aspires to arrive at a new perspective into an existing topic, using the body of knowledge from MCS, management cybernetics and systems theory in general.

1.2 Problem Description

Management control as a separate research topic has been described first by ANTHONY [ANTHONY 1965]. He focused on management control processes that ensure achievement of an organization's goals by efficient use of resources. These processes are supposed to be common to all organizations, no matter the industry or the size of the company. His terminology and framework however, encouraged a strong emphasize on financial and accounting-based controls [MERCHANT & OTLEY 2006, p. 788]. Therefore, in the first decades, the research on this topic was performed mainly in financial and accounting studies. OTLEY for example, agrees that in the past "(…) management control became largely synonymous with management accounting" [OTLEY 1999, p. 364]. He further explains that management control in an accounting context neglects the issue of overall well-being and viability of an organization. Therefore, he suggests a broader definition of MCS by looking beyond the **measurement** of performance towards the **management** of performance. This broader definition includes both the strategic planning and the operational control [OTLEY 1994, p. 294]. Contemporary definitions of MCS do not describe them only as passive mechanisms that ensure achievement of local goals, but also as systems that have the ability to autonomously change objectives, goals and strategies in order to adapt to environmental changes. Consequently, MCS are seen by many authors as crucial for leveraging the dynamic capabilities and thus for contributing to the long term success of the organization (see for example [MACIARIELLO & KIRBY 1994, MERCHANT & VAN DER STEDE 2012, OTLEY 1999, MCCARTHY & GORDON 2010, SIMONS 1995]).

At this point it is required to clarify the relationship between MCS and dynamic capabilities in the context of engineering management. EISENHARDT & MARTIN claim that typical dynamic capabilities are processes such as strategic decision-making, product development and alliancing. Companies gain competitive advantage by using these processes sooner, more astutely, more fortuitously than the competition to create resource configurations that hold this advantage [EISENHARDT & MARTIN 2000, p. 1117]. In contrast to EISENHARDT & MARTIN, WANG & AHMED assert that dynamic capabilities are not these core processes, but systems that are embedded in these core processes [WANG & AHMED 2007, p. 10]. As an example, they take the Total Quality Management (TQM), which is not just a process (as for example quality control), but a system that requires vision, empowering of the employees and building a customer-oriented culture [WANG & AHMED 2007, p. 11]. In this thesis it is argued that what WANG & AHMED refer to as dynamic capabilities are in fact MCS. Indeed, in order to cope with the changes and the uncertainty of the environment, the engineering companies have "embedded" new management systems similar to TQM. Let's take as an example two typical engineering management systems: engineering change management (ECM) and variant management (VM). ECM is often described as an embedded process for coordination of product development activities in terms of changing parts, drawings, and product's software, in order to cope with external and internal influencing factors [ELEZI et al. 2011, p. 1401]. Based on this definition, ECM can be seen as a system embedded in the "core" product development process. Similarly, VM is an interdepartmental management system that coordinates the development, evolution, maintenance and disposal of the product variants based on the changes in market demand and competitive environment. Consequently, VM is a management system embedded in and across multiple "core" processes such as product development, supply chain, marketing and sales. Both these management systems represent control and coordination processes that enable companies to perform their core processes “sooner, more astutely, more fortuitously than the competition” as stated by EISENHARDT & MARTIN. Similarly, different management techniques employ MCS in order to reach their objectives. For example, besides TQM, lean management utilizes MCS to operationalize its principles - continuous flow, pull and kaizen (see section 3.5 for more to this topic).

Most of the research in both strategic management and engineering management, describe these management systems through case studies and best practices relevant to specific companies or industries [WANG & AHMED 2007, p. 2; EISENHARDT & MARTIN 2000, p. 1117]. The conclusions from these research studies therefore are not generally applicable. For example, lean management is proven as very successful management technique at Toyota, but in other companies and industries lean implementation was difficult and not always successful [BORTOLOTTI et al. 2015, BHASIN 2012a]. BHASIN in this regard states that “(…) every company should discover its own way to implement Lean” [BHASIN 2012a, p. 440].

Given the importance of the MCS for development of dynamic capabilities, researchers made efforts to provide a holistic view and descriptions of MCS (see for example [OTLEY 1999, FISHER 1995, SIMONS 1995]). Contingency research for example, starts from the correct assumption that no single MCS is optimal in all situations and circumstances, and that they depend on any of a number of situational factors [MERCHANT & OTLEY 2006, p. 787]. Therefore, MCS should be tailor-designed for specific organizations for successful implementation. Here, design of MCS refers to planning, modeling and embedding of an MCS in an organization. As presented later (see sections 2.3.3 and 3.3), the design of MCS is a complex task, since it involves the embedment of control systems in highly complex systems (organizational entities) that are of sociotechnical nature. In the motivation section of this thesis it was stated that several frameworks for MCS design have a strong impact on research but unfortunately are of lesser importance to industrial practitioners. Although these frameworks provide holistic descriptions of MCS, both on functional and social level, they lack clarity and do not provide step-by-step guidelines on how the MCS should be designed. SIMONS’ framework, as one of the most important and comprehensive MCS design work, gives design considerations that are merely abstract and based on best practices [SIMONS 1995]. TESSIER & OTLEY state that SIMONS framework is criticized for being vague and that it contains ambiguous definitions [TESSIER & OTLEY 2012, p. 171].

Most authors refer to cybernetics as the theoretical backbone of MCS [MACIARIELLO & KIRBY 1994, HOFSTEDE 1978], but this reference is made only to describe the control processes in MCS that enable the homeostatic regulation (achievement of a desired state with the use of simple feedback control systems). This means that in MCS literature processes or systems responsible for adaptability are not of cybernetic nature. For example, SIMONS describes four types of control systems (he calls them control levers) that should constitute a MCS. Only one of them (the diagnostic control system) is described as having a cybernetic nature [SIMONS 1995, p. 59]. He further explains that the majority of the publications about MCS refer to diagnostic control [SIMONS 1995, p. 60], which inherently means that all literature on MCS rely on cybernetics only to describe the rigid feedback control systems that do not contribute to the adaptability of an organization.

This thesis tackles exactly this issue. It will be argued that the state of the art in management cybernetics provides a rich science-based foundation for design of MCS that enable the adaptability of an organization. The adaptability of organizations in relation to environment is key for their viability[1]. There is a well-established model from this body of knowledge, the viable system model (VSM), that incorporates all the organizational functions and communication channels necessary for adaptation to environmental changes and efficient operations. BEER derived the VSM primarily by observing one of the most viable systems to be found in earth – the human nervous system [BEER 1972, BEER 1979]. Based on these enquiries, he extracted the basic mechanisms for adaptability and abstracted these to functional level. Hence, the VSM "(…) represents the isomorphism which underlie any viable system, natural or artificial, biological or social" [ESPEJO & HARNDEN 1989, p. 3]. In other words, VSM represents a meta-systemic model of viable systems that incorporates functions that are necessary and sufficient for a system to be viable [ACHTERBERGH & VRIENS 2009, p. 191]. Although VSM was introduced almost fifty years ago, its strength to address contemporary management challenges such as complexity, learning and adaptability has gained importance in recent years. As GOULD states, "(…) the single most important thing about Beer's work is that it anticipates much of the current fascination with chaos, complexity and the need for rapid strategic adjustments to environmental changes" [GOULD 1999]. For this reason, this thesis strives to identify the value added from adopting the management cybernetics perspective in design of contemporary MCS, with the focus in MCS in engineering companies.

Shedding light on MCS from the management cybernetic perspective yields two main benefits. From the scientific perspective, it could contribute to new insights in designing the MCS in a holistic manner. From a practical perspective, this insight then could lead to an improved methodological support for managers in industry in designing their own MCS.

1.3 Objective, Research Questions and Hypotheses

Based on the discussion in the previous sections, it can be inferred that there is an overlap of the research fields of MCS and management cybernetics in relation to viability of the organizations. Both research fields try to understand and identify systems that ensure achievement of goals, autonomous change of objectives and strategies, for efficient performance and adapting to environmental changes. However, research on MCS lacks of consistent conceptualization of MCS and is still characterized by its fragmented status manifested in divergent theoretical underpinnings [STRAUß & ZECHER 2013, p. 234, TESSIER & OTLEY 2012, p. 171]. Management cybernetics on the other side, is a compact systemic research field that can provide clarity in the theory required for proper conceptualization of the MCS. Therefore, the objective of this thesis is to explore the extent of the theoretical support that management cybernetics can provide to the topic of MCS in general, as well as enquire the potential benefits for the practitioners in engineering companies coming from this new perspective.

[1] Viability is described as the ability to maintain a separate existence in a changing environment [BEER 1979]

To address this objective in systematic manner, three sequential research questions are formulated. The first research question is of descriptive nature as it requires an analysis of existing relevant literature [BLESSING & CHAKRABARTI 2009, p. 91].

Research question 1: What is the scope of the theoretical support that management cybernetics, in particular the viable system model (VSM), provides in understanding and designing of the contemporary MCS?

The second research question is of relational nature [BLESSING & CHAKRABARTI 2009, p. 91], as it requires to relate the VSM support to specific MCS design stage.

Research question 2: At what stage of MCS design does the VSM provide realistic and practical support?

Once these two theoretical research questions are answered, the actual support to managers of engineering companies can be envisaged. This leads to the third research question that is of causal nature [BLESSING & CHAKRABARTI 2009, p. 91].

Research question 3: Does the new management cybernetic perspective on MCS allows for realization of methodical support to practitioners in engineering companies for designing their MCS?

The two first research questions address theoretical issues that need to be tackled before a concrete support to managers is developed. This support is addressed by the third research question. In this way, the thesis strives to contribute to the theoretical body of knowledge related to MCS and at the same time, make this theoretical contribution applicable and bring closer to the managers in engineering companies.

1.4 Research Background and Methodology

The objective of this subchapter is to provide an overview of the context under which this thesis was developed. In section 1.4.1, the experience of the author that served as basis for the conceptualization of this thesis is presented. In section 1.4.2, the research methodology employed for guiding the research in this thesis is presented.

1.4.1 Research Background and Experience

This thesis was developed during the tenure of the author as scientific assistant at the Institute of Product Development at Technical University of Munich (TUM) from January 2010 until end of February 2015. During this time, the author participated in numerous research projects in cooperation with international companies from Germany and USA. In the following, some of these projects that motivated and contributed to the contents of this thesis will be presented.

First project to mention is the Collaborative Research Center SFB 768 on “Managing Cycles in Innovation Processes – Integrated Development of Product Service Systems based on Technical Products”. Within this research center, the author participated in the research project A2: “Modelling and Evaluating Development Relationships across Disciplines” as well as research project B1: “Cycle-oriented Planning and Coordination of Development Processes”. Further, the author co-wrote the research proposal and later conducted research within the transfer project T1: "Methodology for Creating Cycle-robust Module and Platform Strategies". Transfer project's main objective was to bring the research generated in Collaborative Research Center SFB 768 closer to the industry. In this regard, transfer project took and further detailed the methods and tools developed in different research projects of the collaborative center and applied them to an international manufacturer of household appliances. The end result was the development of a concise guidelines for the conception of modular and platform strategy under dynamic influences [BAUER et al. 2014]. The author was responsible in designing and performing the research related to the top-down approach which was divided in three phases [MAURER et al. 2014, p. 15]. In the first phase, the determination of the flexibility of the product features and functions were identified [ELEZI et al. 2015]. In the second phase, the operationalization of this flexibility is planned in form of product-technology roadmaps. In the third phase, life-cycle management of the platform and modular systems was conceptualized, which involved the development of a management control system that guides the operationalization and adaptive measures of the modular and platform strategy. These phases and main tasks within the phases are depicted in Figure 1-1.

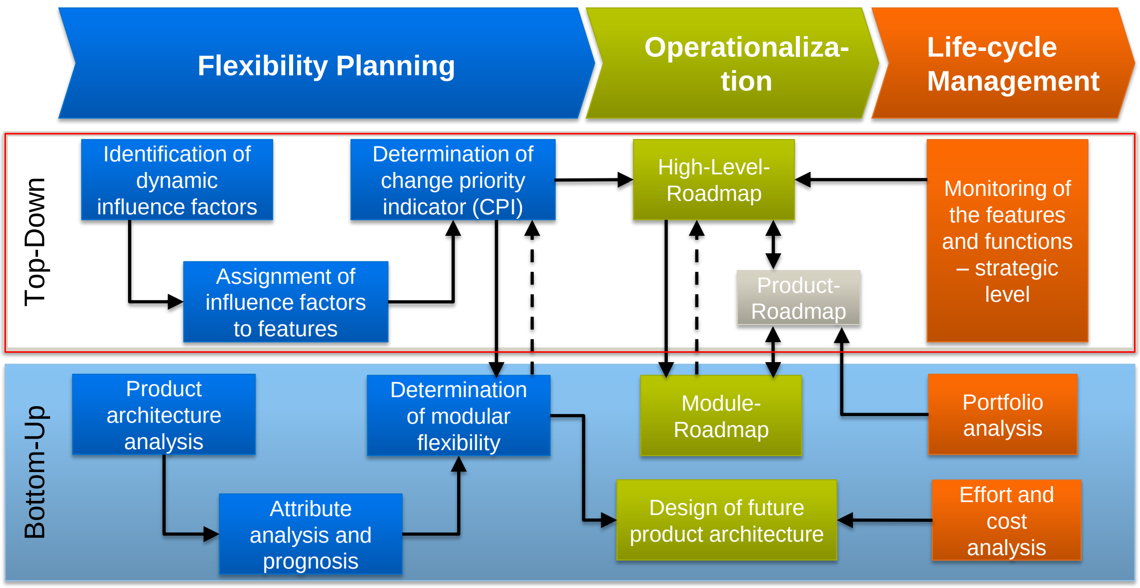

Figure 1-1: Main phases and tasks in SFB 768 transfer project T1: the top-down approach is highlighted in red (based on [BAUER et al. 2014, p. 15])

To sum it up, the objective of the top-down approach was to support increasing the dynamic capabilities of a firm by creating inherent flexibility of the firm's resources (in terms of flexible functions and features of a product family) and by defining formal processes that increase a firm's ability in applying (and maintaining) this flexibility in response to different environmental changes. These formal processes represented the MCS that needed to be tailor-designed for the company, therefore an extensive literature review was conducted to assess the research already performed in this direction. In fact, this project (and in particular the research performed in phase three) provided the motivation for the research presented in this thesis, sine the literature review performed within this project proved a lack of approaches that support managers in engineering companies to design contemporary MCS[2]. This project, besides motivating the research presented in this thesis, also provided empirical data for conducting part of the evaluation research in this thesis. The author supervised many student theses within the framework of this project. The student thesis that was conducted as part of this doctoral project is provided in Table 1-1.

Table 1-1: Student thesis performed in SFB 768 T1 project under author's supervision as part of the author's doctoral project

Referenced as:	Student	Thesis	Title of the Thesis
Produktentwicklung 2014b	Daniel Söldner	Diplom	Life-Cycle Management of Platforms

Other projects that followed with different industrial partners, confirmed the industrial need for approaches that support managers to design contemporary MCS. For example, in a project for analysis and quantification of the complexity in the computer tomography (CT) product family performed in cooperation with an international healthcare device manufacturer, it was realized that processes that enable adaptability of the firm to environmental changes are needed in order to operationalize the inherent flexibility vested in the product architecture of the CT product family. In another project that dealt with product architecture optimization conducted in cooperation with a large OEM in the auto industry, the same conclusion was reached. In both projects, it was observed that the companies focused in creating flexible resources (through technical solutions aiming at product architecture), but neglected formal processes to operationalize and maintain these flexible resources.

During the five years in the Institute of Product Development, the author served as the responsible person for the research collaboration with the Civil and Environmental Engineering Department at the University of California, Berkeley, USA. Within this collaboration, the author had the chance to work closely with Prof. Iris Tommelein, initially on topics such as complexity management and engineering project organizations. From 2013, the research focus shifted into topics more relevant to the author's doctoral project, such as systems and organizational theory for further exploring the management systems that enable the adaptability of organizations in highly dynamic environments. Hence, a great number of theoretical and empirical outcomes for the thesis was generated through this collaboration. On a regular basis, master students were exchanged and many of them were part of the author's doctoral project (see Table 1-2). These students were supervised and coached by Prof. Tommelein and the author jointly.

In April 2014, the author spent one month in University of California, Berkeley as a visiting researcher. The objective of the visit was to further enhance the research agenda of the collaboration with Prof. Tommelein and to visit a 1 billion US Dollar construction project in

[2] Contemporary MCS refer to MCS that do not incorporate only homeostatic regulation, but also enable adaptability of an organization to environmental changes.

San Francisco that served as basis for evaluation research in this thesis. As a direct outcome of this visit, two conference papers and a journal paper were published [ELEZI et al. 2014a, SCHMIDT et al. 2014, STEINHAEUSSER et al. 2015].

Table 1-2: Student theses performed in UC Berkeley under author's supervision as part of the author's doctoral project

Referenced as:	Student	Thesis	Title of the Thesis
Produktentwicklung 2013a	David Resch	Master	Improving Organizational Design and Diagnosis by Supporting Viable System Model Applications with Structural Complexity Management
Produktentwicklung 2013b	Tobias Steinhäußer	Diplom	Management Cybernetics as a theoretical background for lean thinking
Produktentwicklung 2014a	Michael Schmidt	Master	Supporting Organizational Design towards Lean Thinking with Management Cybernetics - An Application of the Viable System Model to the Construction Industry
Produktentwicklung 2014c	Julian Wilberg	Master	Improving Engineering Change Management through the Application of the Viable System Model
Produktentwicklung 2015	Sebastian Spörl	Master	Design and Implementation of Management Control Systems into Organizations

The author also actively participated in the research groups "Systems Engineering" and "Development Processes" where he had the chance to discuss his ideas and gain valuable input from his colleagues related to the research presented in this thesis. In addition, the author is a member of design society and participated regularly in the design society's international conferences (Design Conference 2010, 2012; ICED 2011). Other international conferences regularly attended were DSM Conference (2010, 2011, 2013 and 2014), and IEEE Conference on Industrial Engineering and Engineering Management (2011, 2013, 2014). All these conferences contributed as platforms for discussions with researchers and practitioners and as such provided a substantial contribution to the maturity of this thesis.

1.4.2 Research Methodology

Research methodologies represent frameworks that help researchers to plan and execute systematically their research projects for obtaining scientifically valid and relevant results. In this thesis, the "Design Research Methodology" (DRM) developed by BLESSING & CHAKRABARTI is used as a research framework [BLESSING & CHAKRABARTI 2009]. The primary focus of this methodology is on supporting engineering and industrial design research, although it is suitable for other types of design in wider variety of disciplines [BLESSING & CHAKRABARTI 2009, p. 2]. The decision for using DRM as the research methodology for this thesis is based on the fact that DRM integrates two main strands of research: the development of *understanding* and the development of *support*. These strands are closely linked and should be treated together in order to achieve the overall aim of the design research. Thus, the DRM has two main objectives [BLESSING & CHAKRABARTI 2009, p. 5]:

1. the formulation and validation of models and theories about the phenomenon of design with all its facets (people, product, knowledge/methods/tools, organization, micro-economy and macro-economy), and

2. the development and validation of support founded on these models and theories, in order to improve design practice, including education, and its outcomes.

Based on these goals, the DRM prescribes a methodological framework consisting of four stages.

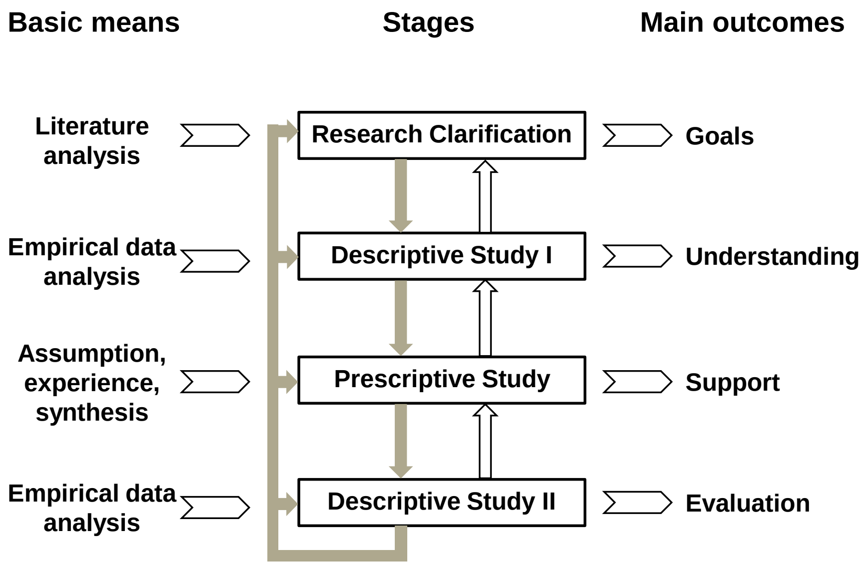

Figure 1-2: DRM methodological framework [BLESSING & CHAKRABARTI 2009, p. 15]

Figure 1-2 shows the main stages of the DRM and the links between these stages. The darker arrows between the stages indicate the main process flow, whereas the hollow arrows the possible iterations.

In the **research clarification** (RC) stage researchers identify the research gap and develop the objectives of the research based on a literature analysis. During the literature analysis, a set of criteria is identified that guide the development of the support that realizes the desired state. Therefore, it is essential that a clear formulation of the problem (initial state) and the support (desired state) is provided. Based on the identified criteria, the understanding of the problem to be tackled is made explicit and the evaluation of the developed support can be evaluated.

The goal of the **descriptive study I** (DS-I) is to make the description detailed enough to determine which factor(s) should be addressed in order to transfer the initial state to the desired state in an efficient and effective manner. This is performed by reviewing the relevant literature in order to get a comprehensive understanding of the underlying problem to be tackled.

In the **prescriptive study** (PS) the understanding developed in DS-I is used to develop the support that amends the initial state. In this stage the researchers have enough information and comprehensive set of criteria to continue with developing the support that transforms the initial state to the desired state. This stage might require literature analysis for developing the support, but it could also require a combination of literature analysis and empirical case studies. In some cases, such as in this doctoral thesis, the support can be developed with using research approaches that guide the design of the support. In this stage however, it is still not clear whether and to what degree the developed support can help in transforming the initial state to the desired state.

In order to determine whether the developed support targets the desired effects, the evaluation of the developed support is performed in **descriptive study II** (DS-II) stage. For this purpose, researchers undertake empirical studies to gain an understanding whether the developed support help in reaching the desired state. This stage provides valuable input on the applicability, usefulness and usability of the developed support. Based on this input, further improvements of the developed support can be suggested. In such cases, the researchers have to step back to the PS stage to implement the suggestions coming from DS-II stage. Thus, the methodological framework of DRM is not only sequential but can contain iterations to previous stages (as seen in Figure 1-2).

Based on the way these stages are performed (comprehensive study or review-based study), BLESSING & CHAKRABARTI distinguish seven types of research projects [BLESSING & CHAKRABARTI 2009, p. 18]. Comprehensive study includes a literature analysis, as well as small-scope empirical studies to assess the situation in the field, whereas the review-based study is based only on literature analysis. The first stage (RC) in all types of research projects is always performed by reviewing the literature, in order to determine the aim, scope and focus of the research project. The first type of research projects according to BLESSING & CHAKRABARTI is focused in comprehensive DS-I in order to identify the criteria of success that can be used in design research. Type two of research projects has an initial PS in addition to a comprehensive DS. Type three of research has a review-based DS-I, a comprehensive PS and an initial DS-II. Type four has a review-based DS-I paired with a review-based PS and a comprehensive DS-II. Comprehensive DS-II has always to be followed by an indication of how the support is to be improved (an iteration back to PS). These first four types focus on a particular research stage, therefore are suitable for PhD projects. Research projects of type five to seven are more appropriate for research groups because of the broad research scope.

In Table 1-3, the research procedure undertaken in this doctoral project is presented. For each stage of DRM the objectives and an overview of research methods is given. In addition, the DRM stages are related to the corresponding chapters of this thesis.

As part of literature review based **RC**, the research need was identified, as well as the objective and the research questions were set. This stage is based on the literature research study presented in chapter 2.

In the **DS-I** stage, a comprehensive understanding of the relationship between management control systems (MCS) and viable system model (VSM) is formed. This was achieved through a literature review and by using functional analogies to compare existing MCS design frameworks with the VSM. This understanding (elaborated in chapter 3) is essential for identifying the criteria that guide the development of the support. In **PS** stage, the criteria and the development of a method for using VSM as theoretical underpinning for design of MCS are presented. For developing the support, the Munich Model of Methods (MMM) as research method is used. The PS stage is described in chapter 4.

Table 1-3: Research procedure based on DRM [BLESSING & CHAKRABARTI 2009]

DRM Stage	Objective	Research Method	Thesis
Research Clarification (RC)	Identification of the research gap, determination of the objective and research questions	Review-based study (literature review)	Chapter 2
Descriptive Study I (DS-I)	Creation of a comprehensive understanding on the relationship between management control systems (MCS) and viable system model (VSM)	Comprehensive study (literature review and functional analogy)	Chapter 3
Prescriptive Study (PS)	Development of a method for using VSM as theoretical underpin for design of MCS	Comprehensive study (Munich Model of Methods)	Chapter 4
Descriptive Study II (DS-II)	Evaluation of the method developed in PS	Initial (emprirical research based on three case studies)	Chapter 5

In **DS-II** stage, the evaluation of the support developed in PS stage was performed. The author applied the method in three case studies conducted in two engineering organizations. The research method used was of initial type and comprised of the evaluation of the support according to three evaluation criteria: the applicability, usefulness and the usability of the support. This research stage is described in chapter 5.

1.5 Thesis Structure Overview

This thesis is structured based on the research stages of DRM. An overview of the structure is provided in Figure 1-3 as a guide for the reader.

Chapter two discusses the relevant theories for this thesis, which includes systems theory, management cybernetics and control systems in engineering companies. Important concepts from these fields of study are described, such as the concept of systems, complexity, variety, law of requisite variety and the Conant-Ashby's theorem, attenuation and amplification of variety, homeostasis, viable system model, contingency theory and management control systems. This chapter provides the theoretical foundation relevant for the subsequent chapters of this thesis.

In *Chapter three*, a discussion is provided for shedding light on the relationship between MCS and the VSM. This is performed by use of literature review and by use of functional analogies as a research method to compare an existing MCS framework with the VSM.

Chapter four represents the heart of this thesis, where the development of a method that uses VSM as theoretical underpinning for MCS design is described. The Munich Model of Methods guides the structure of this chapter starting from requirements identification based on the findings from chapter three. At the end of this chapter, the method is elaborated for easier application in industrial setting.

Chapter five describes the application and the evaluation of the developed method in three case studies. In the first case study the method was applied in the context of lean material control, more precisely in pull-based material supply system. In the second case study, the method was used for design of a MCS that supports the management platform systems. In the third case study, the method was applied in the context of engineering change management. The outcome of the evaluation results was separately described in each case study and a cross-case evaluation is provided at the end of the chapter.

Chapter six provides a conclusory discussion on the overall research conducted within this doctoral project by addressing the initial objective and research questions set in the introduction of this thesis. The discussion is focused on the research and industrial benefit, limitations, as well as suggestions for improvement. A research outlook is provided at the end of this chapter.

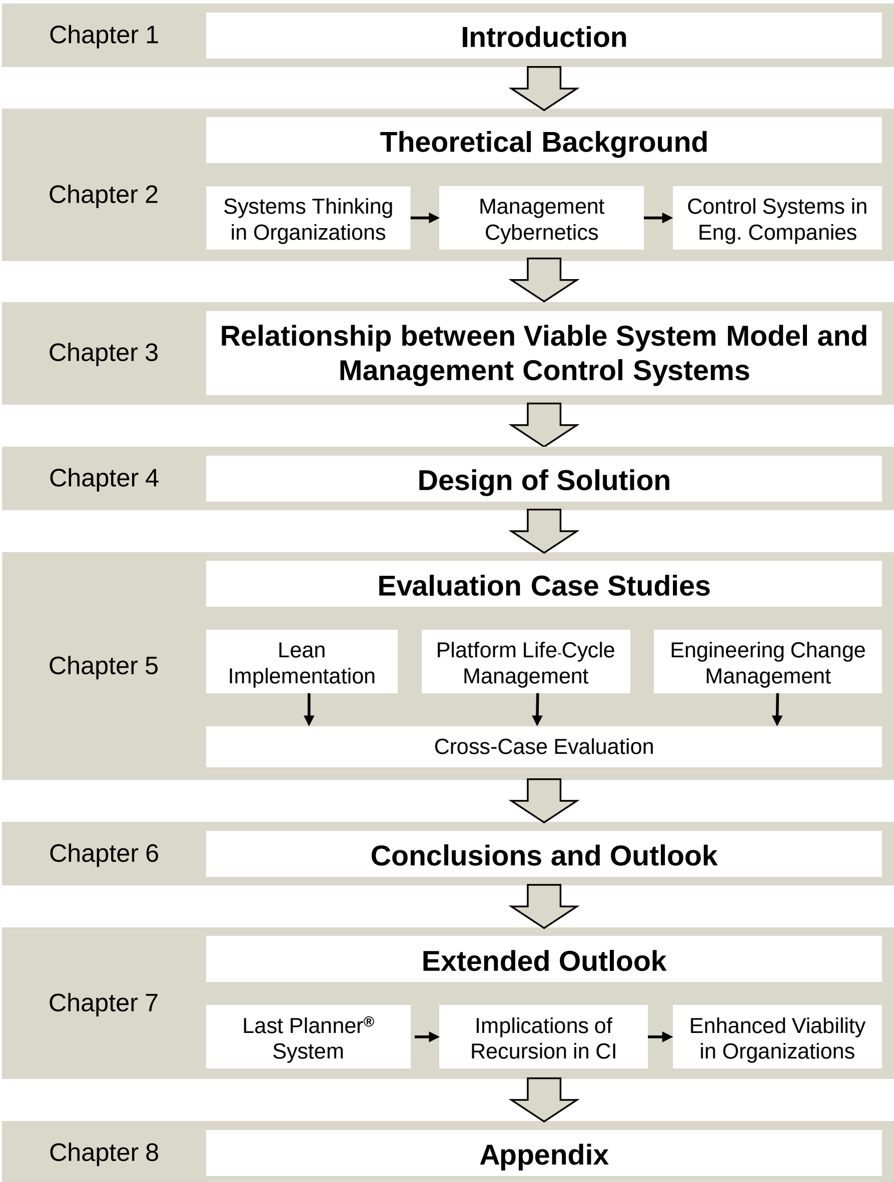

Figure 1-3: Thesis structural overview

Chapter seven provides an extended outlook to illustrate some important implications of the management cybernetic perspective on engineering management topics that point out to promising areas of study requiring further research. These topics include Last Planner System, the implication of recursion in continuous improvement (CI), and enhanced viability in organizations.

Finally, *chapter eight* provides an appendix with useful documents and data generated in this doctoral project.

2. Theoretical Background

In this chapter, relevant concepts, definitions, and theory foundations from the fields of systems thinking in organizations, management cybernetics and management control systems are provided. The objective is to deliver the necessary theoretical background for understanding the prescriptive study of this thesis. Further, the research need is identified as well as an indication of how this research need can be tackled is described. At the end, a short summary and conclusions of this chapter are provided.

2.1 Systems Thinking in Organizations

This subchapter provides an overview of systems thinking as a framework for the analysis of organizations. It starts with an introduction of systems theory and its objectives. Next, basic systemic definitions and concepts relevant for this thesis are described, including – concepts related to systems, types of systems and complexity. After, cybernetics as an important part of the systems theory is introduced since it represents the main source of theoretical concepts used in this thesis. In this subchapter the description of cybernetics is held short, since a more comprehensive description is provided along with the introduction of management cybernetics in subchapter 2.2. In section 2.1.4, the description of organizations based on systemic metaphors is provided. At the end of this subchapter (section 2.1.5), the main systemic paradigms for analyzing organizations are introduced.

2.1.1 Introduction to Systems Theory

The first ideas and concepts in relation to what is today known as systems theory (also referred as general systems theory) were given by Ludwig von Bertalanffy in the first part of the 20th century. However, there were preliminary works on systems theory that also Bertalanffy recognizes as such, for example works from KÖHLER and LOTKA [BERTALANFFY 1968, p. 11]. Systems theory is transdisciplinary scientific field of study that brings together theoretical concepts from different scientific disciplines, such as biology and engineering. It arose as a response to the long established perspective in science – the mechanistic perspective. According to the mechanistic (or reductionist) perspective, entities are divided into smaller parts for analysis. Based on the analysis of these smaller parts, the conclusions about the behavior of the whole entity can be deduced. In contrast, organismic perspective considers entities as undividable. To understand the behavior of the entities, a holistic approach is used which analyses the entities as a “whole”. System theory rests on the organismic perspective, since many complex phenomena, such as emergence and evolution, cannot be explained with the reductionist perspective. As a consequence, systems theory focuses on the relations between the parts which connect them and their constellations. Based on this, HEYLIGHEN & JOSLYN define systems theory as “(…) the transdisciplinary study of the abstract organization of phenomena, independent of their substance, type, or spatial or temporal scale of existence. It investigates both the principles common to all complex entities, and the (usually mathematical) models which can be used to describe them." [HEYLIGHEN & JOSLYN 1992].

According to SKYTTNER, the goals of general systems theory can be specified as follows [SKYTTNER 1996, p. 24]:

- To formulate generalized systems theories including theories of systems dynamics, goal-oriented behavior, historic development, hierarchic structure, and control processes.
- To work out a methodological way of describing the functioning and behavior of systems objects.
- To elaborate generalized models of systems.

As it can be deduced from these goals, systems theory strives for establishing a common language that is not bounded with any context. This common language, referred to in the literature also as a systemic language, makes it possible for theorists and practitioners of different disciplines to communicate with common systemic definitions. Thus, the systemic language opens a whole new perspective to solution-finding for specific systems in an efficient manner. In this regard, systems theory represents a transdisciplinary body of study that emphasizes the intrinsic order and interdependence of the world in all its manifestations [BANATHY & JENLINK 2004, p. 37].

Central to systems theory is the concept of system that will be elaborated on the next section together with other related concepts and definitions relevant for this thesis.

2.1.2 Concepts and Definitions in Systems Theory

Systems

There are many definitions of system in the contemporary systems theory literature. Most of these definitions refer to system as a set of interacting units or elements that form an integrated whole intended to perform a function. For example, BERTALANFFY defines a system as a set of elements standing in interrelations [BERTALANFFY 1968, p. 55]. ACKOFF builds upon this definition stating that a system is a set of two or more elements that satisfy the following conditions [ACKOFF 1981, p. 15]:

- The behavior of each element has an effect on the behavior of the whole.
- The behavior of the elements and their effects on the whole are interdependent.
- In whatever way the subgroups of the elements are formed, all have an effect on the behavior of the whole, but none has an independent effect on it.

System's elements are the building blocks of systems. In systems theory, the nature of the elements and their connections is usually not defined. Each system is embedded in its **environment** where other systems might exist. The **system boundary** represents the delimitation of the system with its environment. The interaction with the environment and other systems is possible through the **inputs and outputs of the system**. ASHBY defines the **state of the system** as "(…) any well-defined condition or property that can be recognized if it occurs again. Every system will naturally have many possible states" [ASHBY 1956, p. 25]. A simple depiction of a system and its interrelated elements is provided in Figure 2-1.

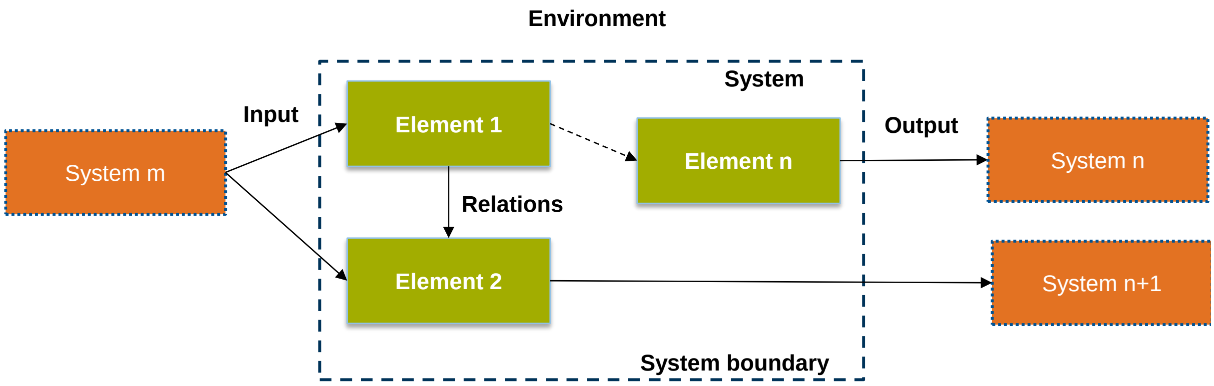

Figure 2-1: A depiction of a system and its interconnections

In systems theory, the system and the related definitions are context neutral, meaning they do not have any physical connotation. The elements constituting the system need to be in a certain structure and relationship with each other. This means that elements that are randomly distributed and with no clear interrelationship do not necessarily constitute a system.

Systems can be categorized as open and closed systems. **Closed systems** represent systems that are considered to be isolated from their environment [BERTALANFFY 1968, p. 39]. Isolated in this context means that these type of systems do not exchange inputs and outputs with the environment, but there could be input of energy from the environment. **Open systems** in difference to closed systems, exchange information, matter and energy with the environment. This exchange is enabled through the inputs and outputs of the system. The internal states of the open systems (hence their outputs also) are dependent on the input from the environment. The rate of change of system's states defines the **dynamics of a system**. Total number of states that a system can theoretically have represents the **state space** and can be an indicator of the complexity of the system. A system is said to be **deterministic** if it follows regular and reproducible sequences of states [ASHBY 1956, p. 24]. This means, that if we know the states of system inputs then we can precisely predict the state of the outputs. For the systems where this is not possible, they are said to be **non-deterministic** or **probabilistic**. Another categorization of systems is made on the basis of their temporary structural behavior. **Static systems** represent systems whose structure (the elements and their interconnections) does not change with time, whereas in **dynamic systems**, their structure is a subject of change. In general, systems are categorized based on different attributes. A very good overview of these classifications can be found in [PULM 2004, p. 36].

One of the key concepts related to systems is **complexity**. There are many definitions of complexity stemming from different disciplines since it is generally recognized that complexity represents a qualitative concept. Even if only the systems theory perspective is taken, complexity appears to be multifaceted and subjective. For example, system theorists analyzing the structure of systems might describe **complex systems** as systems with many elements and many interconnections. However, this way of defining the complexity has a major flaw. As BEER states "(…) if the intention is to measure the complexity of a system, to state its variety, everything will depend on how the system is defined, in short, on who defines it. In particular, it will be vital to know how deeply the observer's insight has penetrated into the nature of the system" [BEER 1966, p. 247]. In other words, complexity is not an attribute of the system, but rather a perception of the observer. For example, dynamic systems and probabilistic systems are generally considered in literature as more complex than static and deterministic systems. Several attempts have been made by various researchers to provide a more or less useful and general quantitative definition, such as algorithmic complexity (sometimes called Kolmogorov complexity), computational complexity or logical depth, thermodynamic depth, and mutual information [BACKLUND 2002, p. 30]. However, the use of such complexity measures is, to say at best, limited to very specific problems. The definition of complexity used in this thesis is based on the definition stemming from cybernetics (described in section 2.2.2).

To illustrate the importance of the complexity concept on systems theory, it is sufficient to mention that there has even been attempts to structure the investigations of systems theory based on the **hierarchy of complexity**. BOULDING proposed nine levels of complexity and listed the typical systems belonging to these levels and their characteristics [BOULDING 1956, p. 202-205]. He suggested that these complexity levels serve "(…) to prevent us from accepting as final a level of theoretical analysis which is below the level of the empirical world (complexity level – note of author) which we are investigating." [BOULDING 1956, p. 207]. Based on this understanding, he states that systems theory "(…) is the skeleton of science in the sense that it aims to provide a framework or structure of systems on which to hang the flesh and blood of particular disciplines and particular subject matters in an orderly and coherent corpus of knowledge." [BOULDING 1956, p. 208]. It is important to mention, that based on this hierarchy, social organizations are placed in the eight position - representing the most complex systems known today (the ninth place which represents the highest complexity is reserved for transcendental systems – an undefined type of system that comprise "inescapable unknowables"). In line with this hierarchy and based on the definitions provided in this section, the organizations in this thesis are regarded as sociotechnical systems (see section 2.1.4) that are open to their environment and respond to changes in environment (open and self-regulating systems), that change their structure and processes in time (dynamic systems), and are non-deterministic. Open and self-regulating systems belong to the knowledge domain of cybernetics, which will be presented in the following section.

2.1.3 First and Second-order Cybernetics

Cybernetics came to prominence as a scientific discipline in late 1940's when Norbert Wiener published his book "Cybernetics: or Control and Communication in the Animal and the Machine" [WIENER 1948]. The term cybernetics derives from the Greek word "kybernetes" meaning steersman or helmsman. Cybernetics deals with special class of systems: the self-regulating systems. Self-regulating systems represent a class of systems that despite the presence of disturbances can maintain a desired state autonomously. The objective of cybernetics as a scientific discipline (by many seen as the most important part of systems theory), is to provide a common language to describe such systems as well as to understand principles of operation and their design. The initial ideas for existence of the common cybernetic language were inspired during the work on designing anti-aircraft artillery targeting systems, and during the analysis of various phenomena in different fields of study, such as electric engineering (electric feedback circuits) and in neurology (nervous system).

What is known as the modern era of cybernetics started immediately after the World War Two. Between 1946 and 1953 the Josiah Macy, Jr. Foundation sponsored a series of conferences in New York City on the subject of "Circular Causal and Feedback Mechanisms in Biological and Social Systems" which pushed forward the agenda of cybernetics [UMPLEBY 2008, p. 2]. After Norbert Wiener published his seminal book in 1948, Heinz von Foerster suggested to change the name of the conference to "Cybernetics: Circular Causal and Feedback Mechanisms in Biological and Social Systems". These conferences became known as the Macy Conferences on Cybernetics [UMPLEBY 2008, p. 2].

Through the 1950s, cyberneticists were moving in the same research direction as the school of general systems theory, that was founded at about the same time by Ludwig von Bartalanffy (see section 2.1.1). Both these fields of study were striving to build a unified science by uncovering the common principles that govern open, evolving systems [HEYLIGHEN & JOSLYN 2001, p. 2]. HEYLIGHEN & JOSLYN explain that although it may appear that cybernetics and systems theory overlap, there is still a difference. Namely, systems theory strives for generalizing the studies of systems at all levels of abstraction, whereas cybernetics focuses on goal-directed, functional systems which make some form of control relation [HEYLIGHEN & JOSLYN 2001, p. 2]. BERTALANFFY was well aware of the overlapping between GST and Cybernetics, stating "(…) systems theory is frequently identified with cybernetics and control theory. This again is incorrect. Cybernetics as the theory of control mechanisms in technology and nature is founded on the concepts of information and feedback, but as part of a general theory of systems" [BERTALANFFY 1968, p. 17].

According to UMPLEBY, the original group of cyberneticists (Macy conferences participants) created approximately four new research traditions [UMPLEBY 2008, p. 3]:

1. The cybernetics of Allen Turing and John von Neumann became computer science, AI, and robotics.
2. Norbert Wiener's cybernetics became part of electrical engineering. This branch of cybernetics includes control mechanisms, from thermostats to automated assembly lines.
3. Warren McCulloch's cybernetics became "second-order" cybernetics.
4. Gregory Bateson and Margaret Mead pursued research of cybernetics in the fields of social sciences, particularly anthropology, psychology, and family therapy.

In general, it can be stated that cybernetics as a theoretical science had a vital influence on the birth of more applicable modern sciences, such as: control theory, computer science, automata theory, artificial intelligence, cognitive science, computer modeling, dynamical systems and so on [HEYLIGHEN & JOSLYN 2001, p. 3]. Cybernetics influenced not only technical sciences, but also social sciences. In this regard, WHITAKER states that "(…) the universality and power of the ideas unleashed in this early 'cybernetics group' were so self-evident as to facilitate these ideas' recurrent adoption and adaptation in a variety of disciplines - especially the social sciences - as time went on” [WHITAKER 2003].

In the 1970s, technical sciences born out of cybernetics, such as computer science and artificial intelligence, had become sciences of their own. The remaining cyberneticists, however, were of the opinion that they had to distinguish themselves from these more applicable sciences by emphasizing autonomy, self-organization, cognition, and the role of the observer in modelling systems [HEYLIGHEN & JOSLYN 2001, p. 3]. In this regard, Heinz von Foerster proposed that the observer of the system is included into the observed system, since the observer perceives a model that is reproduced in his mind, not the real system. As Foerster puts it: “(…) the cybernetics of observed systems we may consider to be first-order cybernetics; while second-order cybernetics is the cybernetics of observing systems“ [VON FOERSTER 2003, p. 286]. A table with different definitions concerning first- and second-order cybernetics is given below [UMPLEBY 2008, p. 7].

Author	First Order Cybernetics	Second Order Cybernetics
Von Foerster	The cybernetics of observed systems	The cybernetics of observing systems
Pask	The purpose of a model	The purpose of a modeler
Varela	Controlled systems	Autonomous systems
Umpleby	Interaction among the variables in a system	Interaction between observer and observed
Umpleby	Theories of social systems	Theories of the interaction between ideas and society

Figure 2-2: Definitions of first- and second-order cybernetics (adapted from [UMPLEBY 2008, p. 7])

The development of second-order cybernetics made possible the application of cybernetics into social sciences. The second-order cybernetics (sometimes referred as cybernetics of cybernetics) represented the missing puzzle that paved the way for what is later known as systemic perspectives on social systems. These perspectives will be introduced in the next section.

In order to keep the theoretical background of this thesis lean, a discussion related to main cybernetic concepts is provided in subchapter 2.2, where management cybernetics is introduced.

2.1.4 Organizations as Systems: The Metaphors of Organizations

Before discussing organizations from a systems perspective, it is important to define first what is meant by the term “organization”. In literature, the term organization is very broad and there is no consistent and comprehensive definition. For example, DAFT provides the following definition: “(…) organizations are (1) social entities that (2) are goal-directed, (3) are designed as deliberately structured and coordinated activity systems, and (4) are linked to the external environment." [DAFT 2012, p. 12]. In the same manner, ACKOFF states: "(…) an organization is (1) a purposeful system that is (2) part of one or more purposeful systems, and (3) parts of which, people, have purposes of their own" [ACKOFF 1981, p. 29]. Similarly, most of the contemporary definitions of organizations agree that organizations pursue clearly formulated goals (goal-directness mentioned in the definition of DAFT), and the communication and cooperation of the constituent elements (in this case humans) are purposeful and deliberate (purposeful systems mentioned in ACKOFF's definition). As such, organizations are highly complex systems that cannot be completely understood. In contemporary organizational literature, many theories are developed to understand at least certain aspects related to organizations. These theories use so called metaphors to explain the inner workings of the organizations. As MORGAN explains "(…) the use of metaphors implies a way of thinking and a way of seeing that pervade how we understand our world generally" [MORGAN 1997, p. 4]. In the following subsections some of the most common metaphors used in organizational context will be presented.

Mechanistic Metaphor on Organizations

In the beginning of last century and in the rise of Taylor's scientific management, the organizations were considered as machines. Scientific management was focused in optimizing operations, and the mechanistic metaphor proved useful for this goal. However, this metaphor is based on two assumptions [GHARAJEDAGHI & ACKOFF 1984, p. 290]: (1) organizations can be completely understood, and (2) such understanding can be obtained by analysis. The analysis of organizations based on this metaphor is performed in three steps [GHARAJEDAGHI & ACKOFF 1984, p. 290]: First, the part of the organization to be analyzed is taken apart, then the behavior of parts are analyzed and understood, and finally based on the understanding of the parts, the behavior of the whole is explained. As it can be noticed, this procedure follows the reductionist paradigm (see subchapter 2.1).

According to MORGAN, mechanistic metaphor is appropriate in cases [MORGAN 1997, p. 27]: (a) where there is a straightforward procedure that needs to be followed, (b) when the environment is stable enough to ensure that the products produced are still appropriate, (c) when high product standardization is sought, (d) when precision is highly important, and (e) when the "human" factor of the organization is compliant and behaves strictly according to the rules.

However, this metaphor has severe limitations [MORGAN 1997, p. 28]: (a) it can create organizational forms that have difficulties to adapt to environmental changes, (b) it can result in mindless and unquestionable bureaucracy, (c) it can have unanticipated and undesired consequences as the interests of employees could prevail over the interest of the organization, and (d) it can have dehumanizing effect upon employees (as shown in an humoristic way by Charlie Chaplin in his famous movie "Modern Times").

The mechanistic metaphor accomplished great results in the beginning of industrial age when the market was relatively stable and there was a high demand of standardized products. As the world gradually entered the age of post-industrialism, the organizational environment has become more ambiguous, dynamic and complex. Adaptability and innovative ability became the key factors determining the survival of the organizations. This led to a new metaphor for studying organizations, which is presented in the next subsection.

Organismic Metaphor on Organizations

The organismic metaphor emerged initially from biology and it implies that organizations have a single purpose: their survival. In contrast to the mechanistic metaphor, the organismic metaphor considers organization as dependent on the environment for essential input and is underpinned with producer-product rather than cause-effect relationships (for the definition of producer-product relationship refer to [ACKOFF & EMERY 2005, p. 19-26]). As is always the case, the organizational environment changes continuously, therefore it is essential for the survival of the organizations to learn and adapt to these changes [GHARAJEDAGHI & ACKOFF 1984, p. 292]. This metaphor considers the organizations as living systems, which means that they have a metabolism and exchange material or energy with their environments [BERTALANFFY 1968, p. 141]. In this regard, GHARAJEDAGHI & ACKOFF state that "(…) an organismically conceptualized corporation, profit, like oxygen in the case of an organism, is taken to be necessary for survival but not the reason for it. Profit is taken as a means; growth as an end. With survival as the ultimate end, planning becomes prediction of environmental changes and preparation for them." [GHARAJEDAGHI & ACKOFF 1984, p. 292].

The organismic metaphor in organizational theory is analogue to the self-regulatory system concept in cybernetics. From cybernetics it is known that self-regulatory systems strive to reach an equilibrium whenever environmental changes are imposed. In the same manner, the organismic metaphor considers that important organizational parameters should be kept in dynamic equilibrium despite the dynamic influences from environmental factors. In this way, the organization can adapt to changes induced by the environment. According to this metaphor, it is essential for the organizations to develop high levels of communication, encourage decentralized decision making in order to enhance the response time and raise the ability to adapt. Unlike the fixed and clearly specified roles as in the mechanistic perspective, the roles of people and teams from organismic metaphor are left broad and general. These are defined in a more abstract functional level, since this ensures that the underlying structure of the organization responds to the stimuli coming from environment even if the organization did not experience such stimuli before. Therefore, this metaphor is focused more on the structure of the organizations (how people communicate and interact) than on defining the roles precisely.

This way of viewing the organizations has several advantages [MORGAN 1997, p. 67-68]: (a) the role of environment is emphasized, (b) survival of the organization is seen as the key ongoing process that needs to be supported, (c) decision-making is contingent on environmental circumstances, and (d) it stresses the virtue of organic forms of organization in the process of innovation. The common limitations assigned to this metaphor include [MORGAN 1997, p. 69-70]: (a) assigns a very concrete image to organizations, although they are social systems, (b) the perspective is too positivistic about the functional unity of the organization, (c) political and other self-interested activity is seen as abnormal, and (d) the danger of the perspective becoming an ideology.

Besides these limitations, the organismic metaphor is quite popular among organizational theorists, since it provides a basis for contingency theory, which is so far the prevailing approach to study organizations in volatile environments (contingency theory is presented in section 2.3.1). What makes the organisms different from the organizations is that organisms consist of elements that are not themselves purposeful, whereas organizations contain purposeful entities in many levels (people, teams, groups of interest, divisions, etc.). The following metaphor strives to incorporate this important feature into the overall picture of the organizations.

Organizations as Social Systems

The mechanistic and organismic metaphors are not very suitable for analysis of organizations, where entities can have purposes of their own that do not necessarily coincide with the purpose of the organization [JACKSON 2003, p. 9-10]. The social system metaphor contains mechanistic and organismic metaphors, but the converse is not true [GHARAJEDAGHI & ACKOFF 1984, p. 297]. In other words, purposeful systems (social systems perspective) include the capabilities of goal-seeking systems (mechanistic perspective) and self-regulating systems (organismic perspective) [GHARAJEDAGHI & ACKOFF 1984, p. 297].

One of the key highlights of the social system metaphor is that it puts in front the human factor. An organization is described simply as a group of people that pursue a common goal, without excluding the possibility that parts of organization have other goals too. In order to have a common goal, the organization needs to examine the environment, model it and predict future development. This is performed by organizational communication that makes possible the conception, adaptation and realization of organizational goals [ACHTERBERGH & VRIENS 2009, p. 18]. However, the communication and consequent information in the organizations is subject to interpretation, distortion and unavailability. Many decisions (for setting the goals for example) are made with limited information and in many cases under false assumptions. In addition, humans are subject to irrational behavior that makes decision-making even more uncertain. This is one of the strongest reasons that makes social systems to be classified as non-deterministic systems.

Engineering companies exhibit two sided nature – social and technical, and are often referred as **sociotechnical systems**. The concept of the sociotechnical system is based on the simple fact that any production system requires both a technology – machinery, plant layout, raw materials, and a work-relationship structure that relates the human operators both to the technology and to each other [COOPER & FOSTER 1971, p. 467].

Organizations as Complex Adaptive Systems

The complex adaptive systems metaphor is fundamentally different from the abovementioned organizational metaphors. According to this metaphor, the constituent members or entities of the organizations (referred to as agents) are connected together in a non-linear manner and have self-organizing property. In addition, the agents have learning capability and behave in a highly unpredicted manner. Therefore, organizations as complex adaptive systems are difficult to observe, capture, analyze, and explain using traditional research tools [MCDANIEL JR et al. 2009, p. 4]. Central in this aspect is the so-called emergent order – which develops through the interaction of many entities in the organization [KURTZ & SNOWDEN 2003, p. 466]. Characteristic of this type of order is that it cannot be controlled with a centralized mechanism. The emergent order is a consequence of self-organizing processes, not because of the presence of central intelligence [KURTZ & SNOWDEN 2003, p. 466].

Other Organizational Metaphors

MORGAN provides further metaphors that are useful for understanding organizations [MORGAN 1997, p. 73-344]. For example, organizations can be seen as **information processing brains**, which presumes the analogy of organizations with information/communication systems that are capable of bringing decisions. Another metaphor is **organizations as cultures**. Central to this metaphor are the social norms and customs manifested as shared beliefs, values and understanding within the members of the organization. The **organizations as political systems** metaphor puts at the forefront the plurality of interests existing within the organizations, and the consequent structures, goals and actions driven by these interests. The **organizations as psychic caves** metaphor recognizes unconscious and conscious processes within the organization as the main cause of imprisonment of people to certain ideas, thoughts and images for explaining their environment. In the **organization as flux and transformation** metaphor, the organizations are seen as entities that constantly change and undergo transformations. The **organizations as instruments of domination** metaphor regards organizations as means for individuals or groups to impose their will on others. JACKSON adds another metaphor, the **organizations as carnivals** (based on the work of [ALVESSON et al. 1996]) that emphasizes creativity, diversity, and ambivalence. This metaphor regards the organization also as a place where people are supposed to have fun [JACKSON 2003, p. 36-37].

Each of these metaphors succeeds to provide a one-sided perspective on organizations at the expense of other metaphors. In this way, a certain metaphor can create a powerful image of organization by suppressing other metaphors. Therefore, metaphors should be used cautiously, as they can easily become distortions for the proper understanding of organizations.

2.1.5 Paradigms and Systems Approaches

Based on the metaphors listed in the previous section, JACKSON categorizes the systems approaches for understanding organizations into four paradigms as seen in Table 2-1 [JACKSON 2003, p. 38]. Although the word “paradigm” today refers to a view or perspective, originally it had another meaning. According to JACKSON “(…) a paradigm had a technical meaning, provided by [KUHN 1970], and referred to the tradition of research regarded as authoritative by a particular research community. It was the set of ideas, assumptions and beliefs that shaped and guided their scientific activity” [JACKSON 2003, p. 37]. With this understanding of the term “paradigm”, the four paradigms of system approaches will be introduced in the next subsections.

Table 2-1: Systems approaches for organizations [adapted from [JACKSON 2003, p. 38]

Paradigm	*Systems Approaches*	*Scholars*
Functionalist	- Hard Systems Thinking - System Dynamics - Organizational Cybernetics - Living Systems Theory - Autopoiesis - Complexity Theory, Theory of Complex Adaptive Systems (CAS)	Russel Ackoff, Charles W. Churchman, Jay W. Forrester, Ludwig von Bertalanffy, Stafford Beer
Interpretative	- Interactive Management - Social Systems Design - Strategic Assumption Surfacing and Testing (SAST) - Social Systems Sciences - Soft Systems Methodology (SSM)	Peter Checkland, Russel Ackoff, Charles W. Churchman, John N. Warfield, Richard Mason & Ian Mitroff
Emancipatory	- Critical Operational Research/Management Science - Critical Systems Approach - Team Syntegrity - Critical Systems Heuristics - Boundary Critique	Stafford Beer, Werner Ulrich, Gerald Midgley, Michael C. Jackson
Postmodern	- Participatory Appraisal of Needs and the Development of Action (PANDA) - Knowledge Systems Diagnosis - Generative Conversation - Systems Story	Ann R. Taket, Leroy White, Warren.K. Topp

Functionalist Paradigm

JACKSON defines the functionalist paradigm as "(…) optimistic (*paradigm* – note from the author) that an understanding can be gained of how systems work by using scientific methods and techniques to probe the nature of the parts of the system, the interrelationships between them and the relationship with the system and its environment" [JACKSON 2003, p. 38]. Therefore, the primary concern of the functionalist paradigm is the structure of the system [JACKSON 2000, p. 211]. The paradigm strives to improve the "functioning" of the system in terms of efficiency, adaptability and survival, hence its name [JACKSON 2003, p. 38]. The associated metaphors to this paradigm are: mechanistic, organismic, brain, flux and transformation metaphors [JACKSON 2003, p. 38]. This paradigm is appropriate whenever the problem can be clearly and unambiguously defined. Some typical systems approaches belonging to this paradigm include hard systems approaches, systems dynamics and organizational cybernetics (also known as management cybernetics – presented in subchapter 2.2).

Interpretive Paradigm

The interpretive paradigm arose as a necessity to address problems in social systems where different purposes, perceptions and interests exist. The paradigm perceives the actions of people and groups of interests within the organization as dominant factor in these systems. By acknowledging that people possess free will, the paradigm "(…) wants to understand the meanings people bring to collaborative activity and to discover where these meanings overlap, and so give birth to shared, purposeful activity" [JACKSON 2003, p. 39]. Hence, the models that utilize this paradigm are used to analyze perceptions of the real-world and to structure debate about changes that are feasible and desirable [JACKSON 2001, p. 241]. This paradigm is related to the culture and political system metaphor.

There are several systems approaches stemming from this paradigm, the most famous one being soft systems methodology (SSM). SSM is introduced by CHECKLAND in response to the perceived failure of traditional systems engineering (SE) particularly in regard to management problems [CHECKLAND 1981, MINGERS & WHITE 2010, p. 10]. CHECKLAND together with his collaborators changed the way organizations are understood by recognizing that organizations as social systems are purposeful systems and came up with a procedure for analyzing organizations that is focused around this aspect. SSM has seven steps, starting with system modeling (by using root definitions) where several models relevant to the problem are designed. In the next steps, these models are discussed and analyzed and as a result the decision makers arrive to an understanding on how the changes can be systematically desirable and feasible [MINGERS & WHITE 2010, p. 11].

Emancipatory Paradigm

The emancipatory paradigm studies social order within social systems and the ways to change it. JACKSON characterizes this paradigm as "(…) suspicious of authority and tries to reveal forms of power and domination that it sees as being illegitimately employed. It criticizes the status quo and wants to encourage a radical reformation of, or revolution in, the current social order" [JACKSON 2003, p. 39]. The underlying assumption guiding this paradigm is that in social systems certain social groups of people take advantage to dominate or discriminate other social groups. These social classes can be distinguished through race, gender, class, sexual orientation, age, capability, and so on [JACKSON 2000, p. 291]. The aim of the paradigm is to emancipate the discriminated social groups that are suffering because of the social status-quo. JACKSON associates this paradigm with psychic prison and instruments of domination metaphors [JACKSON 2003, p. 39].

The most important systems approach associated to this paradigm is the critical systems heuristics (CSH). According to JACKSON "(…) CSH is a practically oriented, emancipatory systems approach that can ensure that planning and decision-making include a critical dimension, and can enable the designs emanating from other systems approaches, whether hard or soft, to be suitably interrogated to reveal whose interests they serve." [JACKSON 2003, p. 213].

Postmodern Paradigm

The postmodern paradigm is the most recent paradigm that takes its name from the fact that it opposes the "rationality" employed by the other three paradigms listed above [JACKSON 2003, p. 39]. As JACKSON further explains, this paradigm asserts that "(…) organizations are far too complex to understand using any of the other paradigms". Therefore, he suggests to take a less serious view on organizations and emphasizes having fun as one of the most important aspect in the organization [JACKSON 2003, p. 39]. This paradigm is associated with the carnival metaphor [JACKSON 2003, p. 39].

2.2 Management Cybernetics

In this subchapter, management cybernetics (MC) also known in literature as organizational cybernetics is introduced. First, the historical development of this research field is presented. Next, most important concepts stemming from management cybernetics that are important for the rest of the thesis are introduced. In section 2.3.3, the meaning of complexity from the MC perspective will be presented. This sets the stage for the introduction of one of the most important laws in MC – the law of requisite variety, and its associated theorem – the Conant-Ashby's theorem. After understanding these two theoretical cornerstones, the attenuation and the amplification of variety as related concepts to management of complexity are introduced. These concepts are crucial for understanding the viable system model, which is presented thereafter. Last but not least, the implications of the viable system model for research and some typical applications in industry are introduced.

2.2.1 Historical Background

The research in MC started in late 1950's as part of the efforts to apply cybernetic theory in other research contexts. Initially, cybernetic theory was successfully transferred in electrical engineering and electronics and later it propagated into other disciplines as diverse as biology, anthropology and psychology. MC was established by the transfer of cybernetic theory into the context of management and organizations. BEER, in his seminal work "Cybernetics and Management", states that cybernetics is the science of control, whereas the management is the profession of control [BEER 1959, p. 239]. As a consequence, he concludes that management systems are subject to cybernetic principles. In the same book, BEER classifies systems based in two dimensions – complexity and behavioral dimension. The first dimension (complexity) has three possible states: simple, complex, and exceedingly complex; whereas the behavioral dimension has two possible states: deterministic and probabilistic. Hence, systems in general can be distinguished in six types (see Table 2-2).

Organizations such as companies belong to exceedingly complex systems and have a probabilistic nature. This type of systems are characterized with a high number of elements interacting in an unpredicted manner. The biggest difficulty with these systems is that they cannot be reduced to a lower degree of complexity for analysis, and the reductionist metaphor provides no explanation of their behavior.

Table 2-2: Categorization of systems [BEER 1959, p. 18]

SYSTEMS	Simple	Complex	Exceedingly Complex
Deterministic	Window catch, billiards, machine-shop lay-out	Electronic digital computers, planetary system, automation	Empty
Probabilistic	Penny tossing, jellyfish movements, statistical quality control	Stockholding, conditioned reflexes, industrial profitability	The economy The brain THE COMPANY

MC is concerned with such systems, in developing methods and models to understand them and ultimately to make these systems manageable. In such efforts, BEER in the year 1972 developed the viable system model (VSM) that represents an organizational model based on cybernetic laws and principles [BEER 1972]. VSM describes functionally all organizations that tend to be viable. **Viability** is described as the ability to maintain a separate existence in a changing environment [BEER 1979]. Companies represent a special type of viable systems, therefore VSM can be used to analyze them (see section 2.2.5).

Although VSM was introduced forty years ago, its strength to address contemporary management challenges such as complexity, learning and adaptability has gained recognition in recent years. As GOULD states: "(…) probably the single most important thing about Beer's work is that it anticipates much of the current fascination with chaos, complexity and the need for rapid strategic adjustments to environmental changes" [GOULD 1999]. After his first publications on VSM, which provided the theoretical foundation of MC, BEER provided a "manual", as he describes, for managers to apply the VSM for design and diagnosis of organizations [BEER 1985]. Other authors followed in the efforts to make the VSM theory more accessible to practitioners. BRITTON (1989) for example, presents a methodology for applying the VSM comprising 15 steps. The methodology combines the approach of interactive planning – a framework for planning procedures featuring five interconnected phases. The Viplan method, presented by ESPEJO & REYES (2011) represents another contribution to VSM application in organizations, which aims at improving organizational performance by diagnosis and design. Another contribution to designing and especially diagnosing organizations from a viable systems perspective was presented by PÉRES RÍOS (2012). This approach comprises similar steps compared to the Viplan method, however placing special emphasis on the diagnostic part. The contributions to MC body of knowledge in recent years are mainly connected to VSM application efforts in different managerial contexts, they will be comprehensively listed in section 2.2.6. In order for these contributions to be understood, basic concepts in MC will be presented in the next sections.

2.2.2 Basic Concepts in Management Cybernetics

As mentioned, systems that are subject of MC (viable systems) are exceedingly complex and probabilistic systems. Engineering organizations belong to this group of systems, being described as sociotechnical systems [LIKER 2004]. The underlying premise in MC is that these organizations exhibit a complexity that is beyond a certain barrier in order to be viable. As a consequence, these systems cannot be analyzed with the traditional management models and tools, as they cannot tackle the issues related to the viability of these systems. For example, applying operational research tools could bring some benefit at operational level, but that is by no means a guarantee for the whole system to be more viable. Therefore, organizations should not be regarded as a loose conflux of events, but as a tightly knit network of information [BEER 1966, p. 23]. In real life, this tightly knit network of information represents complex, uncertain and interacting collection of men and machines, materials and money [BEER 1966, p. 300].

Complexity

At this point, as the discussion is about complex systems, it would be appropriate to define the term complexity. There are many definitions in the existing literature about complexity coming from different scientific disciplines. In the following, only the cybernetic view on complexity will be discussed since this view is relevant for the prescriptive study on this thesis. BEER equates the concept of complexity with the concept of variety [BEER 1966, p. 247]. **Variety** is defined by ASHBY as the number of distinguishable states of the system [ASHBY 1956, p. 126]. In the same manner, MALIK states that variety as an important characteristic of complexity [MALIK 2008, p. 186]. He expands Ashby's definition of complexity by adding that the complexity emerges as a variety of elements interacting between themselves – and thus brings the interplay of elements (in a system) as a part of complexity in the forefront. Organizations in terms of variety are regarded as exceedingly complex systems since, besides comprising a high number of elements (people, resources, machines, etc.) that interact in an unpredicted manner with themselves and the environment, they can present themselves in a huge number of possible states (variety). MC's approach to deal with this high complexity is to design controllers that are able to cope with this high complexity. In this regard, complexity in organizations can be managed with two types of strategies:

1. design a controller that has the same complexity (variety) as the system to be controlled
2. design a controller that utilizes the concept of variety amplification and attenuation

In the first case, the controller is subject to the so called Ashby's law which states that only variety can destroy variety [ASHBY 1956, p. 207]. This means that the controller needs to have answers for all possible states of the system to be controlled. Because of its importance, Ashby's law will be presented in section 2.2.3.

In the second case, the strategy for complexity management is highly important in real-life organizations, as it represents a more realistic solution. Namely, sociotechnical systems such as organizations are so complex, that merely using Ashby's law to design controllers is not feasible because of the enormous variety. In practice, a more pragmatic theorem is used – the

Conant-Ashby's theorem [CONANT & ASHBY 1970]. This theorem states that the best regulator (i.e. best controller – author's note) of a system is one which is a model of that system in the sense that the regulator's actions are merely the system's actions as seen through a mapping h (h being the mapping function of the system to regulator). Conant-Ashby's theorem is presented in more detail in section 2.2.3.

Black box

When studying complex systems such as sociotechnical systems, a concept known as the black box can be very practical. As BEER puts it: "(…) the meaning of the term (black box – author's note) in cybernetics is that of a box to which inputs are observed to lead and from which outputs are observed to emerge. Nothing at all is known about the way in which the inputs and the outputs are connected inside the box which is why it is called black." [BEER 1966, p. 293]. This way of looking into systems is very powerful, as in many cases, the system can be so complex that it is impossible to model accurately enough its constituting elements, connections and states. However, a great deal of the system's behavior can be inferred by observing the relationship of outputs based on the changes of the input. This way, a function that describes the relationship between the output and the input can be established (in literature known as **transfer or system's function**).

Feedback

All controllers in MC utilize a concept known as feedback. This concept cannot be overestimated for its importance in cybernetic systems. In this regard HOAGLAND et al. (2001) state that: "(…) feedback is a central feature of life. The process of feedback governs how we grow, respond to stress and challenge, and regulate factors such as body temperature, blood pressure and cholesterol level. The mechanisms operate at every level, from the interaction of proteins in cells to the interaction of organisms in complex ecologies". A more technical definition of feedback is given by RAMAPRASAD :"(…) feedback is information about the gap between the actual level and the reference level of a system parameter which is used to alter the gap in some way". For example, the information on overspending in travel by a salesperson used to cut his spending in the future is feedback. The system parameter to be controlled is the salesman's travel expenditure. The reference level of the system parameter is the budgeted expenditure, the actual level is the actual expenditure. The gap between the actual level and the reference level is the amount of overspending. Information on the gap when used to alter the gap (most probably to decrease the gap) becomes feedback [RAMAPRASAD 1983, p. 4].

Control, self-regulation, and homeostat

The term **control** means to regulate, to direct or to command [BHATTACHARYA 2009, p. 1]. Control brings together the concept of black box, feedback, and variety and is central to cybernetics. When speaking of control, usually two distinguishable systems are in mind. First, there is a system that needs to be controlled. This system is controlled by keeping its outputs in certain desired states. This control is performed by a second system which acts as a **regulator** by utilizing feedback mechanisms (refer to Figure 2-3). A more general definition is given by BHATTACHARYA who defines the control systems as “(…) a combination of devices and components connected or related so as to command, direct or regulate itself or another system.” [BHATTACHARYA 2009, p. 1]. The system to be controlled is usually referred to as the operating unit in literature, whereas the system utilizing the feedback mechanism is referred to as the control unit. Depending on the application, the inputs and outputs of the control system could be either material, information or energy [LINDEMANN et al. 2009].

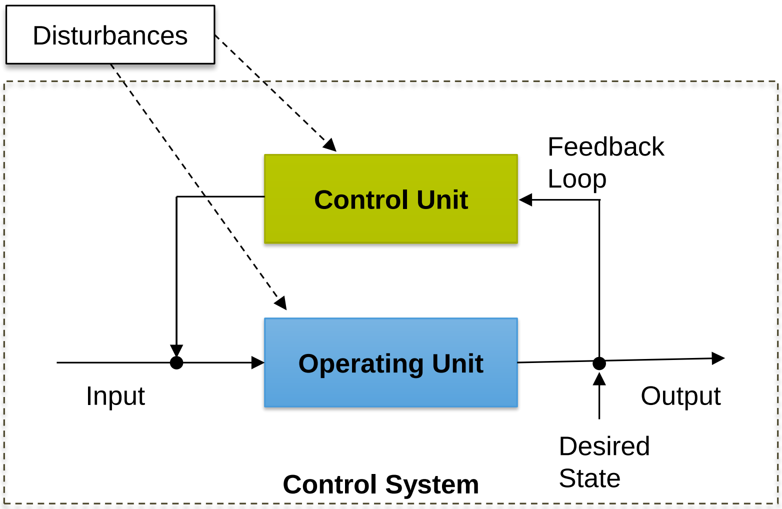

Figure 2-3: Simple closed-loop control system

As shown in Figure 2-3, the control unit utilizes a feedback loop to get the information about the gap between output of the system and the desired state. Theoretically, there are two types of feedback: positive and negative feedback. The control system in Figure 2-3 with positive feedback would either increase rapidly the difference between the output and the desired state, or it would drive the system into an unstable state (such as oscillations). In biological systems for example, positive feedback can be used to create switch-like behavior through auto-regulation of a gene and to create oscillations such as those present in the cell cycle, central pattern generators or circadian rhythm [ASTRÖM & MURRAY 2008, p. 16]. As such, this type of feedback is not so relevant for control systems that are treated in MC. Negative feedback is much more relevant to control systems, as it makes equilibrium of the output sates with the desired states possible even in the presence of disturbances. This error-controlled negative feedback is important “(…) because it immediately demonstrates that systems can be designed that are inherently capable of responses not envisaged in detail by the designer.” [BEER 1966, p. 263]. This statement of BEER is of particular importance in MC, since in sociotechnical systems there is an unpredictable number of possible environmental disturbances and in addition, these disturbances have high variety that can influence the system in an unpredictable manner. Therefore, control systems in MC that control essential outputs (variables) are employed in order to prevent the flow of variety from disturbances to the output of the control system. This is possible by employing the negative feedback concept.

The ability of the control system to keep essential outputs within their desired state despite external unpredicted disturbances is termed **self-regulation**. The control system that has this ability and operates autonomously from external control is referred to as **homeostat** in cybernetics. Homeostats are extremely important in all types of systems. For example, most important bio-physiological processes in biological systems are controlled by homeostats.

The concepts of feedback, control system, self-regulation and homeostat proliferate in all types of complex systems. For example, keeping a body's temperature (biological systems), steering a bike (dynamic systems), managing a company (management systems) or economy of a state (macroeconomic systems) require utilization of control systems based on feedback loops. In MC, a body of research based on these definitions is developed and used to understand organizations and management in a systemic perspective. Therefore, the concepts mentioned in this section are extremely important to understand the discussion in this study. Readers interested in gaining a deeper understanding of these basic concepts, should refer to the classics of cybernetics and MC - in particular [WIENER 1948, ASHBY 1956, BEER 1959, BEER 1966].

2.2.3 Law of Requisite Variety and Conant-Ashby's Theorem

As stated in the previous section, the measure of complexity in cybernetics is variety. Sociotechnical systems are considered to be exceedingly complex systems, which means that they contain a huge variety (large number of possible states) that has to be managed. As BEER explains, variety is used more as a comparative measure of complexity in sociotechnical systems since "(…) the number of possible states in a complicated entrepreneurial system is not precisely countable" [BEER 1985, p. 24]. This possibility to at least comparatively measure complexity with variety, sets the scene for one of the most important cybernetic and systems theory law – the law of requisite variety, also known as Ashby's law. In a simple definition, ASHBY describes the law of requisite variety as "(…) variety can destroy variety." [ASHBY 1956, p. 207]. This means that if a system has variety N, than the regulator of that system has to have a variety N too, or else the regulation of the system will fail [BEER 1979, p. 89]. To illustrate this important law, let us use the example of closed-loop control system as shown in Figure 2-4.

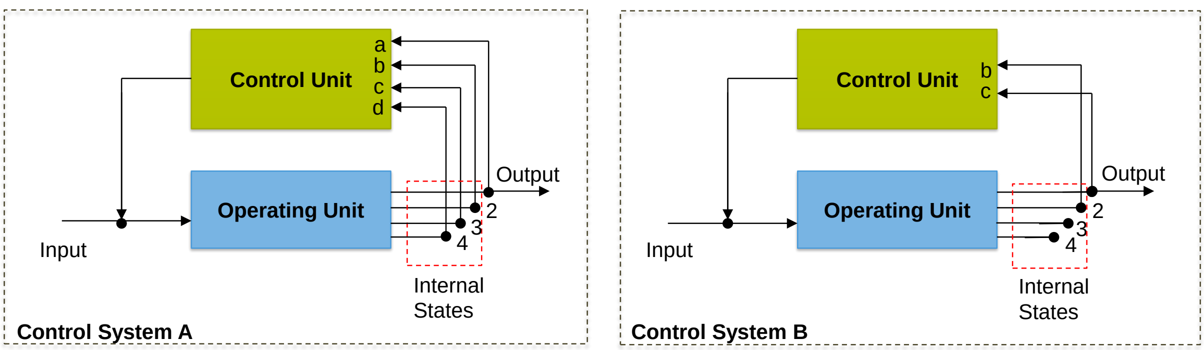

Figure 2-4: Illustration of the law of requisite variety in a control system

The control systems A and B in Figure 2-4 have 1 input, 3 internal states, and 1 output. Let us assume that the input, the output and the internal states work in binary mode (they have only two possible states, 0 and 1). In control system A, the control unit has the same number of inputs [a – d] as the number of internal states and the output of operating unit. If that control unit can respond to all possible states of internal states and the output so the desired level of the output is maintained then it can be stated that the control unit has the requisite variety and therefore obeys Ashby's law. In the control system B, the control unit has fewer inputs [b, c] than the internal states and the output of the operating unit, therefore the control unit does not have the requisite variety to maintain the output at the desired level. Therefore, it can be stated that control system B does not obey Ashby's law and does not represent a stable control system.

Ashby's law is a necessary condition for a stable control system. However, in practice, a more realistic version of this law is used, the Conant-Ashby's theorem. This theorem entails that a good regulator (the control unit in Figure 2-4) has to be a model of the system (operating unit in Figure 2-4) [CONANT & ASHBY 1970]. Models are representations of systems and do not have the complexity (variety) of the real systems. Therefore, the Conant-Ashby's theorem implies that a **good regulator** must include the essential states that are needed for control, not the whole variety of states of the system. A crucial feature of the good regulator is that it prevents the flow of variety from disturbances to the essential variables [ASHBY 1956, p. 201]. This theorem has deep implications in organizational theory, since it basically explains how communication (in the sense of the management) needs to be modeled. Although Ashby's work had a profound influence in organizational theory and especially in initial stages of contingency theory, almost no explicit mention is made of Ashby's law (or Conant-Ashby's theorem) in this body of knowledge [RAADT 1987, p. 518]. The only author who uses Ashby's law and Conant-Ashby's theorem in modeling organizations (and thus providing a great insight on organizational communication and control requirements) is Beer, who recognizes the influence of Ashby's work in his own thoughts in many of his writings. On the importance of Ashby's law in relation to management he states: "(…) this (Ashby's – note from the author) law stands in the same relation to management as the law of gravity stands to Newtonian physics" [BEER 1979, p. 89].

2.2.4 Attenuation and Amplification of Variety

Ashby's law and in particular Conant-Ashby's theorem introduced in previous section have an enormous impact on organizational design and management. Because of this importance, it is to be expected that both the Ashby's law and the Conant-Ashby's theorem are the subject of a large number of research efforts to understand information flow and regulation in organizations. Unfortunately, this is not the case. As stated, only BEER took these two theoretical concepts into account when introducing management cybernetics and in designing the viable system model. BEER considers management as a regulator of the organization [BEER 1959]. From this perspective, it is obvious that management cannot have the required responses for every possible internal state (coming from operations) and external state (coming from the environment). In other words, the complexity in operations and in the environment exceeds the variety that management can handle. Speaking in the language of cybernetics, the proliferation of the variety in the system cannot be met by its regulatory component's variety – therefore, the law of requisite variety is not respected [BEER 1979, p. 90]. To cope with this situation, variety amplification and attenuation mechanisms are required. Variety amplification mechanisms enhance the variety to the number of possible states that the receiving entity needs in order to remain regulated, whereas variety attenuation mechanisms cut down the possible states (decrease variety) that the receiving entity can actually handle [BEER 1985, p. 25, 27]. As such they represent the interfaces between two entities with different variety (see Figure 2-5).

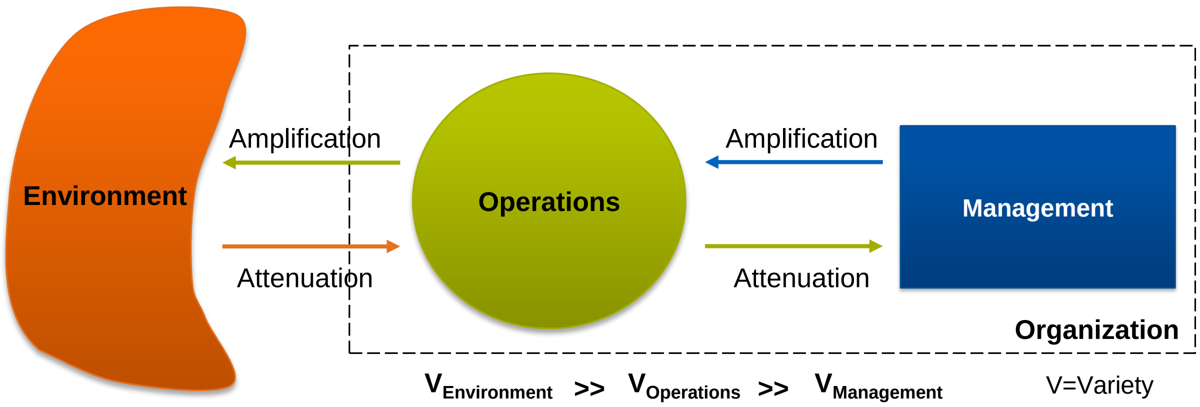

Figure 2-5: Amplification and attenuation mechanisms between organizational entities [based on ESPEJO & REYES 2011, p. 57; BEER 1985, p. 28; ESPEJO & HARNDEN 1989, p. 82]

Figure 2-5 shows that the environment of the organization has the highest variety. In order to comply with Ashby's law, the organization needs to have the same variety as the environment. As this is not possible, the organization must employ attenuation mechanisms to reduce the variety from the environment. Indeed, the organization does not need to distinguish all the possible states of the environment as only a small part of this variety is relevant to it. Therefore, in order to have a good regulator as prescribed by Conant-Ashby's theorem, only the "essential variables" are monitored and kept within acceptable ranges by the organization [ASHBY 1956, p. 197]. The same applies for the interface between operations and management. Operations has a much larger variety than the variety management can handle, therefore attenuation mechanisms are used. The amplification mechanisms on the other side, are employed by entities with lower variety in the direction of entities with the higher variety. For example, if management would want to change the state of a single parameter, that would likely lead to a change of a number of parameters at the operational level.

If these mechanisms are not designed properly, attenuation and amplification will "just happen" in an uncontrolled manner by attenuating the relevant variety and amplifying the unnecessary variety [BEER 1985, p. 26, 27]. Based on this, BEER states "(…) the problem of management itself, which is that of regulating an immense proliferation of variety, is less horrific once the underlying homeostatic regulators are perceived, properly designed, and allowed to absorb the variety of each other's entities" [BEER 1985, p. 29]. Table 2-3 provides examples of attenuating and amplifying mechanisms in management based on [HERRMANN et al. 2008].

Table 2-3: Examples of attenuating and amplifying mechanisms (based on HERRMANN et al. 2008, p. 310]

Attenuation mechanisms	Amplification mechanisms
Standardization: of communication, processes, products etc.	**Hiring and training:** hiring new and training existing employees
Filtering and ignoring: unimportant or unnecessary information; dealing with exceptions/aggregations only	**Empowering:** delegation and empowering of employees
Modeling to gain system comprehension: aggregation of information in form of dynamic or static models	**Extending products and services:** developing, combining, or customizing products and services

The attenuating and amplifying mechanisms, together with other management cybernetic concepts (introduced in subchapter 2.2) were used by BEER to design an organizational model for viable organizations. The next two sections present this model and some of typical applications in academia and industry.

2.2.5 Viable System Model

The viable system model (VSM) represents a functional structural model for organizations that are capable of learning and adapting to dynamically changing environments. It incorporates principles of cybernetics related to viable systems (see viability definition in section 2.2.1). BEER derived the VSM primarily by observing one of the most viable systems to be found on earth – the human nervous system [BEER 1972, BEER 1979]. Based on these observations, he extracted the basic mechanisms of adaptability and abstracted these to a functional level. Hence, the VSM "(…) represents the isomorphisms which underlie any viable system, natural or artificial, biological or social" [ESPEJO & HARNDEN 1989, p. 3]. In other words, VSM represents a meta-systemic model that incorporates necessary and sufficient functions for a system to be viable [ACHTERBERGH & VRIENS 2009, p. 191]. These functions (the definition of the term functions for this thesis is given in subchapter 3.4) are grouped in so called VSM systems (Systems 1 to 5 as seen in Figure 2-6). Systems 1 to 3 are sometimes referred to as autonomic management and serve to realize the goals of the organization. Systems 3 to 5 enable the organization to change and adapt these goals [ACHTERBERGH & VRIENS 2009, p. 192]. In the following paragraphs, these systems will be introduced. For a comprehensive description of VSM systems and VSM in general, refer to [BEER 1972, BEER 1979, BEER 1985, ESPEJO & REYES 2011, PÉRES RÍOS 2012].

In Figure 2-6, every line delineated at each end by a dot indicates that a homeostatic relationship (see section 2.2.2) between the systems is intended. The squiggly lines between operational entities indicate a dependency which may be strong or weak, depending on the purpose of the viable system concerned [STEINHAEUSSER et al. 2015, p. 6].

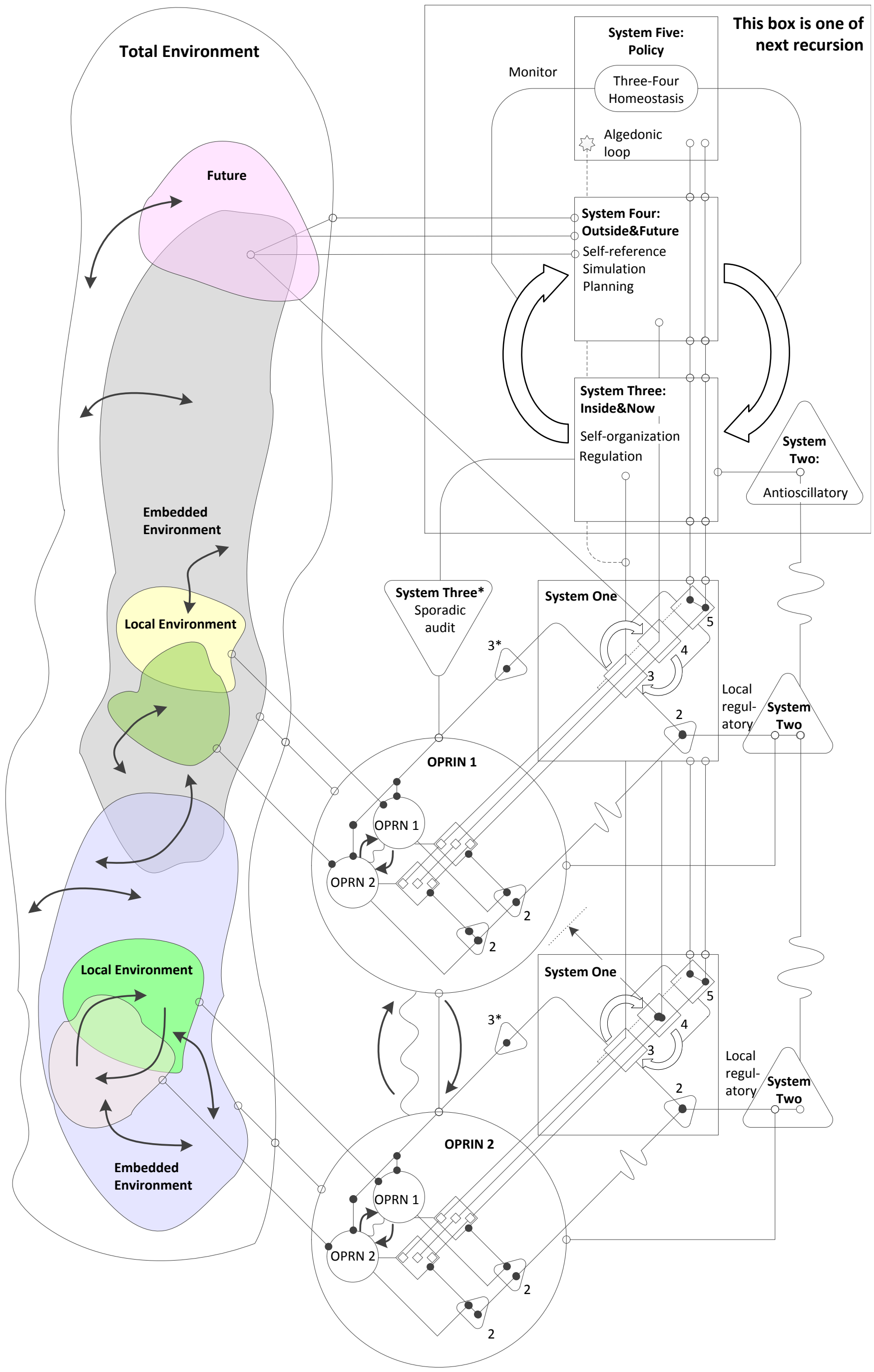

Figure 2-6: Viable System Model (redrawn by [STEINHAEUSSER et al. 2015] after [BEER 1984])

System 1 – Operations

System 1 (S1) represents the collection of functions that ensure the execution of primary activities of a viable system. Primary activities are executed for producing the output of the organization that can be products or services. System 1 entities (see Figure 2-6) are each responsible for interacting with the local environments that could represent customers, suppliers and so on. Besides being connected to the environment, S1 entities are connected internally to system 2 (S2) and system 3* (S3*). S1 entities are coordinated by S2, whereas functions in S3* perform ad-hoc audit. In certain cases there is direct intervention of system 3 (S3) as seen in Figure 2-6, but in general these interventions should be minimized because they jeopardize the autonomy of S1 [BEER 1979, p. 200]. In cases where dramatic changes in the environment (or internally within S1) cause a proliferation of variety and the self-regulatory capacity of S1 is at risk, the algedonic channels serve as direct communication for alerting systems 3 to 5. Figure 2-6 reveals also that VSM is self-referential model (in each S1 there is a whole VSM in a lower recursion level). This means that each S1 entity is itself a VSM. This characteristic of VSM is referred to as **recursivity**.

System 2 - Coordination

System 2 (S2) contains functions responsible for coordination of S1, thus it is a service for S1 [BEER 1979, p. 200, 201]. In this capacity, it serves as communication medium between S1 and S3. The main purpose of S2 is to absorb the large amounts of variety generated in S1 as a consequence of operational activities [PÉRES RÍOS 2012, p. 111]. In addition, S2 functions should guarantee a coordinated and synchronized operation of S1 entities. Thus, S2 is supposed to dampen possible oscillations by coordinating the operations coherently with the requirements of S3 (the operations control). These objectives of S2 are achieved by explicitly describing the tools and procedures related to the coordination of S1 entities [PÉRES RÍOS 2012, p. 111]. S2 is also responsible for sending to “local regulatory S2” (see Figure 2-6) the relevant information coming out of S3 (working norms, new programs, updated quality parameters, new accounting and legislative regulations, etc.) [PÉRES RÍOS 2012, p. 117].

System 3 and 3* – Operational Control and Audit

System 3 (S3) surveys the activities of the operational entities of the viable system (S1 and S2) and is aware of what is going on inside these systems [BEER 1979, p. 202]. To accomplish this, S3 designs and updates S2 in such a way that it absorbs most of the variety generated in S1. S3 also provides goals for each S1 entity derived from strategic objectives (that are communicated through system 4 (S4)). The overall role of S3 in a VSM is to reach an effect of synergy related to the operations of S1 entities [BEER 1979, p. 203]. However, to reach this synergy, S3 does not have to directly command S1 entities, but rather the control and coordination of S1 entities is performed through S2. S3 also negotiates the resources of S1 entities and decides on the necessity of intervening in the operations via authoritarian instructions. This however, needs to be minimized as it endangers the autonomy of S1 entities. S3 is in a homeostatic relationship with S4, which is responsible for monitoring the VSM’s environment and anticipating future changes in the environment. The role of this homeostat is to balance the future prognosis and planning with current operational activities.

To provide direct information to S3 from S1 entities, system 3* (S3*) serves as additional communication channel that provides relevant information to S3 that would otherwise not be available through S2. Hence, S3* has purely an informational purpose and no command or decision-making function [BEER 1979, p. 211]. In a cybernetic sense, S3* provides the second feedback loop from S1 to S3 (the other one being S2) that is employed in an ad hoc manner.

System 4 – Intelligence

As described, S1 to S3 are necessary for daily operations of the viable system. Purely operating without responding to the environment cannot constitute a viable system. Therefore S4 is concerned with monitoring the environment and anticipating the future of the environment surrounding the viable system. Accordingly, S4 houses the viable systems' whole apparatus for adaptation which means that it has to be a model of the viable system of which is a part [BEER 1979, p. 235]. Furthermore, it also needs to have a model of the part of the environment that it is supposed to monitor. The main role of S4 is to compare these two models and analyze how they influence each other in different future scenarios. Based on these analyses, S4 develops strategic plans in line with the values and norms set by system 5 (S5). The strategic plans are also discussed with S3 (homeostatic regulation) to match the actual capabilities to change and adapt.

System 5 – Identity and Policy

System 5 (S5) monitors the operation of S4-S3 homeostat [BEER 1979, p. 259]. This is performed by setting the goals and values and by defining the norms and purpose of the viable system. Thus S5 provides the identity of the VSM which serves as variety sponge for the high variety created in S3 and S4 [BEER 1985, p. 91]. Therefore, S5 exists to makes sure that S4 and S3 operate in line with the identity of the viable system and prevents domination of S3 or S4 in the operations of the viable system [ACHTERBERGH & VRIENS 2009, p. 199].

Final Notes on VSM

As mentioned in the beginning of this section, each system of the VSM is a set of functions that define that system's goals and roles. Most of these functions were defined by [BEER 1972, BEER 1979] but other authors subsequently contributed by expanding them [PÉRES RÍOS 2012, SCHWANINGER 2009].

Along with the VSM, BEER compiled a set of organizational principles and managerial axioms based on the cybernetic body of knowledge [BEER 1979, BEER 1985]. These principles and axioms help in design and analysis of the viable organizations and complement the structural understanding of VSM with more dynamic related knowledge such as: how variety needs to be dynamically managed, how the communication channels need to be designed and how fast information should be transmitted. These principles and axioms are presented and summarized in [STEINHAEUSSER et al. 2013, p. 58, 59]. According to BEER, the VSM, organizational principles and managerial axioms should support managers in designing new organizations and analyzing existing organizations for possible functional, structural and communicational pathologies [BEER 1985].

2.2.6 Implication and Application of Management Cybernetics in Industry

Ever since BEER introduced the MC and its most prominent model, the VSM, several authors have substantially contributed in further developing these topics and related MC with traditional organizational and management theories. The intention of this section is not to list them all, but to provide an overview of some important contributions that enhanced MC either in the academic sense or contributed to application methods and approaches that make it more accessible to industry.

Design and Diagnosis of Organizations

ESPEJO and PÉREZ RÍOS are two authors who brought great contributions in making VSM more accessible to practitioners. Both of them continue in BEER'S footsteps in using VSM as a diagnostic tool. For example, ESPEJO introduces the Viplan method with the aim to improve organizational performance by properly mapping the organization into the VSM structure. This involves identification of different recursion levels and distinguishing different functional entities of an organization (vertical unfolding of complexity) [ESPEJO & REYES 2011]. Based on the insights from these steps, the regulatory functions of the organizations are identified, which can be further diagnosed for structural or functional shortcomings. This analysis allows for restructuring and redistribution of regulatory functions within the organization for improving the operational and strategic efforts.

Similarly, PÉREZ RIOS proposes a method that incorporates more or less the same steps as those in the Viplan method. The difference is that PÉREZ RÍOS focuses on the diagnostic part of the method and the vertical cohesion of the organization. For this purpose, he introduces a set of so-called "pathologies" that support practitioners in identifying functional, structural and communication deficiencies in an organization from MC's perspective. For the complete list of this set of pathologies, please refer to [PÉRES RÍOS 2012, p. 141-179].

ACHTERBERGH & VRIENS in contrast, tackle more philosophic topics, such as the "raison d'être" of organizations, and provide important "arches" (pillars) for understanding organizations as social systems conducting experiments [ACHTERBERGH & VRIENS 2009]. They claim that the common goal which all organizations strive for is that of "rich survival", which is different from simply surviving. As the structural model that enables the rich survival of organizations they suggest the VSM.

Management Strategies

One of the most important authors who studied the implication of MC in management strategies is MALIK. In traditional management strategies, organizations are treated as "constructivist technomorphs", in other words as systems designed by prior rational planning and intentional human intervention. MALIK finds this model inappropriate for organizations that have to deal with high complexity and are faced with a changing environment [MALIK 2008]. He proposes a more suitable model identified in the literature as "systemic-evolutionary", which encompasses systems that self-regulate and evolve in time. To come up with a management strategy that encompasses this model, MALIK uses the VSM for organizations and draws the lessons for management strategy from MC.

Intelligent Organizations

SCHWANINGER proposes a new framework for designing “intelligent organizations” based on management cybernetics [SCHWANINGER 2009]. He uses VSM as a basic model for organizations with a special focus in learning processes. According to him, learning is a very important process in the organization that should be heavily endorsed, since only learning organizations can cope with the high environmental complexity and dynamics they may face.

Viable Systems Approach

GOLINELLI suggests a new approach in the management of organizations which is externally oriented, called the viable system approach. In this approach he uses a new metaphor (see section 2.1.4 for the definition of metaphor) which consists of seeing an organization as a VSM that competes with other VSMs for resources. From this metaphor they deduce a set of abstract concepts on how the organizations (and their environment) should be analyzed [GOLINELLI 2010, GOLINELLI et al. 2002].

Information Flow in Organizations

In order to make organizations more efficient and to increase the quality of decision-making, ROSENKRANZ suggests looking at information flows within the organizations. He proposes a method to analyze, diagnose and design information flows based on systems theory and cybernetics, which relies heavily on the VSM [ROSENKRANZ 2009, ROSENKRANZ & HOLTEN 2011].

2.3 Control Systems in Engineering Companies

After introducing systems theory and MC, it is reasonable to present the relevant literature for this thesis coming from organizational theory. Organizational theory is nowadays not a compact body of knowledge but rather a very broad and diverse set of theories and topics that often contradict each other. However, the most prominent approach rooting from organizational theory for understanding and analyzing organizational structures subject to environmental dynamics is contingency theory. Although contingency theory was developed separately and at first sight independently from systems theory and cybernetics, its main ideas are based on fundamental cybernetic concepts. For this reason, contingency theory represents the organization theories’ “cybernetic view”.

In the following sections, contingency theory will be presented followed by the introduction of management control systems (MCS).

2.3.1 Contingency Theory

Contingency theory remains to date the core explanatory theory of organizational structure [DONALDSON 1999, p. 69]. Contingency theory considers organizations as open systems in relation to their environment. In contrast to cybernetics and systems theory, it draws conclusions based on empirical studies which are based on the positivist research approach [JACKSON 2000, p. 110]. Contingency theory rests on four main ideas [MORGAN 1997, p. 44]:

1. Organizations are open systems that need careful management to satisfy and balance internal needs and to adapt to environmental circumstances.
2. There is no best way of organizing. The appropriate form depends on the kind of tasks or environments with which one is dealing.
3. Different approaches to management may be necessary to perform different tasks within the same organization.
4. Different types or "species" of organizations are needed in different types of environments.

The empirical research conducted within these ideas branched out into two main streams. The first stream studied the impact of the environmental factors and uncertainty into the organizational variables such as structure, performance, efficiency, communication, etc. (see for example [BURNS & STALKER 1961, MILES et al. 1974, MEYER et al. 1985]). The second stream was concerned with defining and measuring environmental variables or factors, such as complexity, turbulence and uncertainty (see for example [DOWNEY & SLOCUM 1975, MILLIKEN 1987]).

In particular, the first stream of empirical research gave very interesting results. For example, BURNS & STALKER for the first time empirically showed that as the environment is more volatile, the organizations need a more flexible organizational structure and more flexible type of management [BURNS & STALKER 1961]. In contrast, when the environment is more stable, a bureaucratic and rigid structure and management is more advantageous. It can be concluded from this study that the mechanistic organizational structure is more suitable for stable environments, whereas the organismic structure is more suitable for volatile environments. Even different organizational subunits have to be designed differently from each other since they are attached or have connections with different subparts of the environment [LAWRENCE et al. 1967]. As a conclusion, the authors state that the performance of an organization is related to the differentiation of the subunits based on the volatility of their corresponding environmental subparts, and the integration of these subunits based on the dynamics of overall environment [LAWRENCE et al. 1967].

Contingency theory sees an organization as an open system consisting of subsystems. Each of these subsystems has a function to fulfill and proper functioning of these subsystems ensures viability of the organization. JACKSON claims that contingency theorists cannot fully agree on what subsystems should be singled out as critical [JACKSON 2000, p. 110]. For example, he points out technical subsystem, the size of the organization, environment, and managerial subsystem as the most important subsystems that ensure viability. In contrast, FISHER provides other contingency factors (he names them contingency variables – note from author) as important: uncertainty, technology and interdependence, "industry-firm-unit" variables, competitive strategy and mission, and observability factors. At the core of modern day contingency theory is the influence of these contingency factors in the structure and design of organizations. Consequently, the contingency theorists strive to understand how the structure of the organization is related to these contingency factors. The alignment of the organizational structure with the contingency factors has been an important subject of study of contingency theorists as it is of particular interest for managers. As PARKER & WITTELOOSTUIJN argue, "(…) in the early contributions, the key logic was that particular internal features of an organization, such as its processes, structures, or technologies, are best suited to particular types of environment or contingencies such as complexity, dynamism, and uncertainty" [PARKER & WITTELOOSTUIJN 2010, p. 540].

In recent times it became obvious to contingency theorists that processes, structures and technologies exist in a symbiotic relationship in an organization and therefore, they have to be observed as a single system. To explain what is meant with symbiotic relationship, consider an operational process within the organization where most of the value is generated (the value chain). This process has a certain structure – people, machines, material-energy-information flowing between them. These processes are very important for the viability of the organization, therefore it is of particular interest that they run efficiently. To achieve this, organizations superimpose other processes which control the operational process – the management (control) processes. This is usually done as in Figure 2-3, which means that a control system with feedback loop(s) are employed. Needless to say, the management processes become part of the whole system, hence changes the structure of the overall system (organization). In literature, these control systems are referred to as management control systems (MCS). Looking at the processes, structure and communication in this way, it became obvious to the contingency theorists that they have to analyze the fit of the organizations not as simple unconditional association among contextual variables (congruent proposition of fit) but as conditional association of many contextual variables (contingent proposition of fit) [FRY & SMITH 1987, p. 117].

2.3.2 Management Control Systems

As described in the previous section, management controls are used to align the organization with contingency factors in such a way that the performance of the organization is increased and the viability is ensured. What is meant with management controls however can lead to a great deal of confusion. First of all, in literature the concept of management controls and management control systems (MCS) is used often synonymously. For example, CHENHALL does not make any distinction between management control and MCS, but refers to both as MCS [CHENHALL 2003]. He further states that the terms management accounting, management accounting systems, organizational controls and management control systems, are used interchangeably [CHENHALL 2003, p. 129].

The other source of confusion is the word "control". A big part of the literature on MCS comes from accounting studies, where the term control is used for describing the mechanisms or processes for monitoring and supervision of operational or managerial performance. OTLEY for example agrees that in the past "(…) management control became largely synonymous with management accounting" [OTLEY 1999, p. 364]. Therefore he suggests a broader definition of the MCS by looking beyond the **measurement** of performance to the **management** of performance [OTLEY 1999, p. 364]. He further argues that management control as seen from accounting studies neglects the issue of overall well-being and viability of the organizations. Other authors share the same perspective on MCS as OTLEY. For example, MACIARIELLO & KIRBY 1994 define MCS as " (…) a set of interrelated communication structures that facilitate the processing of information for the purpose of assisting managers in coordinating the parts and attaining the purpose of an organization on a continuous basis" [MACIARIELLO & KIRBY 1994, p. 38]. They also do not distinguish between management control and MCS, but they emphasize the fact that contemporary MCS have to provide the organizations the ability to adapt to changing environments. In other words, MCS must be designed to handle situations that are not known at the time of their design [MACIARIELLO & KIRBY 1994, p. 40]. In the same manner, MERCHANT & VAN DER STEDE define MCS as any type of mechanism or technique employed by managers to make sure the strategic goals of an organization are achieved or changed when it is required [MERCHANT & VAN DER STEDE 2012, p. 5]. Based on these definitions, it can be inferred that MCS are vital for the viability of organizations in volatile environments.

The most appropriate theoretical model for studying MCS is the cybernetic perspective [MACIARIELLO & KIRBY 1994, p. 40]. The cybernetic paradigm sees MCS as management control processes that use negative feedback loops (as shown in Figure 2-3) and are of processes that ensure: setting goals, measuring achievement, comparing achievement to goals, feeding back information about unwanted variances into the process to be controlled, and correcting the process [HOFSTEDE 1978, p. 451]. Hofstede reports that "(…) a review of nearly 100 books and articles on management control theory issued between 1900 and 1972 reflects entirely the cybernetic paradigm" [HOFSTEDE 1978, p. 451].

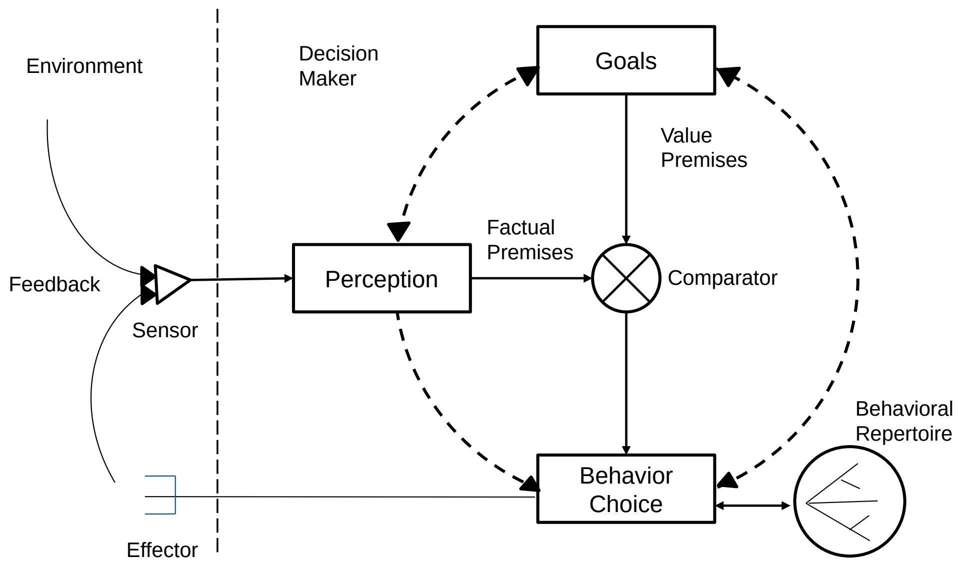

Figure 2-7: The cybernetic paradigm of the control process in organizations [MACIARIELLO & KIRBY 1994, p. 42]

Based on Figure 2-7, MACIARIELLO & KIRBY describe the cybernetic perspective employed in MCS [MACIARIELLO & KIRBY 1994, p. 42-44]. Managers receive data from the environment through the **sensors** of the organization. From the environmental data received, they create an image of the state of the environment (**factual premises**) through a cognitive process denoted as **perception**. The factual premises are then compared to the **value premises** (derived from organizational **goals**), which represent the desired states of the organization (cf. Figure 2-3). The comparing process is depicted with the comparator in Figure 2-7. If a difference between the factual premises and the goals is observed, the managers choose a measure (**behavioral**

choice) to align these two from a set of action courses denoted as **behavioral repertoire**. The behavioral choice is then implemented or realized through an **effector**, which serves as a change agent. The effects of the action are sensed by the sensor, a process called **feedback** (see section 2.2.2). If the action closes or reduces the gap between factual premises and the value premises then it can be again utilized in the future for similar situations. If the action does not reduce or close the gap, a new behavioral choice is identified and implemented through the effector. This process is repeated until the goals of the organization are reached.

Further, MACIARIELLO & KIRBY describe a very important concept related to MSC – the control process hierarchy. They start with the assumption that an organization consists of more than one responsibility center and therefore, the cybernetic perspective should include the "superior – subordinate" levels of control [MACIARIELLO & KIRBY 1994, p. 45]. The goals, they further clarify, are passed from the superior to the subordinates, who have to devise means to meet these ends. These means become a basis for more detailed means in the lower subordinate level and so on (see Figure 2-8).

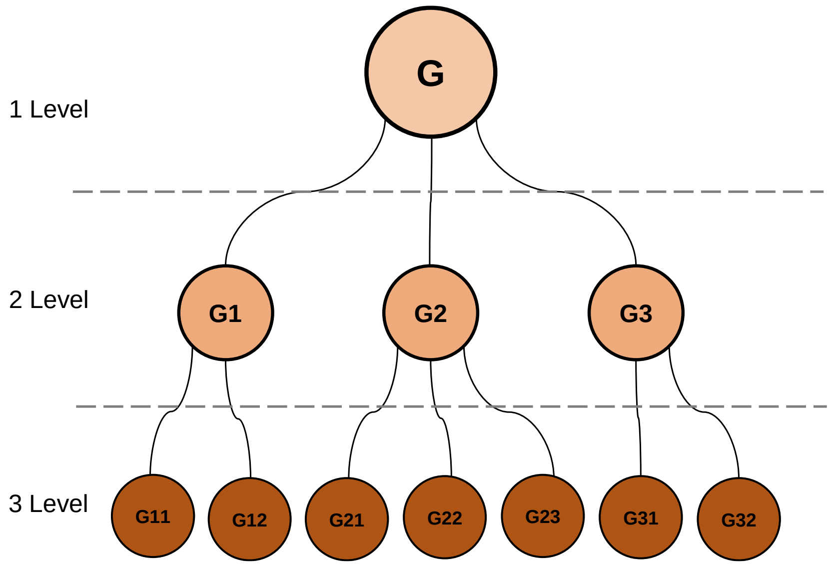

Figure 2-8: Means-end goal hierarchy of goals [MACIARIELLO & KIRBY 1994, p. 46]

This hierarchy of control process manifested through goals and sub-goals appears to assume the recursive character of MCS (as the viable system model (VSM) - see section 2.2.5). The superior goal in the VSM could be the viability of the organization, whereas the immediate subordinate goals could be specific sub-goals that ensure the viability of the organization in the particular recursion level. These subordinate goals are then divided into smaller goals, which can be assigned to lower-level managers. This implies that the decision-making in large companies has to be delegated to different levels of the organization and they all contribute to the viability of the organization. Further, this assumes that particular parts of the companies need to have their autonomy in operations in order to reach the goals assigned to them and thus support the viability of the overall organization. The hierarchical architecture is very important to complex systems such as organizations. In this regard, SIMON states: "(…) we could expect complex systems to be hierarchies in a world in which complexity had to evolve from simplicity. In their dynamics, hierarchies have a property, near-decomposability, that greatly simplifies their behavior." [SIMON 1962, p. 482]. He further clarifies that "(…) most of the complex structures found in the world are enormously redundant, and we can use this redundancy to simplify their description. But to use it, to achieve the simplification, we must find the right representation" [SIMON 1962, p. 481]. As seen in section 2.2.5, this representation could be the VSM, since it exhibits the recursive property which is required to host such a hierarchy of control processes.

In this thesis, MCS that are embedded into core activities and processes of engineering companies (as presented in subchapter 1.2), such as total quality management (TQM), just in time (JIT), variant management and engineering management, are the focus of the research. MCS of different scopes are a subject of this research, ranging from a company-wide "management" philosophies such as management-by-objectives to smaller techniques such as built-in-quality (BiQ). As this thesis focuses in management of performance for enhancing viability, the management accounting systems and accounting controls are not a subject of this research.

2.3.3 Design of Management Control Systems

As mentioned previously, one of main research topics in contingency theory is a body of empirical studies that deal with the performance of different configurations of organizational structures in changing contingent factors (environment, technology, size, culture, strategy, etc.). Therefore, it is to be expected that contingency theory is a provider of studies on how MCS should be designed. MERCHANT & OTLEY in their literature review study paper on control and accountability state that "(…) although the main categories of contingency have been reasonably well established, there has been relatively little progress either in specifying what the appropriate responses to uncertainty should be or in outlining the appropriate design for MCS operating in different conditions" [MERCHANT & OTLEY 2008, 787]. As can be inferred from the quote, the literature lacks generally accepted procedures or guidelines on MCS design. Case specific MCS designs, however, are abundant in literature (see for example [FAUZI 2009, DAVILA 2000]). What comes closest to MCS design are frameworks for understanding MCS. These frameworks explain the objectives, role and constitution of MCS and provide general design recommendations that do not represent design procedures per se, but rather important suggestions and indications for MCS design. The selection of the frameworks for analysis in the descriptive study of this thesis is done based on a recent study by STRAUß & ZECHER where most influencing contemporary MCS frameworks are identified [STRAUß & ZECHER 2013, p. 240]. These frameworks include works of [ANTHONY & GOVINDARAJAN 2007, MERCHANT & VAN DER STEDE 2012, SIMONS 1995]. All these frameworks recognize inherently that there are two types of controls: controls for directing (managing) subordinates in their activities which includes personnel and cultural controls, and the cybernetic controls that include action and results controls. From this perspective, all three most influential frameworks are consistent with each other. In this thesis, a focus will be placed on Simons' framework, since it is oriented more on providing a functional description of the MCS constituents. As it will be shown in subchapter 3.4, this way of describing MCS is more appropriate for conceptualizing the MCS design from systemic perspective. Therefore, in this section, Simons' framework will be introduced, whereas a more comprehensive description is provided in subchapter 3.4.

SIMONS introduced one of the most influential MSC frameworks [SIMONS 1995]. In his framework, four levers of controls as part of MCS that need to be in equilibrium are described: belief systems, boundary systems, diagnostic control systems, and interactive control systems. SIMONS defines belief systems as "(…) explicit set of organizational definitions that senior managers communicate formally and reinforce systematically to provide basic values, purpose, and direction for the organization" [SIMONS 1995, p. 34]. Boundary systems are a set of boundaries for action to organization's stakeholders, which means that they set limits to what should be done based on the trade-off between business risk and opportunity [SIMONS 1995, p. 39]. The diagnostic control systems are feedback systems that "(…) are designed to ensure predictable goal achievement" [SIMONS 1995, p. 59]. Their main purpose is to monitor organizational undertakings and correct deviations from established standards (see Figure 2-9).

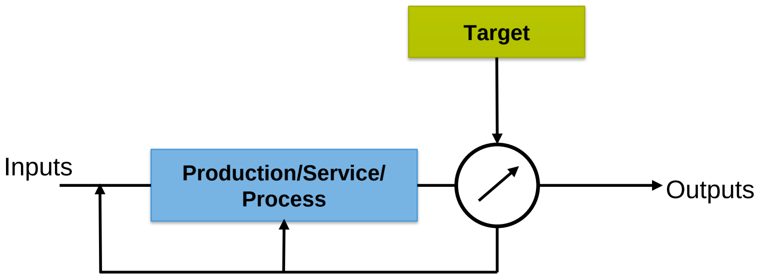

Figure 2-9: Diagnostic control systems [SIMONS 1995, p. 60]

SIMONS also provides a list of typical diagnostic control systems that follow this cybernetic logic (see Table 2-4).

Table 2-4: Typical diagnostic control systems [SIMONS 1995, p. 61]

Diagnostic Control Systems
Goals and objectives systems
Business plans
Profit plans and budgets
Expense center budgets
Project monitoring systems
Brand revenue/market share monitoring systems
Human resource plans
Standard cost accounting systems
Management-by-objectives systems

Based on Figure 2-9, it can be inferred that SIMONS' diagnostic control systems viewed from a cybernetics perspective are closed-loop control system (described in section 2.2.2). As such, these systems are not self-referential, which means they cannot adapt to environmentally or internally induced changes. Therefore, SIMONS proposes the fourth and the last lever of control – the interactive control systems. He defines them as "(…) formal information systems managers use to involve themselves regularly and personally in the decision activities of subordinates" [SIMONS 1995, p. 95]. He further clarifies that interactive control systems are, among others, used to support the bottom-up emergence of strategy [SIMONS 1995, p. 98] by continuous re-estimation of future states and consideration of how to best react. Hence, interactive control systems are not only concerned with forecasting but also with linking forecast to action [SIMONS 1995, p. 123]. All these four levers of control should be designed in a flexible manner since they are supposed to change in the course of time and need to be adjusted to environmental and internal changes [SIMONS 1995, p. 152].

To summarize, SIMONS does not provide a step-by-step guideline on how the MCS should be designed, but rather gives design considerations that are merely abstract and based on best practices. TESSIER & OTLEY for example state that the concept of four levers is being criticized for being vague and contains ambiguous definitions [TESSIER & OTLEY 2012, p. 171]. Because of this, the four control lever framework of SIMONS is widely cited in the scientific literature but its application in MCS design is limited.

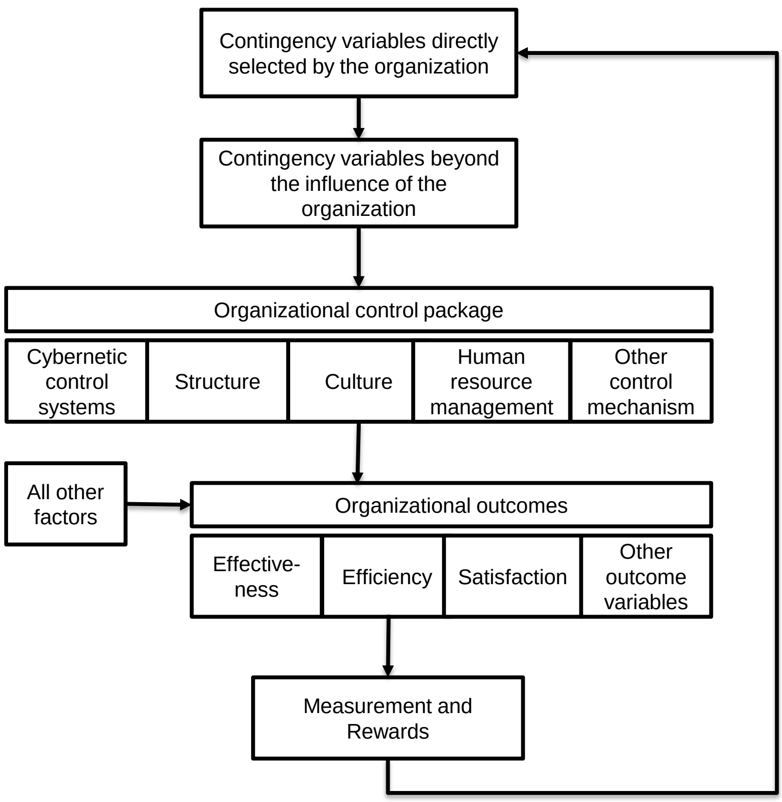

Figure 2-10: Contingency control framework [FISHER 1995, p. 33]

FISHER is another author who provides a framework for the design of MCS that is based on SIMONS' framework [FISHER 1995]. In this framework, consistent with SIMONS' framework, the cybernetic controls are just a part of the overall control package. The top two boxes in Figure 2-10 represent the contingent factors faced by the organization. Based on these factors, the organization selects a control system (or a few of them) represented in five boxes. From the contingency theory literature (see section 2.3.1) it is known that the fit between contingent factors and the organization control package will most likely result in the desired outcomes (more efficient operations, for example). The outcome is then measured and the results are fed back to entities that adjust strategy and make operational decisions [FISHER 1995, p. 32-33]. This framework implies that organizational control should be evaluated as a package (rather than separately) since "(…) there may be complementary and substitution effects among its components" [FISHER 1995, p. 33]. In this way, FISHER makes an important point in emphasizing the importance of taking holistic view on MCS.

Design of MCS as a package is still an open research topic in MCS literature. Most authors agree that MCS should be designed holistically rather than separately because of the interconnection and overlap (see for example [MALMI & BROWN 2008]). In this regard, MALMI & BROWN state that "(…) while studies have looked at control systems individually and at times in combination, the challenge is to understand how all the systems in an MCS package operate as an inter-related whole" [MALMI & BROWN 2008, p. 288]. This appears currently in the literature to be one of the most challenging tasks in the design of MCS.

2.4 Summary and Conclusions of the Theoretical Background

In this chapter basic concepts were presented that are necessary to understand the next parts of this thesis. Focus in this chapter was in three pillars that constitute the areas of relevance and contribution for this thesis as suggested by design research methodology (DRM) [BLESSING & CHAKRABARTI 2009, p. 63].

In the first subchapter, systems thinking in organizations was introduced. The theoretical basis of systems thinking was described and basic definitions and concepts from this theory were introduced. Cybernetics as an important part of systems theory for this thesis was also introduced and the differences between first and second order cybernetics were highlighted. Next, systemic perspectives on organizations were reviewed and different paradigms stemming from systemic metaphors were described. These paradigms help in understanding the organizations as complex systems.

In the second subchapter, a review of management cybernetics (MC) was provided - a topic that serves as conceptual underpinning of this thesis. Basic definitions and concepts of MC were provided and a special focus was paid to the most prominent model of management cybernetics – the viable system model (VSM). VSM represents a functional structural model for viable organizations that are capable of learning and adapting to dynamically changing environment. As such, the VSM is the core reference model to be utilized in the prescriptive study of this thesis.

Third subchapter provided another important perspective on organizations, the contingency theory. This theory rooting from organizational theory is one of the most important approaches for studying organization. In essence, it is an empirical study that strives to understand how contingency factors influence the structure of an organization. Consequently, most efficient organizations are the ones that have the best fit between the contingency factors and their organizational structure. In this sense, the structure of the organization is changed by introduction of management control systems (MCS) which leverage this fit. Therefore, further in this subchapter the MCS were introduced. Next, the most important frameworks for understanding MCS were identified and an exemplary framework was described.

As a conclusion of this part of descriptive study, it can be stated that systems thinking provides very powerful perspectives on organizations as complex systems. As contemporary organizations are operating in highly dynamic environments, the VSM perspective from MC is of particular interest because it provides an insight into the necessary organizational functions that enable adaptability to environmental and internal influences. The research in organizational theory went instead in another direction. Contingent theorists were interested to find out empirically how the contingent factors influence the organizational performance. In these efforts, they found out that MCS play a very important role to adjust the organization into what they refer as "contingency fit" (see section 2.3.1). According to FISHER there are two types of management controls: controls for directing (managing) subordinates in their activities, and the cybernetic control. However, many authors state that the cybernetic control represents the "core" functionality of the management control systems. In this regard, GREEN & WELSH state that "(…) it is our position and the position of other authors (e.g., AULIN 1982, BEER 1959, WIENER 1967) that cybernetics is the basis of control in any system and, thus, the foundation on which any definition of organizational control must rest" [GREEN & WELSH 1988, p. 289].

Initially, MCS were regarded as passive tools designed to assist managers' decision making [CHENHALL 2003, p. 129]. This means, that the MCS were regarded as simple feedback control systems as shown in Figure 2-3. OTLEY points out that this way of looking into MCS is misleading and harmful, since the contemporary organizations are subject of considerable dynamics and uncertainties [OTLEY 1994, p. 294]. He further states that "(…) it is arguably incumbent upon the manager to be continually reformulating strategy to match the environment being faced, and to monitor the implementation of corrective actions at an operational level" [OTLEY 1994, p. 294]. This means that MCS besides having the ability to monitor the fulfillment of the goals set by the management and act correctively in case it is required, they must have the ability to autonomously change objectives, goals and even strategies in order that the organization adapts to the environment. However, despite the recognition that MCS should contain this ability, there is a lack of detailed guidelines on how such MCS should be designed. In the contemporary literature, there are only few frameworks that help in understanding MCS, but are of little support for actual design of MCS (refer to section 2.3.3).

MC in contrast, studies the ability of systems to survive in changing environments (viable systems) in meta-systemic sense. There is a well-established model described in section 2.2.5 (VSM) that incorporates all the functions necessary for adaptation to environmental changes. Therefore, it can be concluded that the cybernetic perspective in MCS is not fully absorbed in

MCS literature, as the VSM can provide much more than just the simple homeostatic regulation.

Therefore, in the next chapter, a deeper look will be given to the contemporary employment of VSM and on what basis this model could support the design of MCS.

3. Relationship between Viable System Model and Management Control Systems

This chapter represents the transition between the first descriptive study and the prescriptive study of this thesis. The objective of this chapter is to enquire whether the VSM as a functional-oriented meta-systemic model, which contains all the necessary functions for adaptability of the organization can support the design of contemporary MCS. The focus is in engineering MCS that support mainly technical strategic management objectives, such as quality, operations effectivity and efficiency, shorter time to market and so on. To achieve this, the chapter starts with an overview of the VSM's contemporary applications and continues with the main challenges of VSM application in organizational settings. Next, the main challenges in MCS design are identified and the functional relationship between VSM and one of the most popular MCS design frameworks [SIMONS 1995] is established. Based on this analysis, a closer look into MCS in engineering companies is provided and the possibilities for VSM support to typical engineering MCS are derived.

3.1 An Overview of VSM Applications in Organizational Settings

As described in section 2.2.6, the VSM is used as a theoretical underpinning for methodologies for design and diagnosis of complex organizations, strategy development and as a framework for intelligent organizations. Numerous application of the VSM-based methodologies were proposed over the past decades. These applications cover a variety of organizations in sizes and industries as well as governmental and public institutions. In the following, a selection of these application efforts is shown.

ESPEJO & HARNDEN highlight several, mostly descriptive and diagnostic applications of the VSM to organizations such as manufacturing firms, television networks, a national trade training network and an educational medical facility [ESPEJO & HARNDEN 1989]. In some of these case studies, they provide prescriptive advice aiming at implementation of improvement measures that are derived from the diagnostic analysis (a validation of these efforts was provided in only one case study, though). WALKER utilizes the VSM as a basis for radical restructuring of a large cooperative, which resulted in a profitable and growing cooperative with increased adaptive capacity compared to the original state [WALKER 1990]. SEARA applies the VSM for restructuring purposes at a major Brazilian mining company for aligning it with a viable organization structure [SEARA 1993]. The successful restructuring resulted in increased operational capability, according to a post-restructuring validation study. BROCKLESBY & CUMMINGS analyze a telecommunication corporation from New Zealand and suggest a transformation of the corporation's structure to correspond to the environmental variety it faces [BROCKLESBY & CUMMINGS 1996]. SCHWANINGER introduces five case studies that demonstrate the power of the VSM as a diagnostic tool in five different organizations. One of these case studies involved a large Swiss insurance company that was restructured based on the VSM. The restructuring was identified as a key to increased success in an evaluation study performed twenty years after the implementation [SCHWANINGER

2006]. Further applications focused on strategic development, redesign of companies' management systems and cohesion between subsets of a large organization. Long-term success of the applications was validated by SCHWANINGER, making a strong argument from the industrial side for the VSM's suitability for organization-wide analysis and redesign. BURGESS & WAKE apply the VSM to small- and medium-sized enterprises and show that analysis based on the VSM can yield valuable insights not only in large and complex organizations [BURGESS & WAKE 2012]. ESPINOSA & WALKER introduce the VSM in an eco-community as a tool for self-reflection, learning and improving communication structures, and task distributions. The desired effects were achieved as the community established autonomous management, adaption and optimization [ESPINOSA & WALKER 2013]. PÉREZ RÍOS et al. display an application of the VSM to university urban planning, helping top-level managers to structure the university urban planning in terms of the complexity it is facing as well as helping to define identity and policy that support cohesion of the complex and geographically distributed organization [PÉREZ RÍOS et al. 2012]. MURAD & CAVANA demonstrate applicability and use of the VSM in project management context through several applications in information and communication technology projects. The VSM was used as a diagnostic tool for potential weaknesses in project functions and communication, offering to their managers a holistic view on complex information communication technology projects [MURAD & CAVANA 2012]. The VSM was also applied recently in the field of disaster response, where the application of the VSM is deemed as useful for identifying generic gaps and opportunities for disaster response communication systems [PREECE et al. 2015]. The case studies in this work indicate that the VSM's structure can be a very useful reference in designing the communication channels in rapidly changing environments. RICHTER & BASTEN 2014 identify thirteen VSM applications in information systems research and state that in all these applications, the practitioners gained a new perspective on common information systems problems and they conclude that VSM application is becoming an upcoming trend in this research field [RICHTER & BASTEN 2014]. Similarly, there is a trend in using the VSM as a diagnosing tool in supply chain (see for example [SHOUSHTARI 2013, HILDBRAND & BODHANYA 2014, BADILLO et al. 2015]) and strategy implementation [ESPINOSA et al. 2015].

The selection of VSM applications provided above is far from exhaustive. However, it gives an impression of how the VSM is applied in different industrial settings. It can be seen that the main contribution of the VSM in industry and governmental organizations is to diagnose existing or to design new organizations by aligning the real-life structure of the organization with the structural characteristics all viable systems share. It can be also seen that its strength to address contemporary management challenges such as complexity, learning and adaptability has gained importance in recent years [ELEZI et al. 2014a]. As GOULD states, "Probably the single most important thing about Beer's work is that it anticipates much of the current fascination with chaos, complexity and the need for rapid strategic adjustments to environmental changes" [GOULD 1999].

Despite these benefits, the VSM is still not widely used among management practitioners. It is seen as an "exotic" management concept, and it failed to enter the management research mainstream – especially in its industrial application [PFIFFNER 2010, p. 1615]. The next subchapter addresses this problem by describing the challenges that the VSM applications in real-life organizations face.

3.2 Challenges in VSM Application

Literature research reveals several challenges that VSM research and especially its application in industry faces. Some of these challenges relate to systems thinking models in general, while some other specifically relate to the VSM. In this subchapter, the general systems thinking challenges will be presented first, being followed by VSM-specific challenges.

A major challenge is that the VSM is difficult to understand in the first place because of its comprehensive and relatively complex underlying theory. ANDERTON states that managers find it difficult to fully grasp the underlying theory (cybernetics and management cybernetics) and therefore do not succeed with applying VSM in practice [ANDERTON 1989]. As a consequence, there have been attempts to clarify how the application of the VSM (in particular VSM diagnostics) can be performed in practice (see for example [BEER 1985, BRITTON & MCCALLION 1985, PÉREZ RÍOS et al. 2012, HILDBRAND & BODHANYA 2014]). This need for clarification exists not only with the VSM, but in general with all holistic models stemming from systems theory [POUVREAU 2013]. In the same manner, ACKOFF states that there are two most important reasons why organizations do not adopt systems thinking [ACKOFF 2006, p. 1]. The first reason is that organizations in general oppose any transforming idea, let alone systems thinking. The second reason relates to managers having little to no knowledge or understanding about systems thinking [ACKOFF 2006, p. 6].

These observations by ACKOFF lead to another challenge. Namely, VSM diagnostics (and other systemic approaches too) imply transformations often involving deep working culture changes that clash with the traditional way of doing business. Therefore, it is hard to find managers who are able and willing to lead and take the responsibility for such transformations in their companies. It simply bears too much risk for any reasonable person. In addition, these transformations are more difficult to conduct in large corporations, because of lack of transparency and understanding of structures and interrelations due to their complexity. This often leads to failure of embracing systems thinking.

When reviewing practical applications of the VSM in literature, it can be inferred that most of the authors consider the VSM as a powerful diagnostic tool in different application contexts. According to PFIFFNER, however, these publications only marginally touch the practical experiences that result from real application of the VSM – although significant application experience is claimed [PFIFFNER 2010, p. 1615]. Therefore, it is extremely difficult for practitioners who do not have sufficient knowledge of the VSM to rely on these publications as a guide for their own application efforts.

Several authors criticize applicability of VSM for not being attentive to social aspects of organizations (see for example [CHECKLAND 1980]). Basis for this criticism is the functionalist paradigm on which the VSM is based that limits it to tackle other important issues of purposeful organizations (see section 2.1.5). As such, the VSM is designed to what VICKERS refers to as circular feedback control processes that support organizations in reaching their objectives [VICKERS 1967]. However, VICKERS further emphasizes that in organizations these objectives are continuously changed as a result of social interaction between the human actors, who often have conflicting perceptions of what represents an objective in an organization. As a consequence, the applicability of VSM in organizations is limited only to organizational design based on the functional model but stripped from social context. In addition, many practitioners believe that the VSM neglects the power struggle within organizations (a consequence of an organization being purposeful system). In this regard, JACKSON states: “(…) in practice, the model (VSM – note of the author) can easily be turned into an autocratic control device serving powerful interests” [JACKSON 1988, p. 570]. Due to the VSM’s inability to tackle these interpretative and emancipatory issues in organizations, many managers hesitate to apply it to their organizations. Researchers have acknowledged this disadvantage, therefore in addition to the VSM they recently started using other systems approaches to tackle the social issues [see for example SHOUSHTARI 2013].

In section 2.2.5 it was stated that the VSM incorporates functions and communication channels that are necessary and sufficient for a system to be viable. While this might be true, there are other requirements to applying the VSM in real life that need to be met in order to ensure the viability of organizations. One of these requirements is the delay in communication channels or in decision-making, which can cause unpredicted organizational behavior, possible seriously jeopardizing viability. System dynamic modeling shows in these cases how delays affect the responsiveness of a system. The effects of delay and other factors important for viability are tackled in [ELEZI et al. 2013]. An overview of these factors are provided in the extended outlook chapter of this thesis.

3.3 Challenges in Design of Contemporary Management Control Systems

In section 2.3.2, initial research on MCS has shown that most literature focuses around the performance measurement. This is because most of the literature on MCS originates from accounting studies, where the term control is used for describing the mechanisms or processes for monitoring and supervision of operational or managerial performance. Since the early 1990’s, it has been recognized that organizations face extremely dynamic and uncertain market conditions, hence a broader framework for MCS is required. The contemporary MCS incorporate not only operational control, but also strategic planning, since in such dynamic and uncertain market conditions revision of strategies should be performed frequently in order to respond effectively to the changing environment [OTLEY 1994, p. 294]. This requires that managers monitor the corrective measures undertaken at the operational level as results of strategy revisions. This enhanced framework is widely recognized by contemporary MCS researchers, who define MCS as mechanisms that enable continuous adaption to changing environmental conditions (see definitions of MCS in section 2.3.2). As already mentioned in section 2.3.3, the contemporary MCS frameworks view MCS as systems comprising of two main parts: (1) controls for directing (managing) subordinates in their activities, which include personnel as well as cultural controls, and (2) cybernetic controls that include action- and result controls. However, it should not be understood that these two types of controls exist separately from another within MCS. Quite the opposite, these controls are interconnected and complement each other to reach the ultimate goal of MCS, which is to ensure that the employees do what is best for the organization by encouraging desirable behavior and by guarding against undesirable behavior [MERCHANT & VAN DER STEDE 2012, p. 8]. This way of looking into MCS implies that there are cybernetic and social structures which constitute MCS. The cybernetic structure represents "what needs to be done" in the sense that employees know what is best for the organization, while the social structure encourages that desirable behavior of the employees.

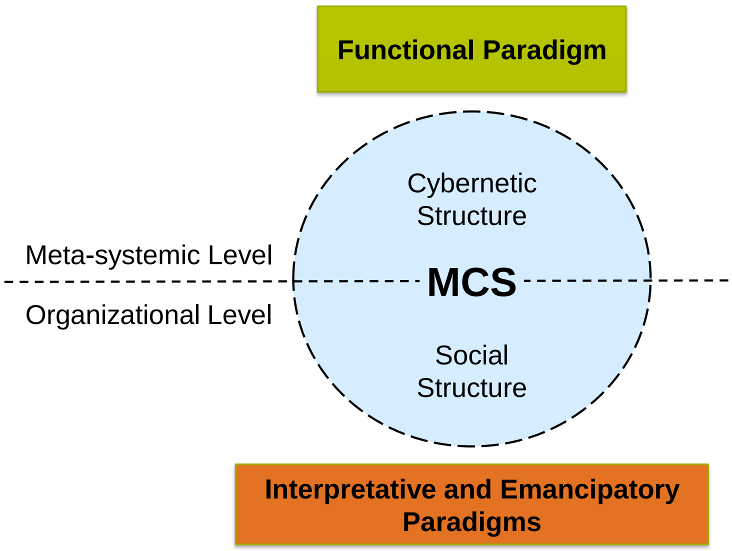

Figure 3-1: MCS main parts with corresponding systemic paradigms

In Figure 3-1 these two main structures of MCS are depicted in a simplistic manner. In reality, these structures are intertwined and a complex relation exists between their substructures. From a systemic perspective, the cybernetic structure can be designed and analyzed by functionalist paradigm. It basically represents a model of MCS that shows what needs to be achieved functionally so that the MCS represents a good controller (see section 2.2.3 for the definition of a good regulator). In contrast, the social part, should ensure that this functionality is achieved in organizations as social systems that involve humans and teams with different purposes and goals. For this part of MSC, interpretative and emancipatory paradigms are appropriate (see section 2.1.5). ANTHONY [ANTHONY 1965] was referring to cybernetic structures when he was trying to find a control process that is common to all organizations no matter the industry they are part of [OTLEY 1994, p. 294]. This structure corresponds to what the contemporary MCS frameworks refer to as control feedback systems (see section 2.2.2) which inherently every MCS must contain. The cybernetic structure on the one hand is a meta-systemic structure across all MCS in all types of organizations. The social structure on the other hand is context specific and has to be analyzed or designed at the organizational level. Because of this property of the cybernetic structure, most of contemporary authors see cybernetics as the most important perspective for designing MCS [MACIARIELLO & KIRBY 1994, p. 40]. The traditional way of designing the cybernetic structure is the homeostatic control system which seeks to maintain the states of controlled parameters within desirable boundaries while prone to the influences of a changing environment – this is what SIMONS refers as diagnostic control system [SIMONS 1995, p. 59-90]. The diagnostic control systems do not contain mechanisms that provide adaptability by changing the MCS itself as a result of continuous strategic reformulation – a task which organizations operating in dynamic environments need to perform in order to be viable (as discussed in the beginning of this subchapter). Therefore SIMONS introduces three control systems in addition to the diagnostic control system, that altogether enable continuous re-estimation of the competitive environment and enable identifying and selecting the best possible measures to ensure the viability [SIMONS 1995, p. 91]. He explicitly states that these three constitutive parts of every MCS (belief, boundary and interactive control systems) are not cybernetic controls but rather information systems that stimulate search and learning, allowing new strategies to emerge based on perceived opportunities and threats [SIMONS 1995, p. 91]. This contradicts the conclusions reached in subchapter 2.2, where management cybernetics is described as the field of study that analyzes cybernetic structures - including those structures necessary for the viability of the organizations. Since the VSM is the management cybernetics' most prominent model for viable organizational structuring, it seems logical to compare how the VSM relates to contemporary MCS understanding. The objective of this comparison is to determine whether VSM can serve as theoretical underpinning for design of cybernetic structures of MCS. This is a necessary step in order to expand the current use of "cybernetic structures" as only homeostatic controls as prescribed by contemporary MCS frameworks. It should be noted, that the first indication of the usefulness of the VSM perspective in understanding the MCS is already described in [O'GRADY et al. 2010]. In this thesis however a formal functional analysis is performed to reach a conclusion about the applicability and usefulness of VSM perspective in MCS.

3.4 Functional Comparison between Management Control Systems and Viable System Model

In order to facilitate the discussion about the relationship of MCS design to systems thinking, the MCS design framework described by SIMONS will be used [SIMONS 1995], because most of other contemporary frameworks contain the same ideas and (functional) requirements for MCS. Therefore, from the research methodology perspective, no downgrade of the analysis' validity is caused. The analysis will be performed on functional level and the producer-product view is adopted (see section 2.1.4). Hence, in the beginning of this subchapter, the definition of a function (in organizational sense) will be provided.

According to ACKOFF & EMERY, the term *function* is a generic concept in systems thinking, same way as *structure* is [ACKOFF & EMERY 2005, p. 26]. SCOTT defines the term function as the way in which a component of a subsystem contributes to the existence and the adaptability of the system [SCOTT 1981, p. 84]. The components of a subsystem in an organizational context can be individuals, groups or whole departments. Therefore, they present a certain *structure* of the organization, which is defined by GRESOV & DRAZIN as "(…) a pattern of relationships between individuals (or groups – note from the author) that transfers and modifies information and physical objects" [GRESOV & DRAZIN 1997, p. 4]. They further emphasize that the concept of structure and function should not be used as synonyms since a structure can fulfill a function in relation to other structures, but it does not equate to the function [GRESOV & DRAZIN 1997, p. 4]. Another important definition, a *functional class* is defined by ACKOFF & EMERY as a set of structurally different objects or events, which are a potential or actual producer of other objects or events of a specified (structural – note of the author) class of any type [ACKOFF & EMERY 2005, p. 26]. The *structural class* in this definition refers to a set of two or more objects (individuals or groups – note from the author) that have one or more structural properties in common [ACKOFF & EMERY 2005, p. 18].

Table 3-1: Structural classes, functional classes and functions of the VSM

Structural Class	Functional Class	Nr.	Functions
System 5 (S5)	Policy/Values	1.	Define and maintain identity, role and strategic goals of organization
		2.	Define ethos, supreme values, norms and rules for organization
		3.	Receive strategic information from S4 and operational management information from S3
		4.	Decide on what S3-S4 homeostat cannot agree on
		5.	Balance internal and external perspectives
System 4 (S4)	Intelligence	6.	Collect information about environment, monitor environment
		7.	Use and maintain a model of the corporation
		8.	Diagnose environment and organization, anticipate possible future changes
		9.	Plan the future of the organization
		10.	Provide S5 with strategic management information
		11.	Communicate changes to S3, "negotiate" with S3 about actual change implementation
System 3 (S3)	Control	12.	Receive information from S1
		13.	Receive information from / have insights into S2
		14.	Receive audit information from S3*
		15.	Receive strategic change information from S4
		16.	Receive information about goals, identities, instructions from S5
		17.	Decide over necessity of acting/changing
		18.	Communicate limitations to changes to S4, "negotiate" implementation of changes
		19.	Provide S5 with operational management information (event-triggered)
		20.	Instruct/command S1s according to meta-level decisions
		21.	Translate vision, goals, identity from S5 to S1
		22.	Assign goals to each S1 unit
		23.	Negotiate and allocate resources for S1
		24.	Define accountability mechanisms for S1
		25.	Provide synergies between S1s, establish overall optimum
System 3* (S3*)	Audit	26.	Audit operational work of S1
		27.	Validate S3's instructions for S1
		28.	Complement information for controlling purposes of S3 and higher
System 2 (S2)	Coordination	29.	Provide communication medium connecting System 1s
		30.	Transmit information about changes beween S1s
		31.	Amplify self-regulatory capacity of S1s
		32.	Prevent oscillations of S1s, e.g. competing over resources, coordinate S1s activities
		33.	Inform S3 or higher about changes which exceed self-regulatory capacity
		34.	Filter input from S1s into S3
System 1 (S1)	Operations	35.	Produce and deliver company's goods/services
		36.	Autonomously adapt to changes in particular environment
		37.	Optimization of ongoing business
		38.	Communicate with other S1s
		39.	Utilize coordination/communication system provided by S2
		40.	Report status to operational controlling (S3)
		41.	Report "extreme risk" to organizational metasystem up to S5
		42.	Receive corporate instructions from organizational metasystem
		43.	Negotiate resources with S3
		44.	Receive goals from S3

To better illustrate these concepts, the VSM can be taken as an example. As previously defined, the VSM is a function-oriented structural meta-systemic model of viable systems. It comprises five systems that correspond to structural classes. Each of these systems contains a set of functions that together represent functional classes. In Table 3-1, the structural and functional classes, and the relevant functions are provided (extracted from [BEER 1972, BEER 1985, SCHWANINGER 2009, PÉRES RÍOS 2012, SIMONS 1995]). It can be noticed that the functions of the VSM are quite generic because VSM represents a meta-systemic model that is valid for all viable organizations.

When describing the levers of control, SIMONS [SIMONS 1995] provides narrative information (sometimes illustrated with case studies) that allows for identification of the functions as defined in this subchapter. For this purpose, the three chapters describing the belief, boundary, interactive and diagnostic control systems were analyzed and the results are summarized in Table 3-2. Two important updates of SIMONS' framework [FERREIRA & OTLEY 2009, TESSIER & OTLEY 2012] were also taken into consideration for the analysis.

Table 3-2: Structural classes, functional classes and functions of control levers (extracted from [SIMONS 1995])

Structural Class	Functional Class	Nr.	Functions
Interactive Control Systems	Search and Learning	1.	Continuous search and information network to scan the changes in the environment
		2.	Deal with strategic uncertainties and strategic renewal
		3.	Focus attention and force dialogue throughout the organization
		4.	Guide bottom-up emergence of strategy
		5.	Translate to senior managers the vision into the new strategy
		6.	Reforecasting of future states based on the current information
		7.	Trigger the revision of the action plans
		8.	Focus on the process
Diagnostic Control Systems	Predictable Goal Achievement	9.	Monitoring of the critical performance measures
		10.	Achieve goals without constant management oversight (management-by-exceptions)
		11.	Setting and negotiating goals
		12.	Receiving updates and exception reports
		13.	Following up on significant exceptions
		14.	Focus on the outcomes
Belief System	Values and Purpose	15.	Provide basic values, purpose and direction for the organization
		16.	Inspire and guide organizational search and discovery
Boundary System	Constrains	17.	Delineate the acceptable domain of activity
		18.	Communicate the acceptable domain for search activity
		19.	Impose codes of business conduct
		20.	Impose strategic boundaries

It should be noted however, that SIMONS provides in addition instructions concerning social aspects of MCS design, such as how to motivate the stakeholders and how to design incentives. These aspects were included in this analysis since they represent issues tackling the social structures, which is not the focus of this thesis.

By comparing the functions of SIMONS' framework with the VSM functions, several similarities can be observed. Interactive control system have functions that observe the environment in terms of changes, uncertainty and forecasting which correspond to system 4 functions of VSM (functions 1, 2, 6 in Table 3-2 compared to functions 6, 8, 9 in Table 3-1). In addition, translating the vision to the senior management into the new strategy (function 5 in Table 3-2) also corresponds to system 4 function – provide system 5 with strategic management information (function 10 in Table 3-1). Focus attention and force dialogue throughout the organization - is another interactive control system function that corresponds to system 3 and system 4 homeostatic connection. The remaining set of interactive control system functions from SIMONS' framework correspond to system 3 of VSM. These are - guide bottom-up emergence of strategy and trigger the revision of the action plans (functions 4, and 7 in Table 3-2) correspond to system 3 functions – communicate limitation to changes to system 4 and negotiate implementation of changes, and decide over necessity of acting/changing (functions 18 and 17).

The functions of diagnostic control system also overlap with the functions of the VSM. For example, setting and negotiating goals (function 11 in Table 3-2) corresponds to system 3 function – assign goals (function 22 in Table 3-1). Similarly, monitoring of the critical performance measures (function 9 in Table 3-2) corresponds to two system 3 functions – receive information from S1 and S2 (functions 12 and 13 in Table 3-1). Function number 10 in Table 3-2 – achieve goals without constant management oversight (management-by-exceptions) corresponds to the autonomous management part of VSM, which comprises of systems 1, 2 and 3. This is actually the topmost function of the diagnostic control system and in VSM is fulfilled by most of system 3, 3*, 2, and 1 functions. Functions 12 and 13 in Table 3-2 correspond to system 3 functions number 14 and 17.

The functions of belief and boundary systems also overlap with the VSM functions, more precisely – with system 5 functions. These two levers of control transform limitless opportunities into a focused domain that the stakeholders can be encouraged to exploit. In cybernetic language, these two systems attenuate huge variety coming from environment, into a manageable variety that is further transmitted to the rest of an organization – which is exactly the same purpose as that of system 5.

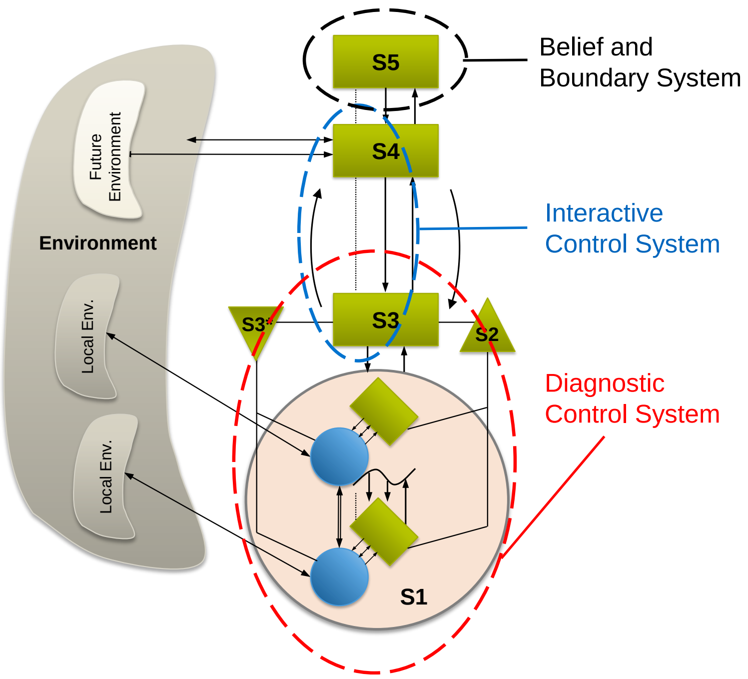

Figure 3-2: Overlapping of control lever functions with the VSM functions

From the comparison performed it can be inferred that the interactive control system overlaps with system 4 of the VSM and partially with system 3. The diagnostic control system overlaps with the autonomous management part of the VSM, namely with system 3, 3*, 2, and 1. And finally, SIMONS' belief and boundary systems overlap with system 5. This outcome is depicted in Figure 3-2.

Besides having similarities, SIMONS' framework also shows differences to the VSM. The main difference lies within the underpinning scientific theories these two approaches are based on. Simons' framework uses contingency theory and general management concepts as its underlying theoretical background, whereas the VSM is based on management cybernetics and cybernetics in general. For example, Simons' framework does not provide much information on how the four control systems communicate with each other. In fact, there is no theoretical support provided by SIMONS in designing the communication channels at all (suggestions are based on best practices). This is extremely important for the viability of the organizations, because this communication enables the emergence of the adaptable behavior of the viable organizations. The VSM contains clear functional instructions on how systems 5 and 4 relate to autonomous management (systems 3, 3*, 2, 1) and the communication channels between them are based on law of requisite variety. Consequently, there are obvious gaps in terms of theoretical underpinning of the SIMONS' framework that make its application in practice very difficult. Such theoretical gap that causes confusion in designing MCS represents for example, the statement that all subordinate managers should engage in the interactive dialogue to the extent demanded by their position [SIMONS 1995, p. 102]. Managers would find this sentence very ambiguous, since they would not be able to set the boundaries of the interactive dialogue based on "extent demanded by their position". This type of ambiguity is present generally in the SIMONS' framework since it is a consequence of hierarchical view on the organization that SIMONS' framework adopts. The hierarchical form of command and control is unnatural to complex evolutionary systems [ESPINOSA et al. 2007, p. 334]. In contrast, VSM as meta-systemic management model is a functional-oriented structural solution to manage complexity in complex systems. As ESPINOSA et al. 2007 clarify "(…) meta-systemic management can provide and distribute information and knowledge required by all to adapt and respond to environmental threats and opportunities, while the model pinpoints the control mechanisms that maximize self-organization at every relevant level, within the overall ethos of the whole" [ESPINOSA et al. 2007, p. 343]. In other words, VSM is a holistic functional representation of control structures that, as it appears, the control systems should be embedded whereas SIMONS' framework describe MCS more as phenomenological control "chunks" in hierarchical organizational structures.

In conclusion, it can be inferred that SIMONS' framework for MCS design and VSM share most of the organizational functions, with the difference that the VSM is a much richer provider of necessary functions and in addition describes functions needed for communication between functional entities. This hints to a very important idea, that the structure of viable systems can be used as the skeleton in which functions of the MCS can be embedded. Being complex systems consisting of cybernetic and social structures, MCS design extends beyond VSM's functional description, and incorporates other systemic paradigms. As shown in Figure 3-1, the social structures of MCS can be analyzed and designed using interpretative and emancipatory systemic paradigms. Therefore, the support that the VSM offers in MCS design is limited only to functional structures of the MCS. As in literature there are no MCS procedures that the author could use as a reference to show in which stage of MCS design this support is possible, Munich Concretization Model (MCM) [LINDEMANN 2009, p. 44-46] is used for this purpose. MCM is primarily developed for describing the design stages for technical products, but it can easily be converted into a model that describes the MCS design stages. In the following, the adapted MCM for this purpose will be presented in order to pinpoint the stage on which the VSM could support the design process of the MCS.

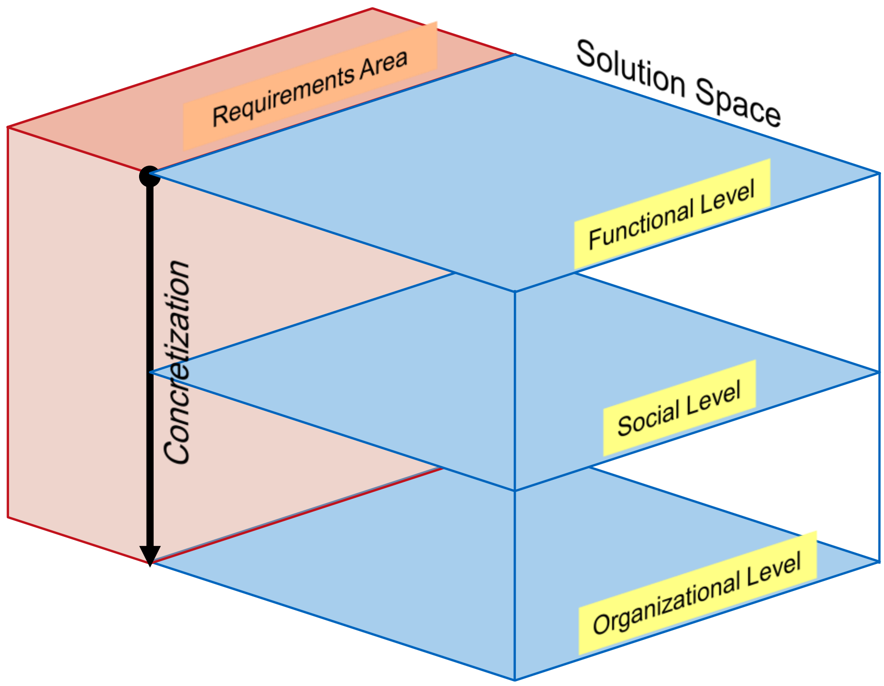

Figure 3-3: Adapted Munich Concretization Model (MCM) for description of MCS design stages

Adapted MCM contains three levels (stages): the functional, social, and organizational levels. As seen in Figure 3-3, the requirement area serves as the starting point for each design stage. Therefore, before each stage, these requirements need to be defined and later can be expanded or complemented in the course of design process. In case of MCS design, this means that before each stage, it should be clear what the objective of each design stage is and what should be achieved.

The functional level is the first design stage where functional models are developed to describe the basic configuration of the system. The level of description at this stage is quite abstract in order to avoid any attachment to certain social or organizational designs, therefore the models developed at this stage are more oriented to the purpose of the system – what needs to be done. Therefore, the functions in the models developed in this stage contain at least one verb and one noun, for example “transmit data …” or “receive instructions …”. Models developed at this stage serve as basis for the lower stages of the design process. For developing conceptual models at functional level, the functionalist paradigm is appropriate.

At the social level the necessary social effects for executing the functions defined in the first level are identified and selected. At this level, the modeling of MCS is seen as design of a purposeful system where the main challenge is to manage interactions of purposeful stakeholders in a highly interdependent social system. The social structure models of MCS should be modeled by taking into account the structure of the organization/departments, responsibility hierarchies, cultural issues, interests and purposes of certain departments or groups and so on. At this stage, the necessary formal communication channels within the social structures are also modeled based on the functional models by addressing social enablers and constraints. Appropriate for this stage of design are the interpretative and emancipatory paradigms.

At the organizational level, the functional and social models are used to design clear guidelines and job descriptions of the concerned organizational stakeholders, which represent the implementation of the MCS in an organization. This also includes the stakeholders, who are provided with necessary tools, methods and techniques to achieve the functional and social requirements. In addition, the incentives for the stakeholders who operationalize MCS are identified and selected. At this stage the bottom-up issues are considered and matched with requirements ascending from the functional and social level. This leads to an agreed MCS process that is embedded/implemented into organizations.

As it is already stated, the VSM is a function-oriented meta-systemic model. As such, it is clear that the support of VSM could be provided at the initial stage for designing MCS – the functional stage. In the initial paragraphs of this subchapter, the functional similarities between the Simons' framework and the VSM were confirmed. Therefore, in the next subchapter, these functional analogies are illustrated in some typical MCS in engineering companies.

3.5 MCS in Engineering Companies

The design of MCS is of particular importance for engineering companies because of two main reasons. First reason is that the environment in which these companies operate is extremely dynamic and uncertain. In such environments, strategic planning as a measure to adapt is almost impossible to operationalize as there is high uncertainty on how the future unfolds. Therefore, engineering companies need to possess properly designed MCS that respond and adapt fast to environmental changes both in strategic and operational level.

The second reason why MCS design is important in engineering companies is that the market is becoming overpopulated by competitors. Therefore, in order to survive in such environments the companies need to develop competitive advantage over competition. The competitive advantage is gained with operational excellence by producing high quality products, affordable products, and short product development cycles for fast deployment in the market. To achieve this, engineering companies employ so-called management approaches, such as lean management, six-sigma, total quality management, cost management and so on. These management practices are possible to implement only by proper design of MCS that ensure that the principles and techniques prescribed by management approaches function properly.

For example, lean management consists of several principles that together should increase the efficiency and effectiveness of the company. To embody these principles, MCS are used for ensuring that the objectives of these principles are reached. For example, in order to achieve “pull and continuous flow”, Kanban system or CONWIP are used. Kanban system is a mechanism in lean production that enables Just-in-Time (JIT) delivery of material or parts by pulling these through the production process based on the changes in customer demands (see for example [MONDEN 2011, ARBULU et al. 2003, TOMMELEIN & LI 1999]). Kanban systems can be implemented by utilizing direct or buffered feedback control systems as depicted in Figure 3-4.

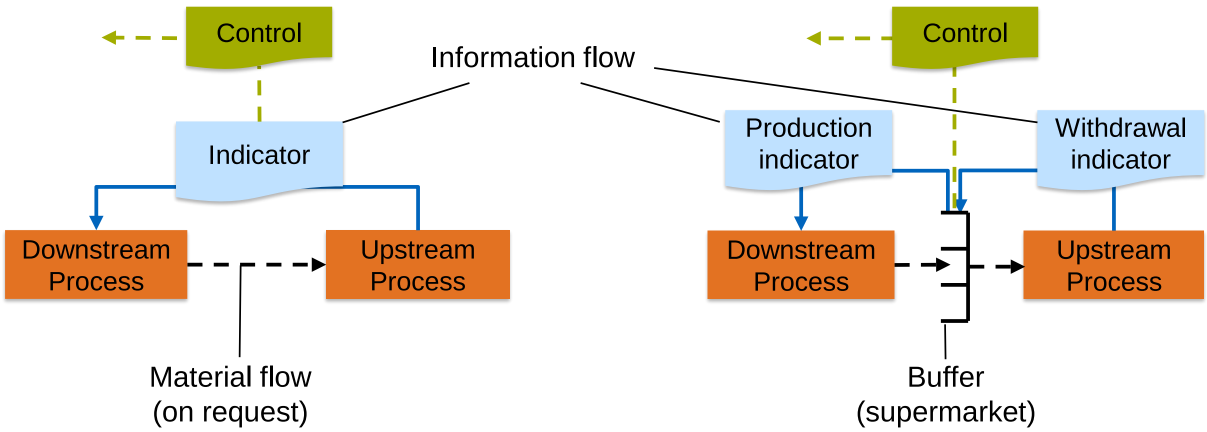

Figure 3-4: Direct and buffered feedback Kanban systems (adapted from [TOMMELEIN & LI 1999; p. 98; ROTHER & SHOOK 1999, p. 42; PRODUKTENTWICKLUNG 2014a, p. 42]

Direct Kanban system utilizes Kanban card (the indicator in Figure 3-4) indicating when the material is needed so it triggers the material flow from the downstream process to the upstream process. The buffered Kanban system, as its name suggests, uses a buffer (also called supermarket) which serves as a temporary inventory for limited quantities of material or parts produced by the downstream process. The upstream process is supplied from the buffer, whereas a production indicator is issued that informs the downstream process to replenish the buffer. This way, the number of parts in the buffer is held stable, as the downstream process produces just enough to replace what was withdrawn from the buffer [TOMMELEIN & LI 1999, p. 98]. Thus, both Kanban systems support the continuous flow of material in a production environment. In this regard, Kanban systems represent typical diagnostic control systems that make possible regulation of the material flow in an autonomous manner. Further, let’s take an example when for a certain reason (customer demand has changed substantially, for example), the flow of material needs to change in order to preserve the efficiency level. This means that certain parameters of the system need to be changed, for example, the batch sizes or the size of the buffer. In these cases, the box depicted as “control” in Figure 3-4 is responsible for changing these parameters. Therefore, the control represents the link of the Kanban system with the interactive control system that senses environmental changes and provides information how the Kanban system needs to adapt to the these changes. Unfortunately, engineering controls are designed as single control systems rather than as a part of holistic organizational structure that provides control and adaptability to environmental changes. This could represent a major problem in implementing engineering controls properly. In lean management, for example, the lack of holistic organizational perspective neglecting complexity and the connection of the management, operations, and the environment, hinders an adequate lean implementation [HERRMANN et al. 2008, p. 310].

A more detailed example of an engineering control from quality management comes from the example of Built-in Quality system (BiQ). BiQ represents an engineering control that ensures that the outcomes of a production process meet the quality expectations without requiring ad-hoc inspection or rework.

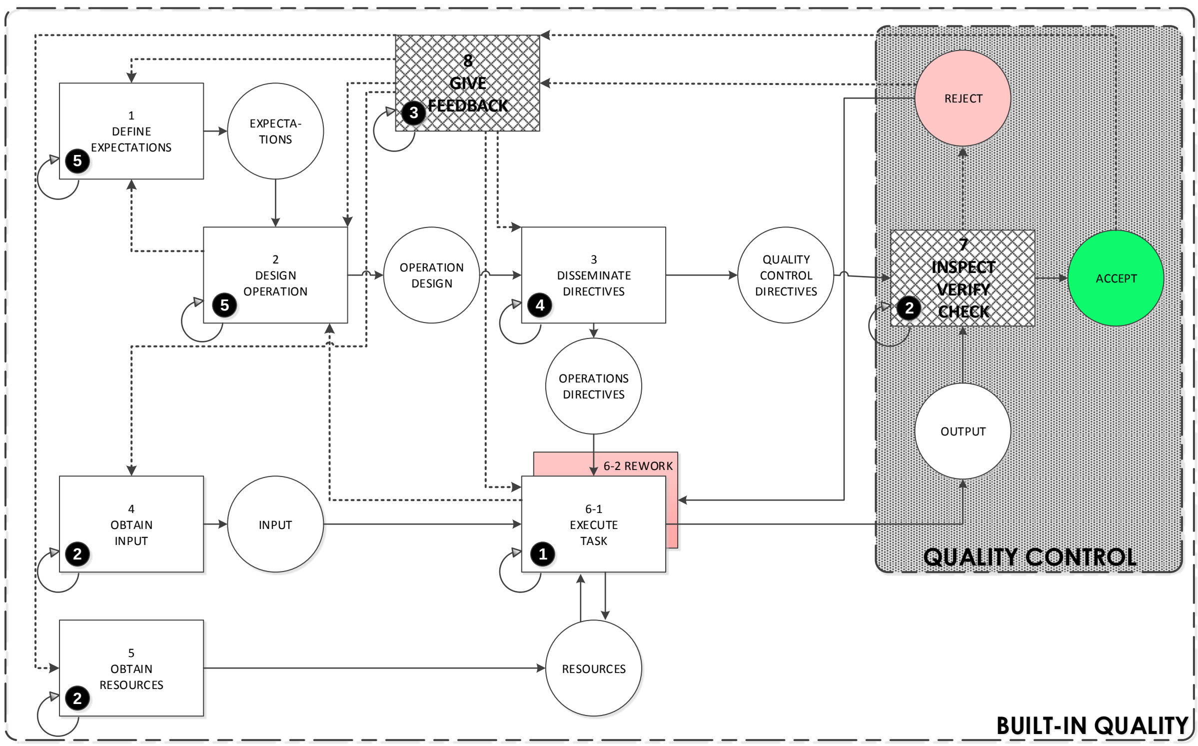

Figure 3-5: Schematics of the BiQ process (inspired by [LICHTIG 2011])

As seen from Figure 3-5, the process of BiQ system is designed based on the customer quality expectations. Based on these expectations, the directives of the operating process is designed that guide the execution the operating process. The output of the operating process is inspected in the quality control part (grey zone in Figure 3-5). The output must conform to the quality requirements in order to be accepted, otherwise the output is rejected. In both cases the stakeholders are informed about the quality control outcome. In case of acceptance, the stakeholders are informed that the operation process is running well and no measures need to be undertaken. In case of rejection, the stakeholders are informed and a different set of measures can be undertaken, such as expectations or inputs can be changed, new resources can be obtained or even an investigation can be performed to find the root cause of the problem. Of course, the measures are taken depending on the circumstances in which the rejection took place. The process described in this paragraph relates to the diagnostic control system part of the BiQ. This part needs intervention of the management only in case that problems occur and the attention of the management is sought.

On functional level, the BiQ system depicted in Figure 3-5 can be mapped into the VSM. As seen in subchapter 3.4, the diagnostic control systems incorporate functions of the autonomous management of the VSM, which represents system 1 to system 3 (see Figure 3-2). In BiQ, the operating process is executed by system 1 that can be comprised of different persons or teams. System 3 supervises the operating control by providing input and resources necessary for execution of the process. System 3 also designs the quality directives that are based on the customer expectations. The quality directives represent system 2 of the VSM and are updated by system 3 whenever the customer expectations change.

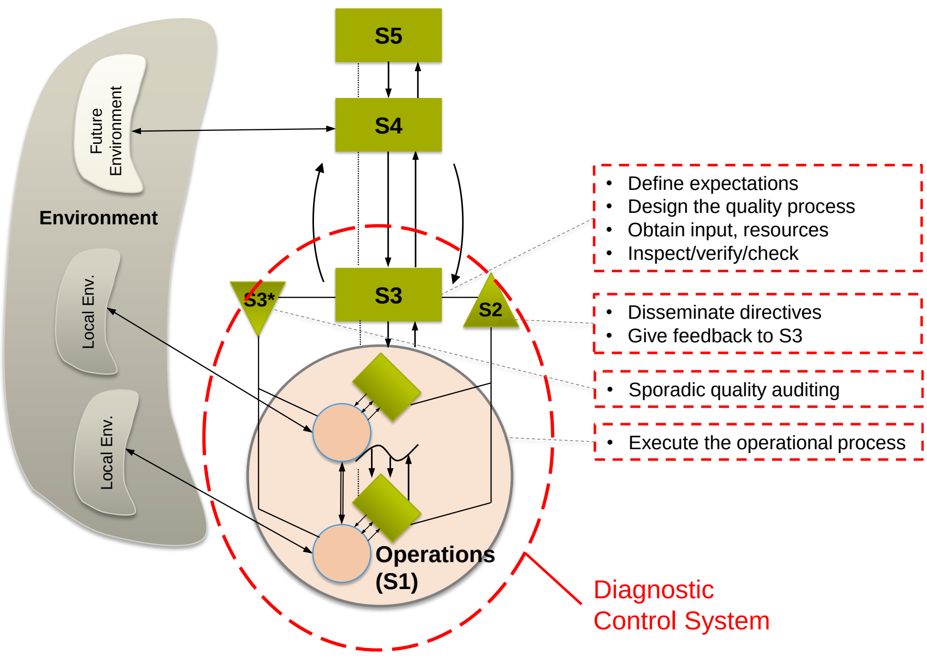

Figure 3-6: Functional mapping of BiQ functions onto VSM

In this functional model, an inadequacy can be easily noticed. System 3 in Figure 3-6 is responsible to define expectations, but this function cannot be performed without having access to information coming from the environment – more particularly customer expectations. Therefore, the current model should incorporate the homeostatic connection between system 3 and system 4 in order that BiQ system establishes the link with the environment and decisions concerning what is required from the environment and what can be done for that requirement internally. For obtaining an adaptable BiQ, system 4 should anticipate the relevant changes in the environment (in case of BiQ, quality related changes) and transmit this information to system 3. The definition of the expectations related to these changes should be done in the homeostatic discussions between system 3 and system 4. In addition, there should be a set of quality definitions that senior managers communicate formally and reinforce systematically to provide basic values, purpose, and direction for quality related issues in the organizations (that could be derived from TQM for example).

This set of values on the other hand should be limited by carefully calculated trade-off between quality related risk and opportunity. This represents typical objective of belief and boundary control systems that in VSM is vested in system 5. The impact of the discussion in this paragraph is reflected on the new functional mapping of BiQ functions onto VSM as seen in Figure 3-7.

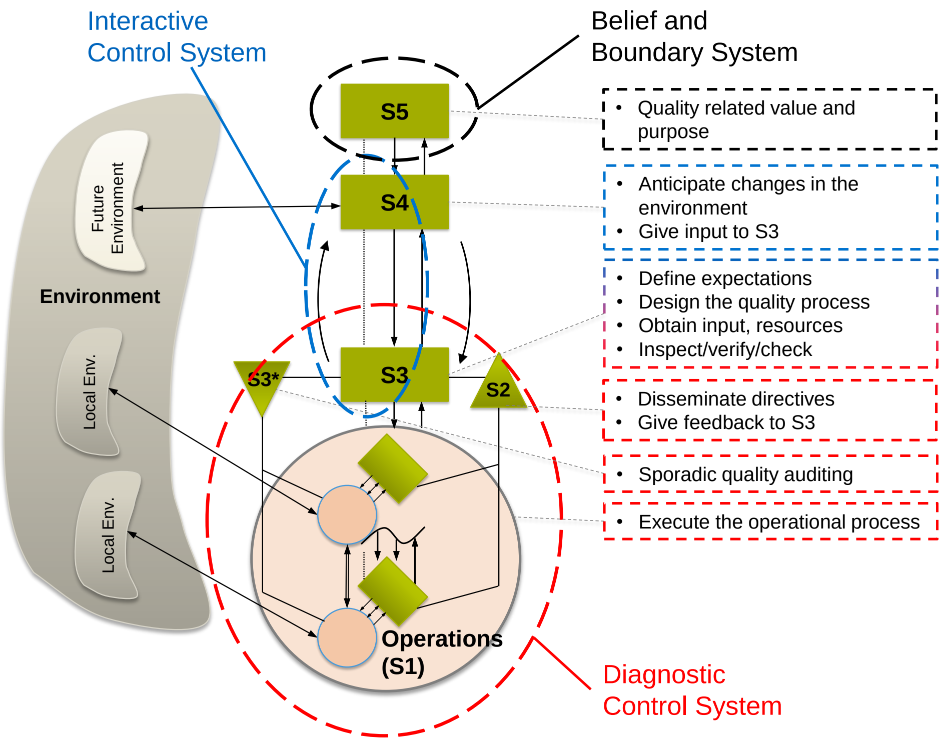

Figure 3-7: BiQ mapping onto VSM as a complete MCS

The example above draws an interesting conclusion. The functions of VSM systems can serve as basis for obtaining context-related functions of the BiQ system. More particularly, the VSM functions serve as theoretical underpinning for designing the interactive, belief and boundary control systems. Moreover, VSM represents a functional organizational model, therefore, the new context-related functions can be assigned to the corresponding functional entity in the organization – assuming these functional entities in the physical organization are identified. This conclusion can be expanded to all MCS, since all of them consist of the four control levers as explained by SIMONS [SIMONS 1995].

Very often, several diagnostic control systems are required to fulfill a certain strategic management objective. This is particularly true for engineering companies that have several engineering departments that are operationally interconnected. Extending on the BiQ example, it is obvious that there needs to be an awareness of quality as a strategic management objective in order that the existence of BiQ makes sense. The quality strategic objectives, however, cannot be reached only with the means of BiQ, but there will be other diagnostic control systems, such as for example different statistical based quality controls or quality process controls. All the diagnostic control systems that serve one strategic objectives should – according to SIMONS – have a common interactive, belief and boundary control system. In case of 2 diagnostic control systems, the mapping onto VSM could look as following.

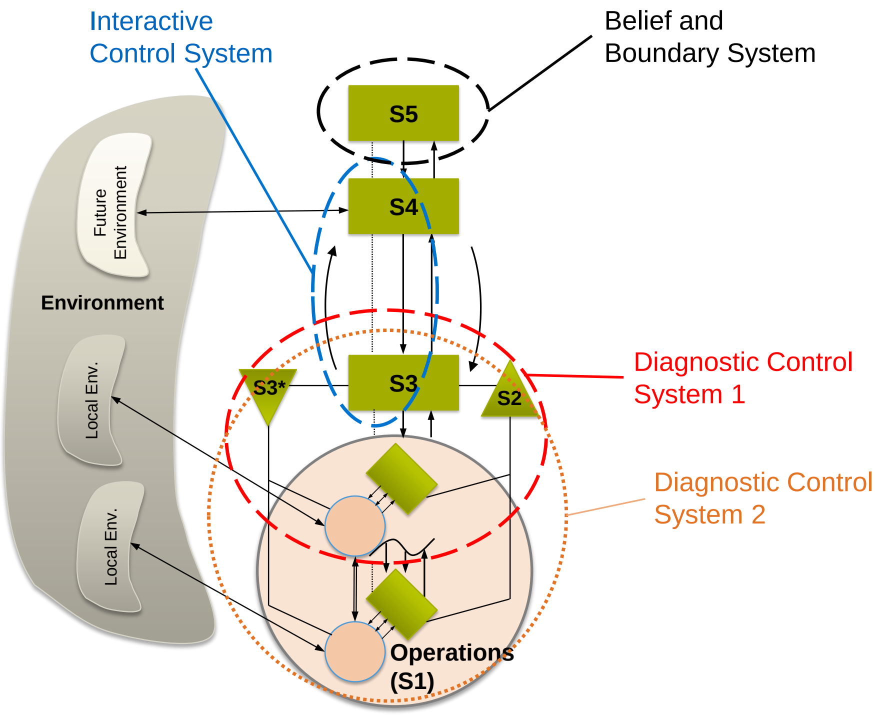

Figure 3-8: Management Control System with two diagnostic control systems mapped onto VSM

In reality, in order to stay viable, engineering companies implement several MCS. Each of these MCS is responsible for steering the organization according to a strategic objective that ensures the long-term viability of the organization. Such MCS could represent efficiency or cost related controls, such as material pull systems, quality control systems, process controls, target cost controls and so on. In addition, there could be MCS required to ensure the functioning of typical engineering control processes, such as variant management, engineering change management and so on. All these MCS could have similar structure as depicted in Figure 3-7, but their implementation would occur in different recursive levels. There could be cases where in a single recursive level, two or more MCS are implemented. This means that two or more interactive control systems would coexist in the same recursion level. VSM perspective also reveals that there can be several MCS implemented in different recursion levels. In higher recursive levels, main principles or objectives of management approaches could represent belief, boundary and interactive control systems, whereas in lower recursive levels process and action controls MCS are implemented.

As it can be observed, VSM provides a very rich and holistic view on MCS in engineering companies. This view implies the existence of several MCS in different recursive levels, which is contrary to the understanding stemming from SIMONS' framework that implies several diagnostic control systems but only one belief, boundary, and interactive control system to be present in an organization. Moreover, the VSM perspective implies a fractal topology of MCS. This means that structures as in Figure 3-8 are consecutively repeated in different recursive levels. How these fractal parts then are interconnected, can be understood from the VSM functional descriptions of the communication channels for each system.

3.6 Summary and Conclusions of the Chapter

As already mentioned in the introduction, the objective of this chapter is to enquire whether the VSM can support the design of contemporary MCS. In this chapter an overview of main VSM applications in industry and application challenges were presented. Contemporarily, the VSM is used mainly as a diagnostic tool for assessing the viability of organizations. However, there are new trends to apply the VSM in other research fields than organizational design, such as supply chain, strategy implementation, and management information systems. Despite successful VSM applications in industry, the VSM is still regarded as an exotic management concept and is still not part of management mainstream research. This is because there are certain difficulties in applying the VSM in real-life industrial environment. Among these difficulties, the complexity of the theory underlying the VSM and the VSM's inability to address the social context in an organization prove to be the main challenges.

Concerning MCS design, contemporary literature still lacks clear design guidelines for adaptable MCS that ensure the viability of the organization. Most of the prevailing frameworks agree that there is a functional structure of the MCS that is based on cybernetic principles, and the social part that is based on psychology, group psychology, human relations and other social sciences. Contemporary MCS frameworks acknowledge that the functional part of the MCS should incorporate cybernetic controls that ensure that the operational objectives are reached. However, mechanisms that enable MCS to reformulate strategies and adapt to environmental and internal changes are explicitly described as of a non-cybernetic nature. This represents a contradiction with another body of knowledge, the management cybernetics, which provides a cybernetic model that incorporates functional structures for viable (which inherently are adaptable) systems – the VSM. Therefore, the possibility that the VSM serves as theoretical underpinning for design of contemporary MCS on functional level was enquired. The analysis showed that the VSM incorporates all the functions required for all 4 levers of control (belief, boundary, interactive and diagnostic control systems) to a greater, more detailed extent than SIMONS' framework. In addition, the VSM has advantages in the sense that it provides a structure for associated groups of functions (VSM systems), which ultimately leads to a better insight which functional entities of the organization these functions should be embedded in. This is a great advantage that the VSM provides, since these functional entities would provide the structure for embodiment of several MCS, as it is usually the case in real-life engineering companies. The MCS package (several MCS coexisting in the organization) as a concept have existed for more than 30 years in literature, but there has been little explicit theorizing or empirical research on the topic [MALMI & BROWN 2008, p. 287]. Therefore, looking into MCS through the VSM perspective, could provide the first step in understanding how MCS interact within the organization.

An example of Built-in Quality (BiQ) system was used as an example to illustrate how generic VSM functions relate to context-related functions of BiQ (provided in subchapter

3.5). The information stemming from the functional model of BiQ was sufficient to relate these with the VSM generic functions. However, in the functional model of BiQ there was no information about the interactive, boundary and belief control system. Based on the generic functions of the VSM, the context-specific functions for the missing control systems of BiQ could be anticipated. This example provides a preliminary confirmation, that the VSM can support the design of engineering MCS on functional level.

Based on the analysis and the conclusions in this chapter, the requirements (criteria) for developing the prescriptive study in this thesis can be deduced.

4. Design of Solution

This chapter represents the core of the prescriptive study of this thesis. The objective of this study is to describe the research methodology used for obtaining a functionalist approach in a form of a method that uses VSM as the theoretical underpinning for identification of necessary functions of MCS in engineering organizations. To achieve this, the need for support is first reinstated and put into a wider picture based on the discussion in chapter 3. As a next step, the requirements for the method are summarized based on the literature research (chapter 2) and on the analysis provided in chapter 3. The method is then conceptualized and in the elaboration section the methodical steps are described. The structure of the chapter therefore corresponds to the stages for development of the solution in the design research methodology (DRM) [BLESSING & CHAKRABARTI 2009, p. 145]

4.1 Task Clarification and Limitations

In subchapter 3.1, the MCS were described as systems that contain two main structures, the cybernetic and the social structure (see Figure 3-1). The cybernetic structure, as described in subchapter 3.4, can be viewed and compared with the VSM perspective. This means that the design of MCS cybernetic structure can be based on the VSM functional structure. The social structure on the other side, is the means with which the MCS are "enforced" in organizations as social systems. Therefore, these structures are subject to another set of systemic paradigms (interpretative and emancipatory paradigms). At a very abstract level, the MCS design incorporates the design of these two structures in an iterative manner (see Figure 4-1).

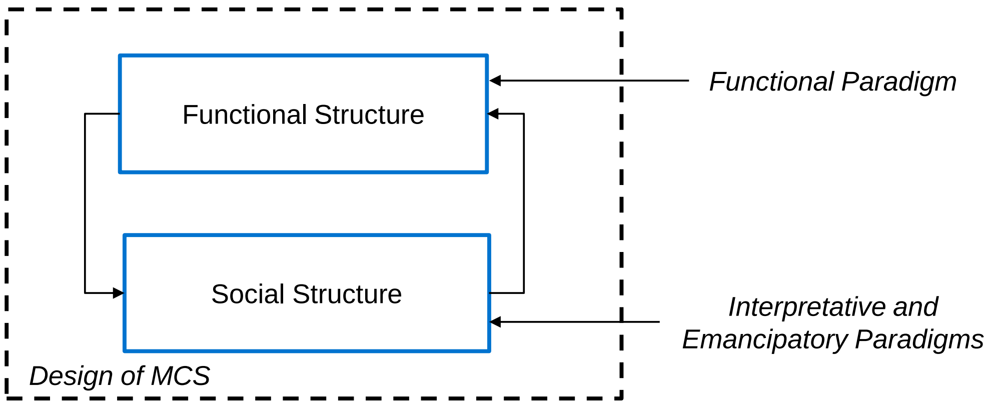

Figure 4-1: The interaction between functional and social structures in MCS design

Unfortunately, in literature there is no design procedure for contemporary MCS but rather frameworks that recommend what features and characteristics the MCS should have (see section 2.3.3). Therefore, a good starting point for describing the design of MCS can be found in design sciences, where descriptive models exist that are primarily developed for describing the design stages of technical products (see for example [EHRLENSPIEL 2009, PAHL et al.

2007, RODENACKER 1991]). These models however, can easily be converted into models that describe the MCS design stages (as shown in subchapter 3.3). In this thesis, modified Munich Concretization Model (MCM) will be used to describe the objective of the solution development presented in this chapter, the anchoring of this support in the MCS design process, as well as its limitations.

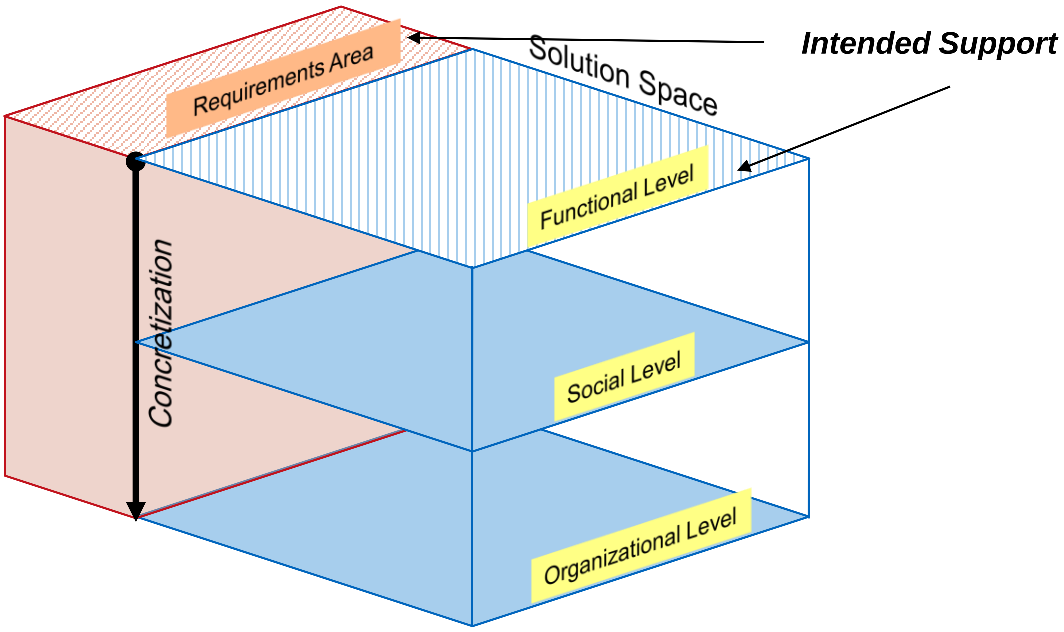

Figure 4-2: Munich Concretization Model (MCM) as description for MCS design stages (adapted from [LINDEMANN 2009, p. 27])

As seen in Figure 4-2, the intended support is anchored at the functional level. The functional level is the first design stage where functional models are developed to describe the basic configuration of the system. The level of description at this stage is quite abstract in order to avoid any attachment to certain physical designs, therefore the models developed at this stage are more oriented to the purpose of the system – what needs to be performed. Therefore, the functions in the models developed in this stage contain at least one verb and one noun, for example "transmit data…" or "receive instructions…". For developing models at functional level, the functionalist paradigm is appropriate. The objective is thus, by use of the VSM as functionalist canonical model, design the functional model of contemporary MCS. In order to achieve this objective, a method will be developed that would help managers and practitioners to design such models. According to PONN & LINDEMANN, a method represents a description of a rule-based and planned procedure, based on which certain activities should be executed in order to reach an objective [PONN & LINDEMANN 2011, p. 22]. Similarly, MIDGLEY defines method as "(…) a set of techniques operated in a sequence (or sometimes iteratively) to achieve a given purpose" [MIDGLEY 2000, p. 105]. A method should be distinguished from a methodology since a methodology represents a set of theoretical concepts that justify the conception of a method or methods [MIDGLEY 2000, p. 105] – referred as research methodology in the beginning of this chapter. The use of the concept "method" and “methodology” in this thesis follows these definitions. From the discussion above, it can be understood that the intended support is limited at developing a method at the functional stage of the MCS design. The outcome of the method, which is expected to be a functional model of the MCS, will then serve as the basis for the next design stage.

4.2 Requirements of the Method

For systematic method development, the Munich Model of Methods (MMM) [LINDEMANN 2009, p. 59-62, BRAUN & LINDEMANN 2003] is applied. The MMM’s is used in this thesis since essentially MMM can be used for developing methods for all design problems irrespective of the domain [BRAUN & LINDEMANN 2003]. The objective behind MMM is to support the developer or the practitioner in method selection, adaptation and application by providing a guided navigation through the method design process. MMM consists of 4 stages: clarification of method application, method selection, method adaptation and method application. In this subchapter, the first stage of MMM will be elaborated.

Table 4-1: Criteria for conception of the method

Preconditions	Application requirements	Target requirements of the method
• MCS description available • Vertical complexity unfolding already performed • Existing organizational functional structure known • Basic knowledge on VSM required for the users of the method	• Basic knowledge on VSM required for the users of the method • Functional analogies between general VSM functions and MCS context-specific functions	• Systematization of MCS description into the VSM systems • Identification of the missing functions • Systematization of the comprehensive MCS functions into the functional organizational entities
General requirements	**Boundary conditions**	**Objectives**
• Applicable for all MCS in engineering industries • For all sizes of the organizations • Applicable in all levels of the organization • Applicable for all sizes of MCSs • Ease of use	• Analysis only at functional level • The social part of the MCS not a subject of the method	• Support the functional design of the MCS in engineering companies • Ensure that a comprehensive and detailed list of MSC functions is available for the next MCS design step
Available input	**Questions to clarify**	**Desired output**
• MSC description • VSM functions derived from literature • Vertical unfolding of organization • Existing organizational structure	• Who should execute the method	• A comprehensive MCS functional model including all levers of control • Embedded MSC functions into the organizational functional entities

In the first stage of MMM, the identification the requirements that are vital for method development is performed. These requirements are grouped in nine categories as shown in Table 4-1.

Preconditions: Before the method can be applied, several preconditions need to be fulfilled. Firstly, there should be a description of MCS available, which shall be functionally modeled. If this precondition is not fulfilled, the users of the method need to have a clear idea of the MCS that is required to be modeled. Next, a vertical unfolding of the complexity (see section 2.2.6) needs to be performed in order to have a view on the recursion levels of the organization. This is particularly important since it is essential for the users of the method to understand in which recursion level the MCS should be embedded. The vertical unfolding of complexity also helps to identify the stakeholders that need to be included in execution of the method. Since the method tackles only the functional level of MCS design, the embedding of the MCS should be envisaged on the functional entities of the organization at the appropriate recursion level. In addition, the users of the method need to be well informed about the VSM systems and functions in order that the method is appropriately executed. Therefore, this precondition is at the same time an application requirement as well.

Application requirements: In addition to the basic knowledge of VSM, the users of the method need to be acquainted and able to perform functional analogies, as a core cognitive exercise for executing the method. This is essential since the functions derived from the MCS description (from now on referred to as context-specific functions) need to be assigned to general functions of the VSM (see subchapter 3.4). The inverse needs to be done, when there is a missing context-specific functions and a functional analogy needs to be performed based on the VSM functions (which are general and meta-systemic). The context-specific functions derived this way, might have to undergo a functional break-down into several sub-functions.

Target requirement of the method: The method should allow for structuring of the MCS description into the VSM systems. This includes the identification of context-related MCS functions from the description of the MCS and by means of functional analogies relate them to the appropriate functions of the VSM. By doing so, it becomes possible to identify the missing functions that are required in order to have a complete functional model of the MCS. The method should therefore, allow for performing functional analogies in the opposite way, namely to generate context-related functions from the analogically similar functions of VSM. In order to prepare the ground for the next level of modeling (social level), the comprehensive list of MCS functions should be assigned to the appropriate functional entities of the organization. These requirements are a direct consequence of the discussion in subchapter 3.4.

General Requirements: In this category mainly the requirements concerning usability of the method are grouped. Because functional modeling proposed in this thesis involves comparison with the meta-systemic functions of the VSM, the method should be applicable for all engineering related MCS. Also, it should be applicable for all sizes and levels of the organizations. This is possible because of recursive property of the VSM that can tackle all levels of organizations (see section 2.2.5). Despite these challenging requirements, the method should remain easy to use, since the VSM theory is quite hard to be fully comprehended within a short time.

<u>Boundary conditions:</u> The method should provide support only at the functional level of the MSC design process. The output of this support should serve as input for the next design stage. This is a direct requirement from the discussion in subchapter 3.4.

<u>Objectives:</u> The main objective of the method is to provide support in identification of necessary functions for MCS design in engineering companies. This method uses the VSM as a theoretical underpinning for the functional modeling (see subchapter 3.4 and 3.5 for the discussion why is this necessary and useful). The second objective of the method is to provide the basis for the next design stage, the social level (see Figure 4-2).

<u>Available input:</u> The most important input for the method is the MCS initial description. In literature, the MCS are provided usually as narrative descriptions or process models. In certain circumstances, a specific MCS system that is not described earlier could be sought to be implemented. In these cases, an elaborate description of objectives and requirements for such an MCS should be provided. This information is then used to derive the necessary functions of the MCS in the course of method execution. Since MCS functions should be compared with the VSM functions, a comprehensive list of VSM functions should be available (see SCHMIDT et al. 2014, p.6). In addition, the results of vertical unfolding of the complexity (see section 2.2.6) should be available as an input for the method, in order to identify the recursion level(s) in which the functional model of the MCS should be embedded. The organigram of the organization is also required as an input for the method in order to identify the stakeholders that should be involved in the execution of the method. This is done by comparing the recursive levels with the organizational organogram (see next paragraph).

<u>Questions to clarify:</u> In order that the method is executed properly, the right stakeholders need to be part of the execution. After having a better view on of the recursion level(s) in which the MCS should be embedded, the functional entities are compared with the existing organigram in order to identify the managers that will be affected by the method's outcome. These stakeholders should take part on the method execution since in this way the transparency and agreement on required functions is ensured.

<u>Desired output:</u> Based on the objectives of the method, it can be inferred that the output of the method should be a comprehensive list of MCS functions. The list encompasses context-related functions that are assigned to different VSM systems, therefore it represents the comprehensive functional model of the MCS. As such, these functions are embedded to functional entities in the appropriate recursive level of the organization. In this form, the functional model is the appropriate input for the next MCS design stage.

These criteria form the basis for the conception of the method, which is described in the next subchapter.

4.3 Conceptualization of the Method

Based on Munich Model of Methods (MMM), the conceptualization of a method is performed in three stages [BRAUN & LINDEMANN 2003]. The first stage is the selection of a method, where an already existing method that performs similar task as the desired method is selected. In the second stage – method adaptation, the selected method is adapted to fit the desired requirements. The last stage is method execution, where it is described how the method is to be used or executed. The conceptualization of the method guided by MMM is described in the following sections.

4.3.1 Method Selection and Adaptation

Method selection can be performed in three different ways [BRAUN & LINDEMANN 2003, p. 2]. The first way is to select a method from a pool of methods that exist to support a certain activity of a superordinate process. The second way is to select a method that best matches the requirements. Last but not least, a method can be selected by analyzing the elementary tasks (within a superordinate task) that the method should perform, and then existing methods that correspond to elementary tasks are aggregated to perform the superordinate task. For method selection in this study, the second alternative was chosen, since the first and third alternative are used in cases where a method needs to be embedded in an existing superordinate process. That is not the case with the method to be developed in this thesis, therefore the second alternative that relies on the requirements (provided in subchapter 4.2) is used.

The requirements described in subchapter 4.2 imply several conditions for the new method. Application requirements for example imply the method should contain functional analogy as a cognitive process. This is required in order to fulfill the target requirement of the method, which is the systematization of MCS description into the VSM functional structure. To achieve this systematization, context-related functions from the MCS description should be deduced and the functional analogy should be performed in order to classify these functions into the appropriate VSM system. After performing the systematization, the next target requirement of the method is to identify which context-related functions are missing in order to amend the list of functions. This is performed by inversely applying the functional analogy, this time from VSM functions to context-related functions. The last target requirement of the method implies that once the comprehensive list of functions is deduced, each function is instantiated to the existing functional entities of the organization.

Based on these requirements, a comprehensive search in different research fields is performed. The outcome of the search was that several suitable methods were identified that in fact represent a certain class of methods that are used for creative solution finding. For example, in the field of biomimetics technical problems are solved with solutions inspired from nature [NAGEL et al. 2008, LINDEMANN & GRAMANN 2004]. Obviously, direct emulation of a natural solution is impossible, hence both the technical problem and the nature-inspired solution are abstracted to the functional level which allows for development of innovative technical solutions by transferring the natural solution as a functional concept to the corresponding technical context. A similar method is central to the TRIZ innovation methodology, where problems are abstracted to a conceptual level, then appropriate conceptual solutions are found and this solution is instantiated [ILEVBARE et al. 2013]. As it can be noticed, all these methods use functional analogies for finding solutions for technical problems. This class of methods is recognized in literature as general problem-solving approach [LINDEMANN 2009, p. 28].

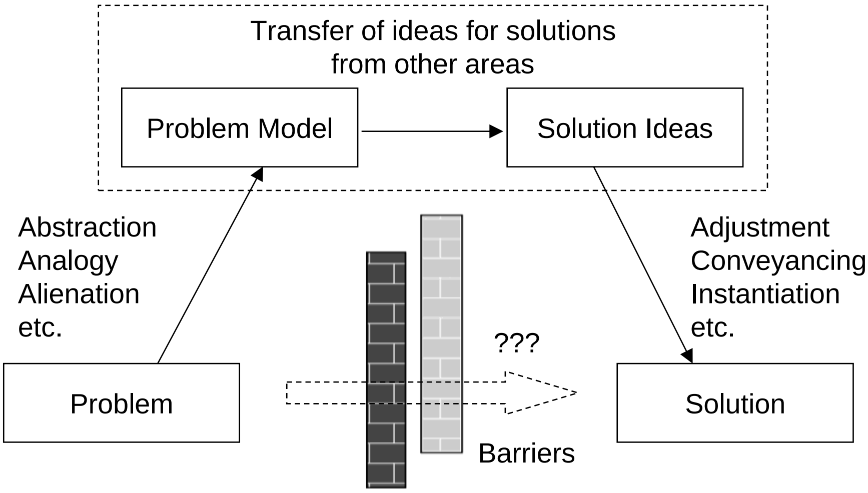

Figure 4-3: General problem-solving approach (translated from [LINDEMANN 2009, p. 29]

As seen in Figure 4-3, in the attempts to find a solution where cognitive efforts are required, there are different barriers that hamper the generation of solution. These barriers can be manifested in the form of thinking in old solution patterns, fear from making mistakes, satisfaction with the known and personal experience [LINDEMANN 2009, p. 28]. In our case, the MCS are usually described with the hierarchical organizational structures in mind (the problem). In addition, the managers that are supposed to implement these MCS also think in hierarchical mode since this is what they see and experience from the organizational structure (the barrier). As described in the last paragraphs of subchapter 3.4, the hierarchical way of thinking is unnatural to adaptable systems, therefore thinking in this way is a barrier for implementing contemporary MCS. To overcome these barriers, LINDEMANN suggests to use various mechanisms (for example abstraction, systematic variation, analogy or alienation) to circumvent or dissolve the barriers between the problem and the possible solution. The problem is sometimes dissolved at a different level or domain, from where the ideas can be transferred to the actual problem again [LINDEMANN 2009, p. 28]. In our case, the other domain is the meta-systemic level of the VSM, from where the identification and the amendment of the missing functions is performed. In this way the barrier is circumvented (hierarchical thinking) by finding the solution at the VSM's meta-systemic level. Based on the discussion in this section and the requirements identified in subchapter 4.2, the following method is derived from adapting the general problem-solving approach (see Figure 4-4). The method will be further elaborated in subchapter 4.4, whereas in the following section method execution will be described.

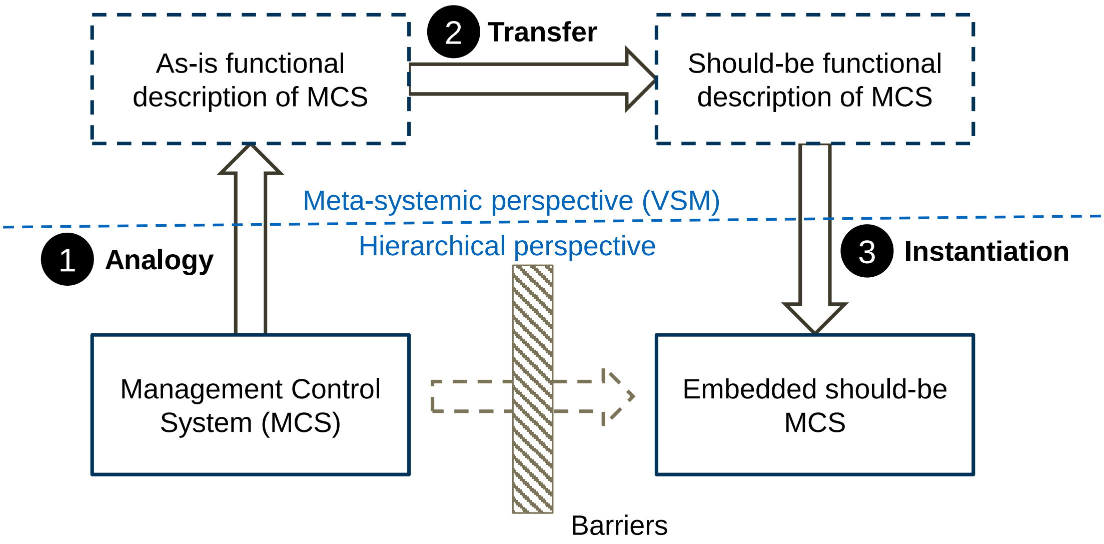

Figure 4-4: The derived method adapted for the functional level of MCS design

4.3.2 Method Execution

Based on the problem description, it is clear that this method should be executed by managers whose departments are actively involved in the operations of the MCS to be designed. Therefore, as it is stated in subchapter 4.2, the vertical unfolding of complexity should be performed in order to identify the stakeholders (managers) who need to be included in execution of the method. In order to achieve an agreement of these stakeholders on the functionality of the MCS, it is suggested that all method's steps are performed in a brainstorming session, where each manager will provide his opinion based on his perspective. The method could be moderated by an outsider who is not necessarily involved in the operations of the company, but has a solid knowledge on VSM.

4.4 Elaboration of the Method

As seen in Figure 4-4, the functional description of the MCS to be designed is brought into VSM meta-systemic level by use of functional analogy. At the new level, the functions are clustered into five systems of the VSM, based on similarities they bear with the functions within different systems of the VSM ("as-is" functional description of the MCS). As most of MCS are designed for a certain purpose (e.g. streamlining the flow of material, control of deadlines of engineering changes etc.), they will usually lack important functions that are essential for adaptation in changing circumstances. These functions are transferred from VSM to the functional description of the MCS and thus, the "should-be" functional description is obtained. The "should be" description is then further elaborated and embedded into the organizational functional structure. In the following, the three steps of the method will be elaborated.

In the first step of the method (**analogy** – see Figure 4-4), initially a list of all the functions is derived from the MCS description (the initial context-related functions). This can be performed based on existing literature on the MCS to be implemented or based on expert's knowledge. The initial context-related functions are then categorized into the VSM systems based on functional analogies. For this purpose, a list of generic VSM functions can be utilized as provided in [SCHMIDT et al. 2014]. Usually the descriptions of MCSs in literature most commonly are a mix of tasks, activities, and goals that these MCS need to incorporate. Therefore, it is crucial for this step that this mix of information spreading across different abstraction levels is properly translated to context-related functions. Based on the input information from the vertical complexity unfolding, as well as from the focus and scope of the MCS, it should be assessed whether the MCS is to be embedded in one or more recursion levels. As a result of this step, the "as-is" functional description of the MCS classified in VSM systems is obtained. As already stated in section 4.3.2, the step is performed in a brainstorming session with the managers concerned.

The objective of the second step (**transfer** – see Figure 4-4) is to identify the missing and under-represented functions of the "as-is" functional description and to transfer the solution based on the VSM functions. This is accomplished by comparing the "as-is" MCS functions from step one with the VSM functions. By doing so, general functions that do not have an analogical counterpart from the context-related functions are identified. These VSM functions are then converted into context-specific functions and added to the "should-be" MCS functional description. This is achieved by means of functional analogy but performed in the opposite way compared to step one. The execution of step two should be performed in a moderated brainstorming session with the involved managers, as they could provide additional insights into the required context-specific MCS functions. As a result of this step, all the necessary functions are identified and clustered into appropriate VSM systems. This represents the functional conceptual solution of the MCS (should-be functional description).

The last step (**instantiation** – see Figure 4-4) is also executed through a moderated brainstorm session. The purpose of this step is to further detail the newly obtained context-related functions and allocate each of them into the appropriate functional entity of the organization. Therefore, as input for this step serve the "should-be" functional description of the MCS as well as the functional organizational entities structure of the concerned recursive levels (obtained through the vertical complexity unfolding). The functional organizational entities structure on the one hand contains all the departments, teams and/or individuals that perform control functions in the organization clustered in appropriate VSM systems. On the other hand, the "should-be" MSC functional description contains the context-related functions clustered to the VSM systems. By bringing together these two sets of clusters, it is possible to link the MCS functions with the organizational entities. It can herewith be ensured that the required functions (of all control levers) of the MCS are properly assigned to existing organizational functional entities.

4.5 Summary of the Design of Solution

Chapter four described the research steps undertaken in order to develop a method for supporting the design of MCS at the functional level. The Munich Model of Methods (MMM) is used as the guiding research methodology for achieving this goal. Initially, the intended support is framed into the functional level of the MCS design process (subchapter 4.1). In subchapter 4.2, the requirements for the method development were set based on the literature review and the analysis provided in subchapters 3.4 and 3.5. Based on these requirements, the conceptualization of the method is explained in subchapter 4.3. The conceptualization of the method is performed by following the three steps of MMM: method selection, method adaptation, and method execution. As a result, a method that supports the design of MCS on functional level is obtained. In subchapter 4.4, the method was elaborated and suggestions on how to apply it are provided. The method contains three steps: analogy, transfer, and instantiation step. The functional analogy step allows to identify the context-related functions from the MCS initial description and order these to the VSM meta-systemic structure. In the transfer step, missing context-related functions are identified. The missing context-related functions are analogically deduced from the corresponding VSM functions and are transferred into the MCS “should-be” functional model. In the instantiation step, the functional MCS model is further detailed and embedded into the functional entities of the organizational entities.

The method as such is designed to support the first level of MCS design – the functional level. Design at the social level is not supported by this method. However, once the method is applied and all the necessary functions for adaptable MCS are identified and embedded into the functional organizational entities, the preconditions to start with social level design are fulfilled. Therefore, the output of the method serves as input for the next MCS design level – the social level.

In the following chapter, the evaluation of the method will be provided based in three industrial case studies.

5. Evaluation Case Studies

This chapter describes the descriptive study II (DS-II) undertaken for evaluating the method developed in chapter 4. Based on DRM, this study belongs to initial DS-II type, as it is focused in evaluating the applicability, usability and the usefulness of the method. These three evaluation criteria were assessed based on empirical studies conducted with the managers that participated directly in the execution of the method in their company. The evaluation of the method was performed in three case studies. The first case study was performed in a large construction project in San Francisco. The method in this case study was applied in the context of pull-based material supply system. The second case study took place in an international manufacturer of home appliances, more specifically in the refrigerator business unit. In this case study, the method was applied to identify the functional model of the MCS that enables the platform life-cycle management. The third case study is also performed in a construction project (as the first case study) but the method application context was engineering change management. Evaluation of the method is provided for each case study and at the end of the chapter, the cross-case evaluation is described.

5.1 Lean Pull-based Material Supply System Case Study

In the first case study, the method described in chapter 4 is applied in the context of lean material supply. The subchapter starts with a short introduction of lean management in general and the need for a systemic perspective on lean implementation efforts. In section 5.1.2 the context in which the lean implementation case study was performed is introduced. Next, the application of the method presented in chapter 4 is provided in section 5.1.3. At the end, the evaluation results in relation to applicability, usability and usefulness of the method are described (section 5.1.4). A short summary of the case study is provided in section 5.1.5. This case study was performed as part of the research collaboration with the Department of Civil and Environmental Engineering at the University of California in Berkeley, within the author's doctoral project.

5.1.1 Challenges in Implementation of Lean Principles

Lean thinking, as a way to improve processes in an efficient and effective manner, originated and was developed at Toyota after the Second World War and since the 1990s has been widely used around the world in manufacturing and service industries with considerable success. Specifying customer value and delivering it expeditiously without waste is the paradigm of lean thinking [LIKER 2004]. Lean was rapidly adopted by companies around the globe both within and outside the automobile industry, the construction business being one example [BALLARD et al. 2007, HINES et al. 2004, PAEZ et al. 2005]. Lean thinking is based on a holistic management philosophy that is supported by a set of principles implemented by means of practical methods [LIKER 2004]. WOMACK & JONES stated five principles of lean thinking as a result of their intense studies of the Toyota Production System (TPS), namely specifying value, identifying the value stream, making value flow without interruptions, letting the customer pull value from the producer, and pursuing perfection [WOMACK & JONES 1996]. LIKER went on to capture Toyota's management philosophy by outlining 14 principles in four categories – philosophy, process, people and partners, problem solving [LIKER 2004]. This more extensive description of the TPS identifies its management characteristics which in some aspects are largely different from traditional top-down-driven western management culture.

Regrettably, implementation of lean by organizations other than Toyota all too often is limited to mimicking or emulating these practical methods rather than fully embracing the principles they implement. BHASIN in this regard states that "(…) every company should discover its own way to implement Lean" [BHASIN 2012a, p. 440]. Simple emulation leads to limited, unsustainable, and dissatisfactory results, reasons being differences in social and cultural systems surrounding the target organizations on the one hand, and corporate culture and attitudes amongst employees towards notions of lean thinking within the organizations on the other hand [BHASIN 2012b, DOMINICI & PALUMBO 2013, STONE 2012]. The importance of embedding lean methods appropriately in a management system can be observed in the way Toyota implements their TPS. According to GHARAJEDAGHI, Toyota created lean production system based on systems thinking, more precisely **cybernetic principles**, which made possible flexibility and control to serve as basis for their competitive advantage [GHARAJEDAGHI 2011, p. 22]. In contrast, many of its emulators first are concerned with implementing methods and tools [WOMACK 2007] and then deal with the organizational change. By doing so, the emulating companies miss two important issues. First, they fail implementing important aspects that are difficult to emulate, such as the "hidden" mechanisms that enable lean methods to adapt to externally and internally induced changes. Second, because of totally different context these emulating companies operate in, they fail to adapt the methods to their own needs, which ultimately leads to failure in embedding them properly into their existing management systems.

In this case study, these issues are addressed by applying the method presented in chapter 4. In order to support managers in dealing with these issues, a systems perspective on lean principles is obligatory. This perspective requires that lean principles are regarded as principles that are operationalized through the management control systems (MCS). As indicated in section 2.3.2, MCS are defined as any type of mechanism or technique employed by managers to make sure the strategic or operational goals of an organization are achieved or changed when it is required [MERCHANT & VAN DER STEDE 2012. p. 5]. In this study, whenever MCSs are employed to reach goals that result from lean principles, they are referred to as lean control systems (LCS). In other words, a LCS is used to achieve a certain desired state of the system required by the corresponding lean principle. For example, in order to achieve pull and continuous flow (lean principle), Kanban or CONWIP are used (both LCS).

The first of the abovementioned issues is the implementation of important aspects that are difficult to emulate, such as the "hidden" mechanisms that enable lean control mechanisms to adapt to externally induced changes. To tackle this issue, the method employs the VSM as a holistic model of an organization. As explained in section 2.2.5, this model incorporates all the generic functions required for survival of an organism in a changing environment.

Therefore, the method uses the VSM as a canonical model for comparing whether the LCS have the necessary functions for adapting to environmental and internal changes. If this is not the case, a should-be LCS is proposed that incorporates the necessary functions. Thereby, a functional model of the should-be LCS is obtained that contains the necessary functions for adaptation.

The second implementation issue relates to the failure of the emulating companies to adapt the LCS to their own needs and context. This ultimately leads to the failure in embedding them properly into their existing management systems. This issue is addressed by the method by assigning the LCS functions to the right functional entities of the organization. These functional entities (systems of the VSM) exist in all organizations, under the assumption that they strive to be viable. Consequently, the functions are assigned to appropriate organizational entities.

Based on this discussion, the use of the method for addressing the two above mentioned implementation issues in lean is justified. In the following section, the context of the case study is presented.

5.1.2 Introduction of the Context

The first study took place in a ca. one billion USD construction project in San Francisco – the Cathedral Hill Hospital (CHH). Owner of the project is Sutter Health, a non-for-profit organization [SUTTER_HEALTH 2014], who upon successful completion of the project will run the hospital. The CHH project started in 2005 but because of political problems had to be stopped in 2011. The project resumed in summer 2013 but part of its initial capacity had to be relocated to another existing hospital south of San Francisco. The CHH, a twelve-storied home for the cardiology, oncology, emergency care and transplant departments for women and children, will create ca. 69,000 m^2 of diagnostic, treatment, and inpatient bed space. An adjacent 23,500 m^2, nine-storied medical office building will accommodate outpatient services and support the health care professionals [CALIFORNIA_PACIFIC_MEDICAL_CENTER 2014]. For managing the construction project, HerreroBoldt partnership is established between California-based Herrero Builders Inc. and the Boldt Company – a major Wisconsin based general contractor company. HerreroBoldt and the trade partners in the project work under an Integrated Form of Agreement (IFOA). This implies that the project management and the trade partners are together responsible for meeting the target costs and they share rewards in case of profit but also share losses in case of exceeding target costs [LICHTIG 2010, p. 86]. Fostered by IFOA, the project can be considered a good model for successful implementation of Target Value Design, the Last Planner® System during design, building visualization, collaborative and set-based design, problem solving, and built-in quality [HAMZEH et al. 2009, p. 167].

The case study was conducted just before the end of the demolishment of the earlier structure on the site. The timing was perfect for the case study since preparation for the production phase was well underway. However, most of the personnel required for the production phase were not hired. Production phase in this case study refers to all the activities of planning, coordination and execution of all operational activities for physically constructing the building. Project management was very interested to implement lean management into the production phase and the preparation efforts for implementing lean methods such as pull-based material supply, Last Planner® System and tact time among others, were underway [PRODUKTENTWICKLUNG 2014a, p. 67]. Focus of the case study was in the pull-based material supply system. As explained in section 5.1.1, material supply system as a lean principle is operationalized through a lean control system (LCS). As such, material supply system is suitable for being a subject of the method presented in chapter 4.

5.1.3 Method Execution

Before starting with the method application, the vertical complexity unfolding of the project organization in CHH was performed. The vertical unfolding was performed by interviewing the project managers and consulting the organizational charts.

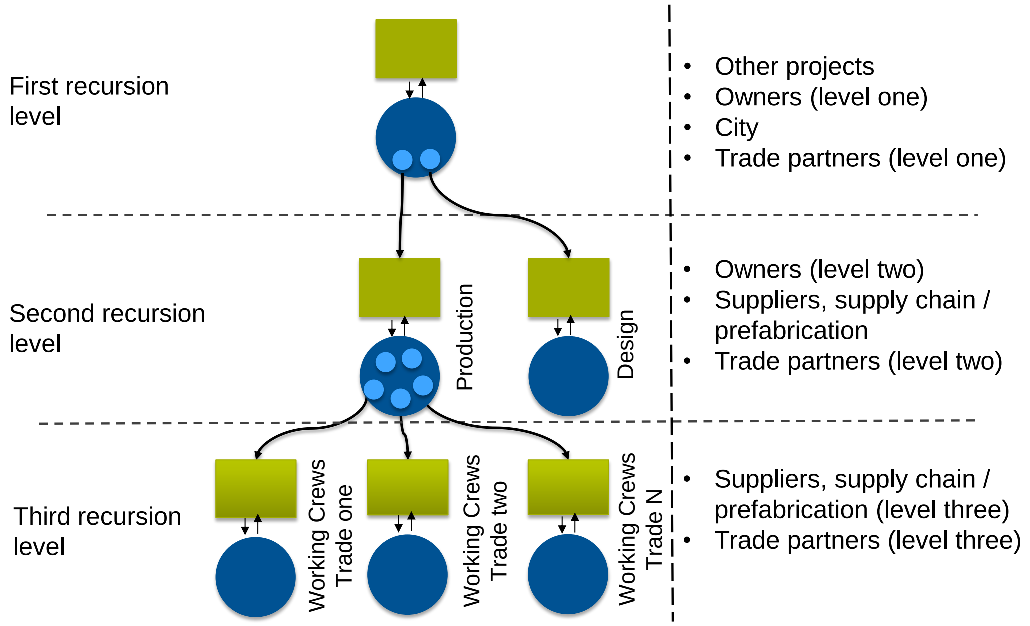

Figure 5-1: Vertical complexity unfolding in CHH project

As seen in Figure 5-1, the first recursion level represents the overall CHH project. In the second recursion level, there are two VSMs: production and design organizations. In reality, these two organizations (and project phases) overlap, as design includes all activities that have to do with designing and planning architectural and engineering work including engineering changes during production. Therefore, these two organizations coexist till the end of production. Unfolding the organizations in this way is quite normal for project organizations, as for example BRITTON & PARKER unfold the project under their consideration in the same manner [BRITTON & PARKER 1993]. It is important to mention that the material supply system is present within the production VSM. Therefore the focus of our analysis is in this recursive level, as the management of material supply system is distributed within the systems of production VSM. The operational units of production VSM (system 1) are different trade partners' working teams that operate directly in the construction and represent the third recursive level. Some of these crews are dedicated for material supply, which means that they are directly affected by the management systems of the second recursive level. Therefore, it is obvious that the production VSM at the second recursive level is the subject of the method to be applied.

Step One and Two (Analogy and Transfer)

Because of the early planning stage, no running material supply system was designed or established for the project during this case study. Most of the positions in relation to the material supply system were still vacant and the suppliers and prefabrication partners were still not actively engaged. Therefore, the method had to be adapted to these circumstances and in agreement with the manager in charge of designing the material supply system, the steps one and two of the method were performed in parallel and in a different way as prescribed in the method. The lack of stakeholders hampered the performance of brainstorming session of the first step, therefore, the initial material supply system functions were obtained from project-own RAM (see third step under for the definition of RAM) and by individual discussions with the production managers in CHH project, who provided input about the material supply system employed in the previous construction projects (as the material supply system for CHH project still did not exist).

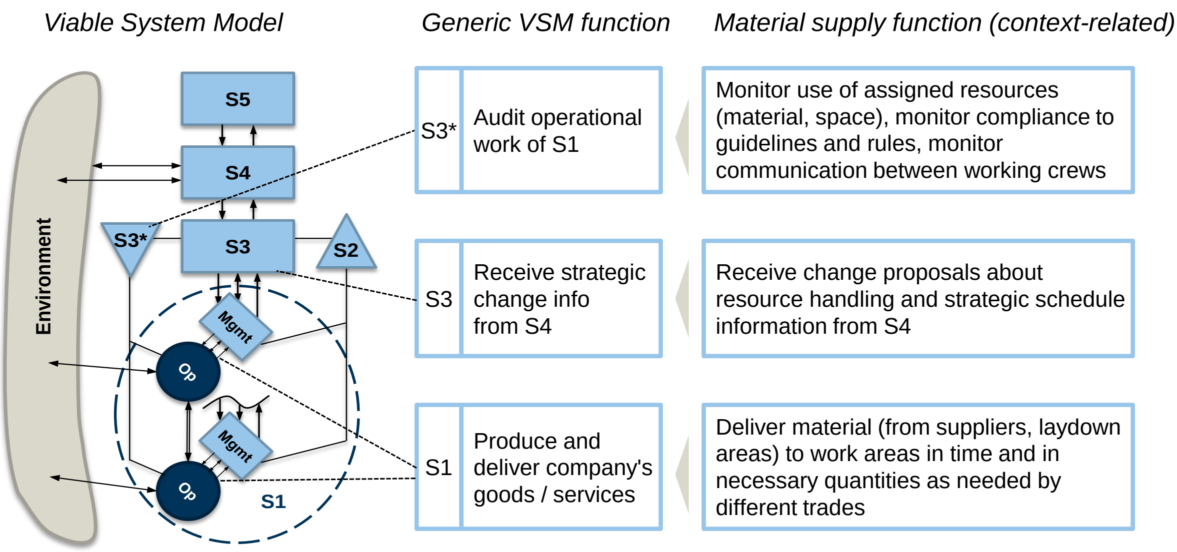

Figure 5-2: Excerpt of material supply functions corresponding to the VSM functions

This way, a preliminary list of functions was obtained which was further enriched by obtaining analogic functions based on VSM functions. This was performed mainly with the manager responsible for the design of the material supply system. In this manner, an extensive list of functions was obtained containing 46 entries. In Figure 5-2 only a small excerpt of the identified context-related functions is provided.

Step Three - Instantiation

The third step (instantiation) was conducted in consultation with the project's production management experts. Besides the minimum two inputs required for this step of the method (VSM representation of the organizational entities from step one, and the list of functions from step two) a project-own responsibility assignment matrix (RAM) was available. A RAM is a matrix that contains two domains, namely functions and organizational entities, as well as assignments linking these two domains [KERZNER 2013]. The RAM contained a list of tasks and activities already planned for the project's production system, and their assignment to different organizational entities. The RAM was used in step three to link the obtained functions from step two with existing organizational entities. The tasks and activities given in the RAM were quite abstract so they could be regarded as functions. Therefore, the given list could be directly rearranged in accordance to the VSM overview of the organization (obtained with vertical complexity unfolding - Figure 5-1). At this point, the functions obtained in step 2 that were missing in the RAM, were added to the latter. In addition, functions from the given RAM that matched functions obtained from step two but were unclear (e.g. too generally phrased), were rephrased appropriately. To ensure non-ambiguous understanding of original and new RAM functions, specific terms had to be clarified with the project's experts. This clarity showed to be essential for comparison of the conceptual solution with the existing RAM functions, and even more so in terms of usefulness of the results. Figure 5-3 gives an outline of the inputs and the resulting output of the first part of the instantiation step.

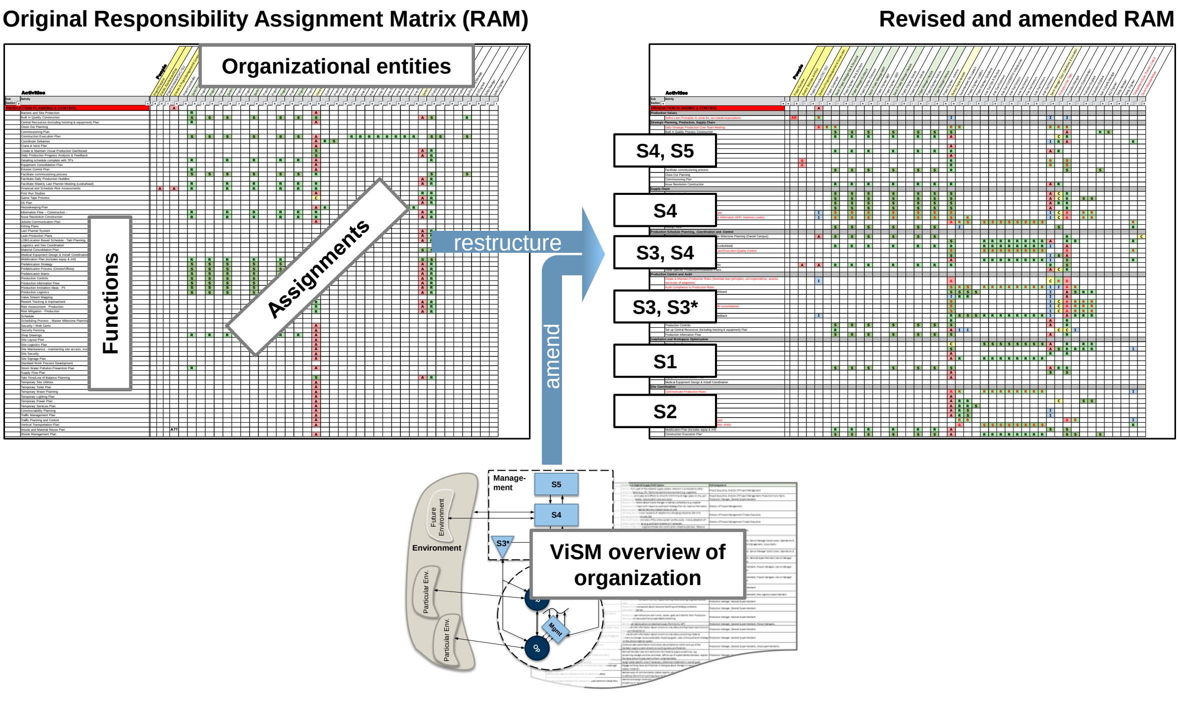

Figure 5-3: Outlined inputs and results of the first part of instantiation

To complete the instantiation step, the revised and amended RAM functions were assigned to appropriate organizational entities as shown in Figure 5-3. In this project, the assignments are differentiated into several degrees: responsible, accountable, support, consult and inform. Based on these so-called RASCI-definitions (see [JACKA & KELLER 2009]), the organizational entities were linked to the corresponding RAM functions. In expert workshops, the assignments were set referring to the VSM overview of the organization (e.g., by asking "who was seen as part of VSM system X, and what functions are to be fulfilled?"). The different degrees of assignments allowed for documentation of required communication channels, since senders (e.g., those responsible) and recipients (e.g., those to be informed) of information necessary for control could be defined. Figure 5-4 shows an excerpt of the resulting assignments.

S3: Receive change proposals about resource handling and strategic schedule information from S4

S3*: Monitor use of assigned resources (material, space), monitor compliance to guidelines and rules, monitor communication between working crews

Functions		People: Director of Project Management & Construction	General Superintendent	Superintendent Site Logistics	Project Engineer Logistics	Project Engineer Operations	Senior Manager Const. Operations & Innovation	Production Core Team	Production Manager	Production Superintendent	Production Engineer	Produ
Strategic Planning, Production, Supply Chain												
Daily Strategic Production Core Team Meeting		A	R	R			R	R	R			
Prefabrication Strategy			S				A	C	R			
Prefabrication Process (Onsite/Offsite)			S				A	C	R		S	S
Production Control and Audit												
Audit Compliance to Production Rules			S	R	S		I	I	A	R		
Create & Maintain Visual Production Dashboard			S	S	S	S	I		A	S	R	R
Create & Maintain Logistics Dashboard			I	R	R		I		A			

Figure 5-4: Examples of derived context-related functions (red font), new assignments (red font) and revised assignments (blue font)

Overall, the project's initial RAM was amended by 10 functions (related only to pull-based material supply) that did not exist in the first place. Furthermore, circa 208 (compared to circa 248 in the original RAM) responsibility assignments resulted from the application of the method, including many adjustments to the already existing assignments. The output of the method (amended RAM) can be seen in Appendix 9.1.

As a result of performing the method, the RAM was greatly detailed in terms of assigning tasks to be performed by project personnel and in terms of transparency of the assignments. The obtained functional representation of the pull-based material supply system is equipped with the mechanisms that enable adaptation to external and internal changes. The task assignments laid the ground for appropriate job descriptions for positions yet to be filled. In addition, the identified control functions can be used for redesigning the overall production process, and design requirements for information systems that support material supply were about to be derived from the VSM's suggested communication channel structure.

Table 5-1: Functions added to the original RAM

Cluster	Function
Production Values (S5)	• Define material supply to strive for • Set overall expectations based on lean principles
Strategic Planning, Supply Chain (S4)	• Daily strategic production core team meeting (trade partner production managers and superintendents)
Production Control and Audit (S3, S3*)	• Audit compliance to production rules • Create & maintain logistics dashboard • Production tracking and analysis
Site Coordination (S2)	• Communicate production rules • Coordinate deliveries (a.k.a. delivery calendar) • Set up & communicate inventory dashboard • Maintain inventory dashboard (consumables, tools)

5.1.4 Evaluation Results of the First Case Study

Usually the prescriptive study is evaluated with the industry representatives who were involved directly with implementing the support. The method in this study was evaluated after its application by the project expert who was involved and contributed in application of the method. As the Design Research Methodology [BLESSING & CHAKRABARTI 2009] suggests, applicability and usability of the method as well as usefulness of the generated results were rated in a questionnaire that was designed to tackle these three evaluation criteria. The questionnaire, as data-collection method, was designed in such a manner that it requires as little interpretation or translation as possible before analysis. The full questionnaire can be found in Appendix 9.2. Closed questions of the questionnaire uses a six-point Likert scale, with 1 being “strongly disagree”, 2 – “disagree”, 3 – “disagree somewhat”, 4 – “agree somewhat”, 5 – “agree”, and 6 - “strongly agree”. It was decided to pick this scale, to avoid giving the participants a neutral option as it would be the case with a five-point Likert scale.

Applicability

Although VSM was conceived complicated and too abstract for direct application in its generic form, bringing it to a context-related level as part of the transfer step was regarded as helpful.

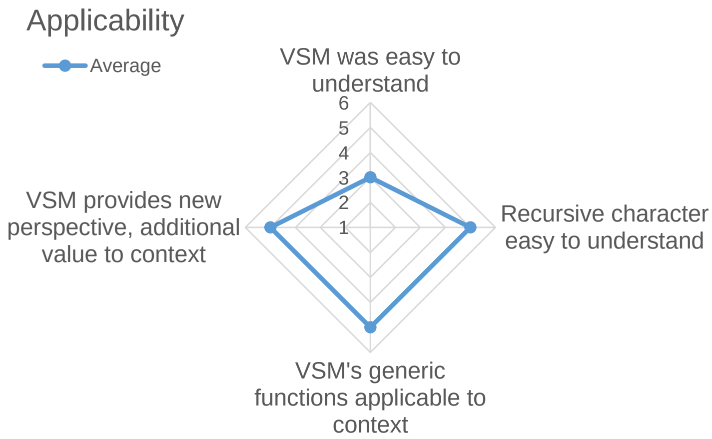

Figure 5-5: Evaluation of the applicability of the method in the first case study

Therefore, the analogy of functions as one of the key challenges in applying the method was not perceived as difficult – quite the opposite, it was seen as easy (scored 5 out of maximum 6 points). VSM was seen as a new perspective that brings additional value for lean material supply system (scored 5). A positive answer was given to the question whether the general functions of the VSM describe the functions required in lean material supply – therefore they are applicable for this context (scored 5). In addition, the recursive character of the VSM is stated as easy to understand and describes the experience of the experts in real projects (scored 5). The average score of applicability when all questions are taken into account is 4,5.

<u>Usability:</u>

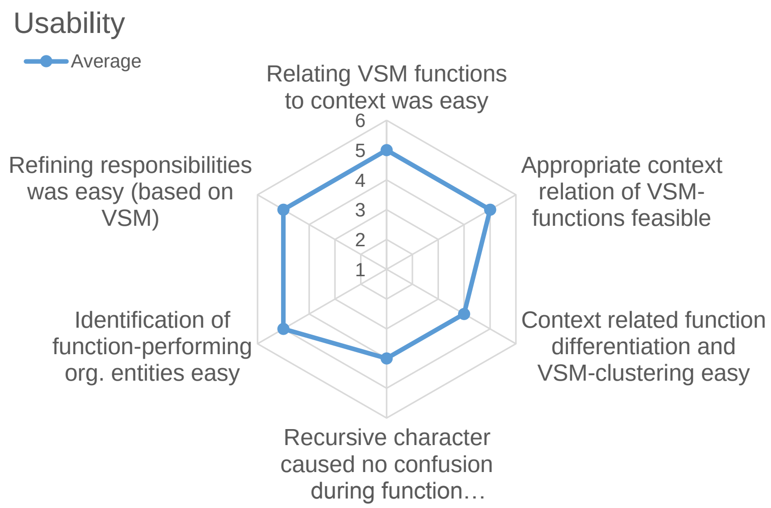

Figure 5-6: Evaluation of the usability of the method in the first case study

In terms of usability, the method was evaluated as easy to apply when reaching the context-related level and subsequently instantiating the context-related functions by assigning them to appropriate organizational entities (scored 5). Identification of the existing organizational structures that perform (some of) the VSM functions and refining the responsibilities (RASCI-chart) based on the context-related functions was also evaluated as easy (both scored 5). However, the clustering of functions as suggested by the VSM was perceived less easy (scored 4). Similarly, the recursive character of VSM appears to confuse the slightly the definition of functions (scored 4). The average score of usability when all questions are taken into account is 4,7.

Usefulness:

The results generated by applying the method were generally regarded as useful in terms of structural refinements, communication development and exposure of previously undetected challenges (all scored 5). The list of context-related functions is perceived as comprehensive to a certain degree (scored 4,5). However, the context-related functions were seen as somewhat essential to adaptability of lean material supply (scored 4). Same score was given to the recursive perspective as instrumental to bring additional value to the lean material supply system. The average score of applicability when all questions are taken into account is 4,6.

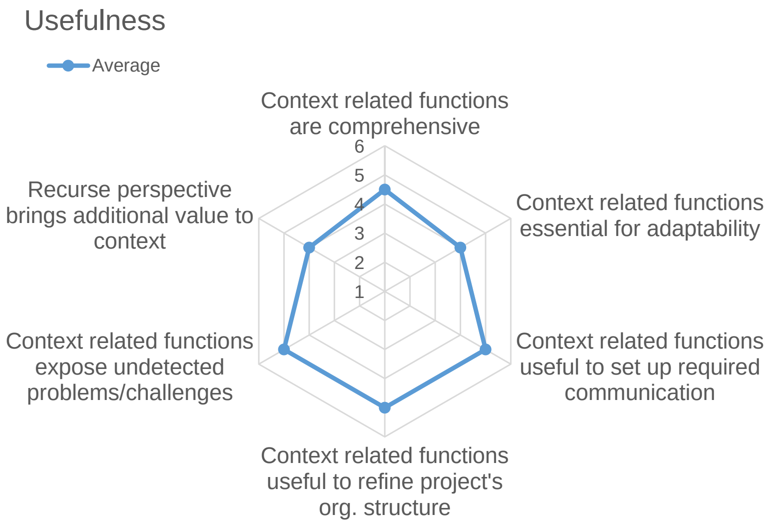

Figure 5-7: Evaluation of the usefulness of the method in the first case study

5.1.5 Summary of the First Case Study

When implementing lean, organizations face many issues. Two of them were identified in literature and described in the introduction of this case study. The first issue is the implementation of important aspects that are difficult to emulate, such as the “hidden” mechanisms that enable lean control mechanisms to adapt to externally induced changes. To tackle this challenge, the method utilizes the VSM as a canonical model for comparing, whether the employed LCS feature the functions necessary for adaptation to environmental and internal changes. This comparison is performed by means of functional analogies.

The second implementation issue is the different context these companies operate in. Because of this difference, the companies fail to embed the LCS to their own management systems, which ultimately leads to failure in adopting them properly into their existing management structures. This challenge is tackled in this case study by embedding the LCS functions to the right functional entities of the organization.

According to the manager responsible for lean material supply system interviewed after the application of the method, having the opportunity to work with this method provided him a new valuable perspective on how material supply systems can be implemented. As shown in Figure 5-8, the method scored very well in all three important evaluation categories: application, usefulness and usability. One of the biggest weaknesses of the method exposed in this case study is that VSM is considered a very theoretical model and not so easy to understand. This problem can be tackled by organizing workshops on VSM theory before the application of the method and by connecting the model to the real processes that exist in the context.

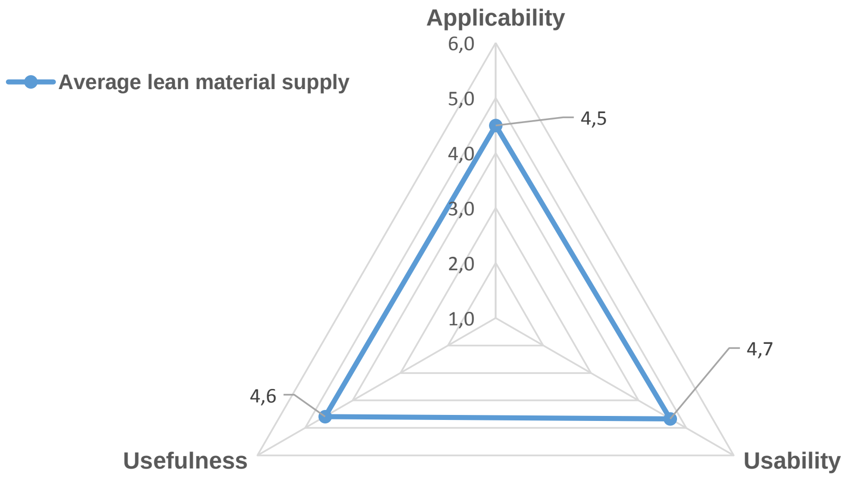

Figure 5-8: Evaluation results for the first case study

5.2 Platform Life-Cycle Management Case Study

In the second case study, the method is applied in the context of platform life-cycle management. This subchapter begins with a description of the initial situation pertinent to the case study and argues why platform control systems can be regarded as MCS (section 5.2.1). In section 5.2.2, the application of the proposed method is described. The evaluation results of applicability, usability and usefulness of the method are described in section 5.2.3. Section 5.2.4 provides a summary of the second case study. This case study was performed as part of the author's doctoral project within the Collaborative Research Center SFB 768, transfer project 1 (see section 1.4.1).

5.2.1 Introduction of the Context

The second case study was performed within the SFB 768 collaboration research center. The author was involved in transfer project T1 (SFB 768 T1): "Methodology for Creating Cycle-robust Module and Platform Strategies". The goal of the project was to develop concise guidelines for conception of modular and platform strategy under dynamic influences. For addressing this goal, two approaches were developed that in an interactive manner make possible the emergence of the modular and platform strategy. The top-down approach addressed strategic dynamic requirements in relation to the platform systems, whereas the bottom-up approach addressed the technical requirements at product architecture level. The author was responsible in designing and performing the research related to the top-down approach, which was divided into three phases. In the first phase, the required flexibility of the product's features and functions is determined [ELEZI et al. 2015]. In the second phase, the operationalization of this flexibility is planned in form of product-technology roadmaps. The third phase addresses the planning of life-cycle management measures for product platform and modules, which involves the development of a control system that guides the operationalization of the modular and platform strategy and facilitates adaptive measures.

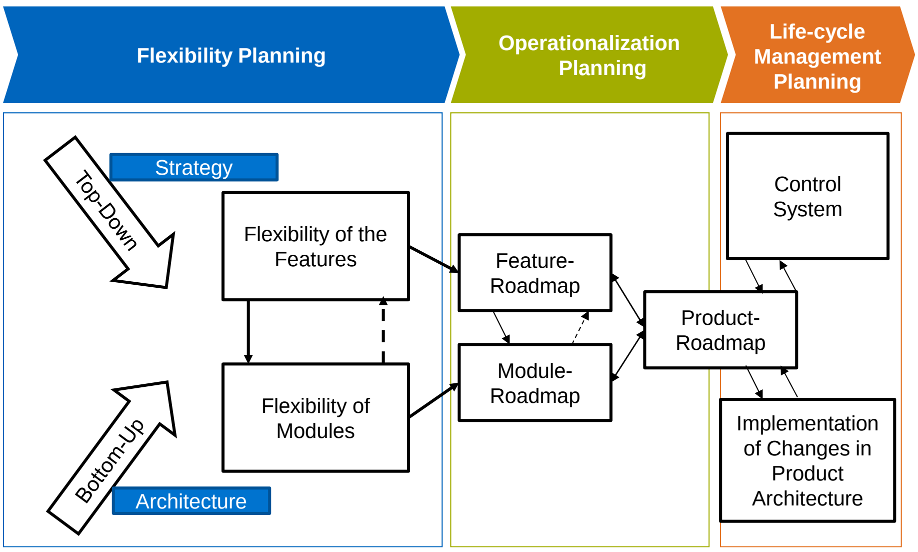

Figure 5-9: The three research phases of SFB 768 – transfer project 1 (translated from [MAURER et al. 2014, p. 15])

The main task in the third phase was to develop a control system that monitors the internal and external influence factors for controlling the progress of the planned activities in relation to platform system. The control system should monitor the environment for unanticipated changes of the influencing factors and contain processes that initiate the right response to these changes. In other words, the control system to be designed for this project was a typical management control system (MCS – as defined in section 2.3.2). As such, this control system was subject to the method described in chapter 4. Therefore, in phase three of the SFB 768 T1 project, the method was applied for conceptualizing the necessary control functions of the MCS in an industrial setting. This industrial setting is introduced in the next paragraph.

The case study was performed in one of the world's largest manufacturers of household appliances, with 47,000 employees in 50 countries and several billion Euro revenue in 2014 and more than 40 production locations in Europe, Asia and America. Company's product range is split up into divisions for cooking, refrigeration, dishwashers, and laundry. The case study was performed in business unit refrigeration (BUR) of the company, which alone offers ca. 1000 variants of freezers, refrigerators and combined refrigerators. In 2013, BUR started an internal project for increasing the degree of modularity in their products. The main objective of the project was to evaluate the long-term differentiation requirements for the products and based on this information assess the degree of the flexibility that has to be vested in the modules. The flexible modules that are required for differentiation would be designed in several variants to ensure that the products fit to possible changes in customer preferences. In cooperation with SFB 768 T1, the internal project thus was focused in making the product architecture more responsive to market demand. This form of the product architecture arrangement however bares certain risks. The first risk is that, although the product architecture is initially ready for responding to the changes of customer preferences, the company could fail to identify the right time for introducing changes in their product portfolio as response to those changes. In addition, unpredicted changes can occur that require changes in current product architecture or even can make it obsolete, e.g. a new technology that changes entirely the product architecture or a set of influencing factors occur that are totally different from initial anticipation (at the time when the product architecture was conceptualized). Therefore, in order to be responsive to market changes, the companies applying platform systems should incorporate a MCS that monitors the environment for aligning the product architecture to changes in the market. As part of the third phase in SFB 768 T1 project, such a MCS was conceptualized at the functional level by use of the method proposed in this thesis. In the following, the MCS conceptualized in this case study will be referred to as modular architecture control system (MACS).

5.2.2 Method Execution

An important fact in relation to this case study is that previously no MACS existed in BUR. The literature in engineering management also lacks guidelines and descriptions of MACS that monitor the modular and platform architectures. This had an important implication for the application of the method in this case study as the MACS had to be developed from scratch.

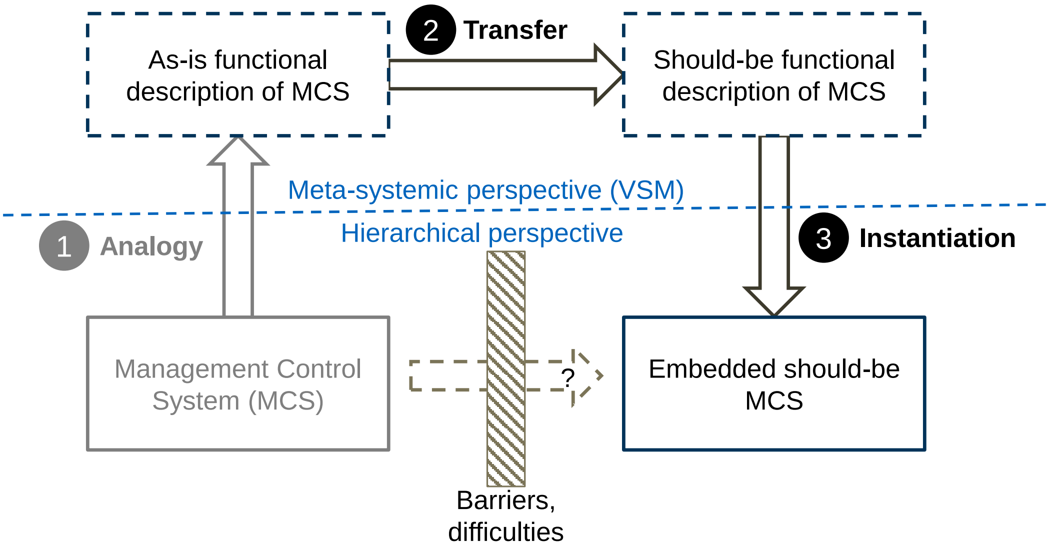

Figure 5-10: Adapted method for the platform lifecycle management case study

As no MACS was in place, the application of the method began with step two in order to derive the should-be functional description of the MACS directly (refer to Figure 5-10). This way of using the method is conceived more difficult, as each VSM function needs to be analyzed for possible deductions of analogical context-related functions. Hence, in this case study, the BUR managers were very actively involved and engaged in applying the method.

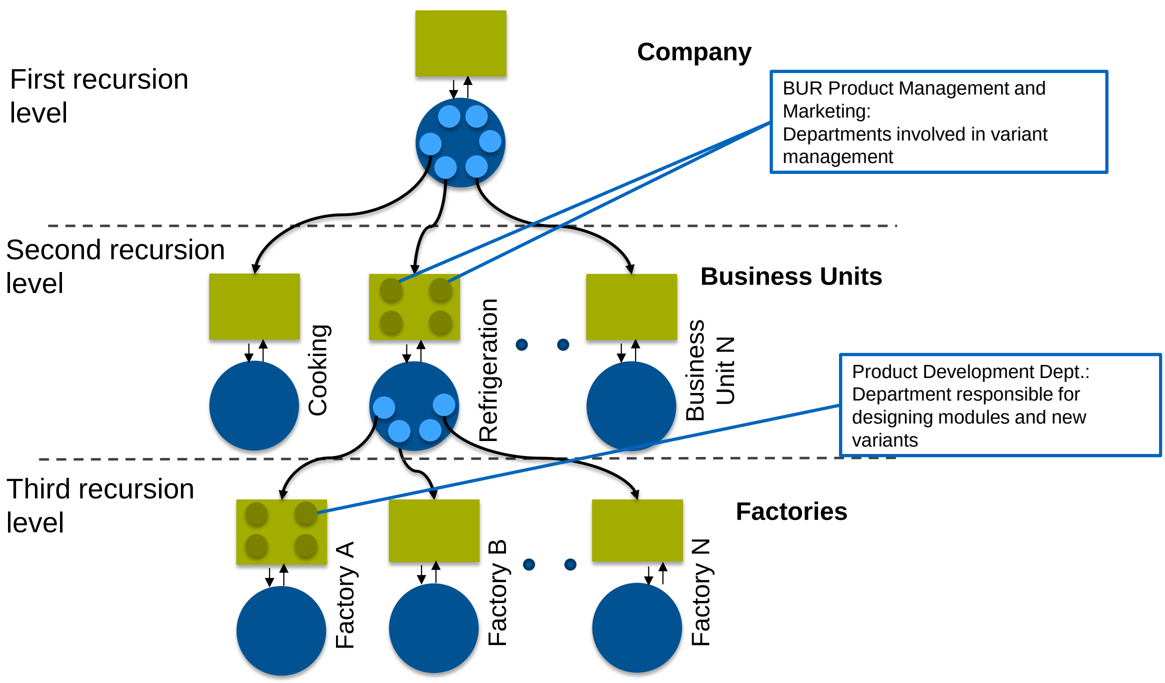

Figure 5-11: Vertical unfolding of the company and the relevant recursive levels for the case study

Because of practical reasons, management required that the MACS was designed in such a way that it can be embedded into the existing BUR's variant management structure easily. This requirement implied that the vertical complexity unfolding was focused on assessing in which of the organization's existing recursive levels the variant management structure was represented.

As seen in the Figure 5-11, the relevant structures of BUR's variant management exist in the 2^{nd} and 3^{rd} recursion levels. At the second recursion level, product management and product marketing departments are involved, whereas at the third recursion level, the product development department is involved. For the MACS, both these recursion levels are highly relevant since control processes are present in both of them. For example, at the second level strategic decision making about the required flexibility is made, whereas in the third level technical decisions about the feasibility of technical solutions are taken, among others.

Table 5-2: Departments involved in variant management and their role from VSM perspective

VSM Systems	First recursive level	Second recursive level
S5	BUR Policy	Central Development
S4	Product Marketing	Pre-development
S3	Product Management, Marketing	Head of development center
S2	Project Office, VM guidelines	VM guidelines
S1	Variant Coordinator	Team leader

Once the roles of the departments from the VSM perspective were known, the application of the method could begin. As explained above, the method was applied beginning with step two.

Step Two (Transfer)

The functions of MACS in the second recursion level were derived entirely from the general functions of the VSM in a workshop involving experts from three departments: product management, product marketing and development department. In the workshop, each VSM function was discussed and the appropriate context-related function was derived based on functional analogies. The final list of context-related functions of the MACS contains 36 functions categorized in the 5 systems of the VSM (see appendix 9.3). In similar manner, the context-related functions for the third recursion level were obtained. However, the workshop with the managers of the third recursion level could not be performed. Therefore, a workshop with the PE cybernetic group was conducted to complete this step for the third recursion level. For this reason, only the application of the method for the second recursion level was evaluated (section 5.2.3) as it contains feedback from the managers of BUR.

Step Three (Instantiation)

In this step, the functions obtained in the second step were allocated to appropriate functional entities of BUR. As BUR's management required to allocate these functions within the variant management's functional structure, Table 5-2 was used as the key element for allocating the functions to these entities for both recursive levels. Appendix 9.3 shows the MACS functions and their assignments to the organizational functional entities for the second recursion level.

5.2.3 Evaluation Results of the Second Case Study

Same as in the first case study, the evaluation of the method was performed along three criteria: applicability, usefulness and usability. The evaluation was performed after the workshop that was organized for identification of the context-related functions. Overall three participants were involved in the evaluation, and each of them participated in the application of the method. The participants were managers coming from three departments: product management, product marketing and engineering department of BUR. The evaluation was performed with the help of a questionnaire. The questionnaire, as a data collection method, was designed in such a manner that it requires minimal interpretation for analysis. The closed questions of the questionnaire used a six-point Likert scale, 1 being "strongly disagree", 2 - "disagree", 3 - "disagree somewhat", 4 - "agree somewhat", 5 - "agree", and 6 - "strongly agree". This scale was chosen in order not to give the participants a neutral option as it would be the case with a five-point Likert scale. The full questionnaire can be found in appendix 9.4.

<u>Applicability</u>

For assessing the applicability of the method, five questions were formulated. In the diagram bellow (Figure 5-12), the results in regard to the applicability of the method obtained from the questionnaires are shown.

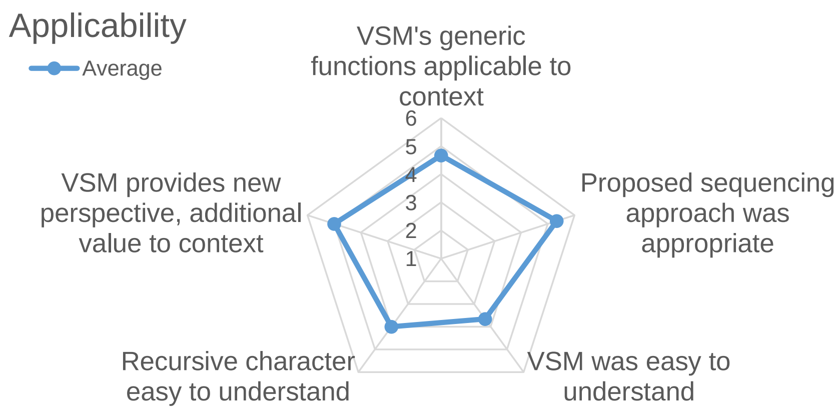

Figure 5-12: Evaluation of the applicability of the method in the second case study

The managers consider that the generic functions of the VSM are applicable for obtaining the context-related functions of the MACS, which justifies the use of the VSM as an appropriate source of the required functions (scored 4,7). The applicability of the context-related functions in designing the MACS control process (which can be derived from the VSM structure) was also evaluated as appropriate (scored 5,3). Similar as in the previous case study, the managers find it moderately difficult to fully understand the VSM (scored 3,7). The recursive character of VSM was seen slightly less difficult but still challenging (scored 4). According to the managers, VSM provides a new perspective that brings additional value to platform life-cycle management (scored 5).

Usability

In assessing the method's usability in this case study, the managers had to answer three questions. Each of the questions was designed to get feedback about each step of the method.

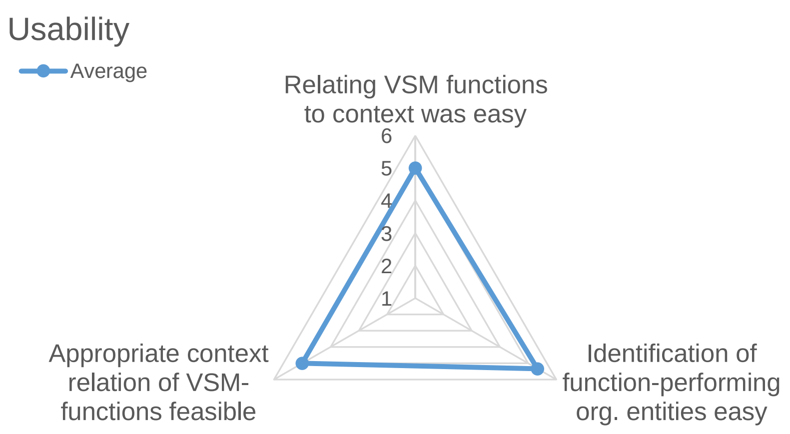

Figure 5-13: Evaluation of the usability of the method in the second case study

The first question concerned easiness to relate VSM's generic functions to context-related functions specific to MACS. The experts gave quite a high score to the questions which communicates relative easiness to do so (scored 5). The second question concerned easiness to identify the existing structures (within the company) that perform some of the functions of the VSM. Again, the experts provided a high score affirming the question (scored 5,3). Lastly, generic functions of the VSM were appropriately brought into the context of platform life-cycle management, based on the manager's feedback to the third question (scored 5).

Usefulness

For assessing the usefulness of the method for the particular case study, six questions were formulated. In Figure 5-14, the results in regard to this evaluating criterion are shown.

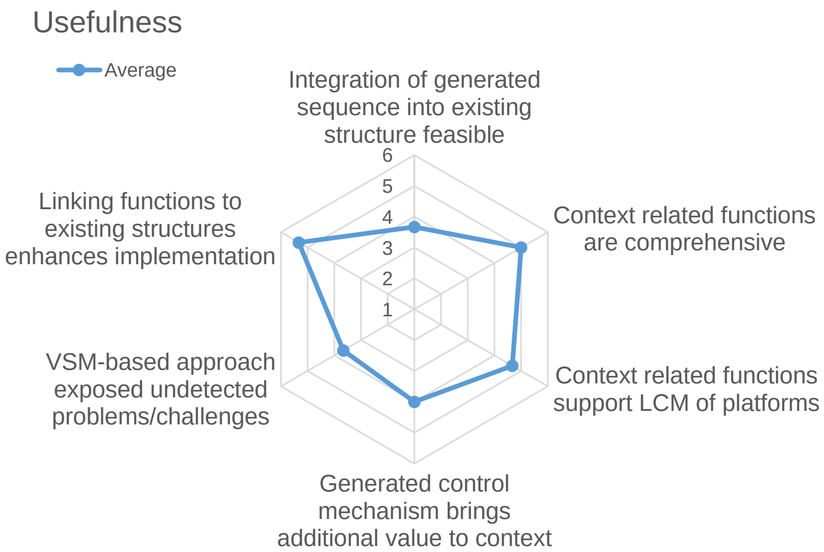

Figure 5-14: Evaluation of the usefulness of the method in the second case study

The first question caused division of the manager's opinions. Namely, two managers considered the method to expose some problems which would not be detected otherwise (both gave score 5 and 4 respectively), whereas one manager considered this not being the case (gave score 2). The average score related to this question therefore is quite low (3,7). The list of context-related functions (the outcome of the workshop) is regarded as comprehensive (scored 5). More or less, all managers were of the opinion that context-related functions can be useful to set up a MACS for lifecycle management of platforms (scored 4,7). Similarly, managers agreed to a certain degree that the control processes obtained from the context-related functions brought additional value (scored 4). The managers strongly agreed that the allocation of functions to existing structures and responsible persons helps in understanding and implementing the MACS (scored 5,3).

5.2.4 Summary of the Second Case Study

This case study was performed within the framework of the SFB 768 T1 "A methodology for conception of cycle-driven platform and module strategy". The industry partner in this case study was the business unit refrigerator of an international home appliances manufacturer.

The method described in chapter 4 was applied to identify the necessary context-related functions for design of a modular architecture control system that operationalizes the life-cycle management of platforms. In addition, a suggestion on how these functions should be embedded in the existing variant management functional structure of BUR was provided.

The evaluation of the method implementation in this case study was performed as an initial descriptive study II (DS-II). For this type of evaluation, at least three criteria must be assessed: applicability, usability and usefulness [BLESSING & CHAKRABARTI 2009, p. 195].

The evaluation was performed with the help of questionnaire that was designed to tackle the three abovementioned evaluation criteria.

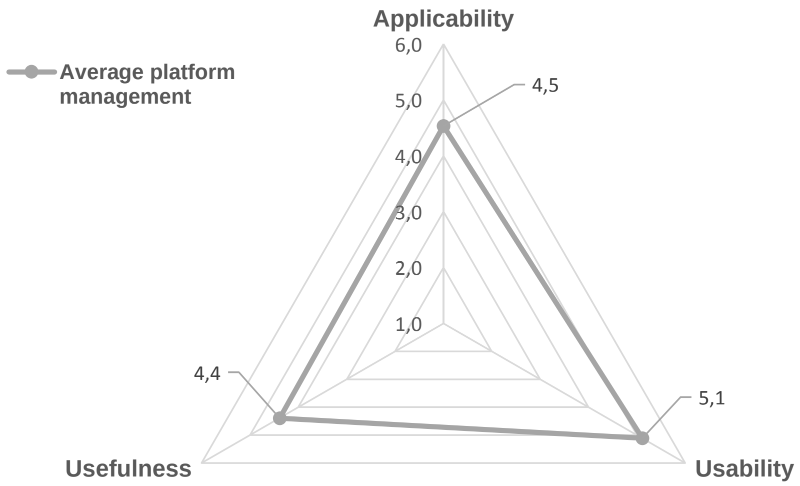

Figure 5-15: Aggregated evaluation results for the second case study

Based on the feedback from three managers that were actively involved in the application of the method, all three evaluation criteria were rated positively. The highest average score (5,1 out of 6) was given to the usability of the method (the output of the method). The questions in the questionnaire related to the usability of the two method steps applied in this case study (transfer and instantiation step).

The second evaluation criterion, applicability of the method, was also rated moderately high (4,5 out of 6). It is important to notice that the managers had difficulties to fully grasp the VSM and the theory behind it in the limited time-frame of the workshop. This factor contributed to a somewhat lower score of applicability in comparison with usability.

The third criterion, usefulness of the results, scored lowest (4,4 out of 6). This is due to the fact that one of the managers did not agree that the method exposed some of the problems and challenges that otherwise would not have been exposed, whereas the two other experts thought the opposite.

In conclusion, the evaluation results of the second case study indicate that the method is appropriate for functional conceptualization of MACS and the managers are pleased with the outcome of the method application.

5.3 Engineering Change Management Case Study

In the third case study, the method described in chapter 4 is applied in context of Engineering Change Management (ECM). The subchapter starts with a short introduction to ECM, with a special emphasis on representing ECM as a MCS. In section 5.3.2 the context in which the third case study was performed is introduced. The application of the method is described in section 5.3.2. The evaluation results for applicability, usability and usefulness of the method in the ECM case study are shown in section 5.3.4. A short summary of the third case study is provided at the end of this subchapter (section 5.3.5). This case study was performed within the research collaboration with the Department of Civil and Environmental Engineering at the University of California, Berkeley, as part of the author's doctoral project.

5.3.1 Engineering Change Management as Management Control System

Engineering change (EC) processes are present at the back end of almost all product development projects. EC processes usually change parts, drawings, software of the product, in order to meet variations in internal and external requirements. Therefore, engineering change management (ECM) is crucial for overall success of the product development efforts as it is used to coordinate process activities which drive the maturity progress of the product. The causes of changes can be diverse, ranging from external ones (such as change in customer preferences, newly available technologies, possible malfunctions of the product) to internal ones (such as manufacturing issues, modularization requirements, financial and budget restrictions) [NADIA et al. 2006].

Although engineering changes potentially increase the quality and the probability of the product's success in the market, they are also the main reason for delay of the product's market introduction and for additional costs. Due to the fact that changes are inevitable and essential to maintain the competitiveness in the market, proper management of these changes is an imperative. Engineering changes are important drivers of development costs, product lead time and productivity – a failure in controlling them leads to time delays, lack of control over the configuration of products, cost increase and profitability drops. Therefore, ECM has to be organized in an effective and efficient way [HUANG & MAK 1999a, LOCH & TERWIESCH 1999, REDDI & MOON 2011].

Though engineering changes are necessary, the negative impact of changes in product development cycle time and cost has been reported in a number of studies. ACAR et al. conducted a survey in UK companies involved in designing and manufacturing and discovered that over 50% of these companies consider ECs as the main source of problems in their product development efforts [ACAR et al. 1998]. BROWN shows in his study that the majority of changes cause scrap, wasted inventory, and disruption to supply and manufacturing [BROWN 2006]. SODERBERG states that ECs consume one-third to one-half of engineering capacity [SODERBERG 1989]. Additionally, LINCKE estimates that 20% to 50% of tool costs for developing a product are incurred as a consequence of EC efforts [LINCKE 1995]. Another interesting result comes from FRICKE et al. who in their study of German manufacturing firms explain that only 40% to 60% of ECs were technically necessary [FRICKE et al. 2000]. DEUBZER et al. conducted another survey with 50 German manufacturing companies, which shows that 56% of design changes happen after the initial design phase, of which 39% are deemed avoidable [DEUBZER et al. 2006].

Nevertheless, changes and their release are generally associated with significant delays, in which the total processing time of ECs is often several times higher than the time needed for their resolution. For this reason, most companies have defined formal processes for the realization and implementation of ECs [JARRATT et al. 2004, LOCH & TERWIESCH 1999]. Well-structured processes are in general supported and monitored by specially organized departments. Moreover, there are companies that have informal ad-hoc processes for documenting and monitoring the ECs [HUANG & MAK 1998]. Designers need support for making decisions about how to implement ECs and organize their EC processes. In each case, complex questions that arise during engineering changes must be answered to assure the success of a product [LINDEMANN 2009]. Therefore coordinated actions to comply with e.g. control of complexity, planning reliability and regulatory frameworks are required [SHARAFI et al. 2010]. However, the EC processes have a crucial role in improving the product and as mentioned above, provide means for companies to cope with highly dynamic changes in the market, and efforts to completely eliminate them are unrealistic. This means that better management of ECs can lead to improvements in the overall EC process and consequently shorten the PD cycle time and reduce costs.

Most challenges in contemporary ECM lay in communication and control aspects. Although the importance of communication is discussed in the contemporary ECM literature for addressing specific issues, control aspects are not discussed [HUANG et al. 2003, HUANG & MAK 1999b, HUANG & MAK 2003, HUANG et al. 2001]. HUANG & MAK identified, besides others, poor communication among involved parties, people indifference and insufficient cooperation within ECM as critical issues [HUANG & MAK 1999a]. Initial stages of EC process provide enormous potential to harmonize communication between change stakeholders mainly because of the presence of informal communication that cannot be formalized entirely [TAVCAR & DUHOVNIK 2005]. A connective role for coordinating correlated departments in performing ECs is mentioned as an important structural feature. Furthermore, literature demands for flexible workflows due to the high degree of unpredictability and uncertainty [LOCH & TERWIESCH 1999, TAVCAR & DUHOVNIK 2005]. Coordination, communication and process control are identified as being especially important for ECM due to its larger context of allied concurrent engineering (ACE) [CHEN et al. 2002]. Additionally, IVINS et al. suggest an approach emphasizing the need for establishing powerful control and coordination functions and also demanding for flexible and transparent processes [IVINS et al. 2004]. In the context of ACE, literature outlines the interconnection of ECM with the new product development process, containing some overlaps within a multi-project environment. One example is competing resources between NPD and ECM [LI & MOON 2011]. Finally, FRICKE et al. state that literature agrees on the necessity of implementing changes more efficiently, however research lacks in approaches and methods to do so [FRICKE et al. 2000].

To summarize, HUANG et al. and IVINS et al. refer to ECM as a system facing various management difficulties [HUANG et al. 2001, IVINS et al. 2004]. These difficulties, as mentioned above, include coordination, communication and control difficulties among others. In this context, ECM can be regarded as management control system (MCS), as it tries to steer the efforts of the engineering towards efficient and effective engineering changes. Therefore, ECM represents a perfect subject for the application of the method developed in this study (chapter 4). In the following section, the context of the case study in which the method was applied is introduced.

5.3.2 Introduction of the Context

In 1971, a 6,6 M_L (Richter scale) earthquake hit California and devastated urban parts of Los Angeles. It caused a lot of fatalities and material damage, but the most shocking fact was that a hospital collapsed killing most of the patients and healthcare workers and in addition most of other hospitals were damaged to a state of being non-functional. The health service was paralyzed in Los Angeles when it was most needed. Learning from this tragic episode, the Californian State Legislature passed the Alfred E. Alquist Hospital Seismic Safety Act in 1973 to prevent similar events from happening again [SHWARZENEGGER et al. 2005]. The main purpose of this act is to support building of hospitals in California that can sustain major earthquakes and remain functional in the aftermath.

The responsible body to oversee the implementation of this act during the design and construction of hospitals in California is Office of Statewide Health Planning and Development (OSHPD). Main responsibilities of OSHPD include: establishing building standards that govern construction of these types of facilities; reviewing the plans and specifications for new construction, alteration, renovation, or additions to health facilities; and observing construction in progress to ensure compliance with the approved plans and specifications [COLEMAN 2013, p. 2]. Each hospital project needs to employ an Inspector of Record (OPR) [OSHPD 2011], whose main responsibility is to ensure the implementation of the Alfred E. Alquist Act and serve as liaison with OSHPD. Once the detailed design of the building project is approved by OSHPD, any incremental change to design should be reported to OSHPD for further approval. In addition to OSHPD requirements, there are other legal requirements that each building project needs to comply, such as the requirements from the California Building Code (CBC), and requirements from Americans for Disabilities Act (ADA). All these legal requirements made engineering change management (ECM) a very important process at the CHH project (CHH project is already introduced in section 5.1.2). The management of CHH project recognized, that for a successful completion of the project, a proper ECM structure and process should be in place. It is important to note that the engineering changes at this point were mainly focused in changing an old structural plan that was approved by OSHPD. The new structural plan (that was agreed with the local authorities) was changed gradually by using engineering changes that were submitted one by one to OSHPD for approval. Therefore, the case study is focused in design changes concerning structure of the building on project management level and at the level of the contractors performing design tasks in the building plan.

At the time when this case study was conducted, the CHH project was still in the detailed design phase. In the construction field, the old building was almost fully demolished. Each contractor or stakeholder in design is responsible for one or several parts of the design, which at the end are connected by building information modelling (BIM). BIM represents the development and use of computer-generated n-dimensional (n-D) models to simulate the planning, design, construction and operation of a facility [AZHAR 2011, p. 1].

5.3.3 Method Execution

As stated in the prescriptive part of this thesis (chapter 4), the vertical complexity unfolding of the organization should be performed before starting with the method execution. In this case study, the unfolding was performed by interviewing the project executive, OSHPD and commissioning manager, as well as the senior manager for structural cluster [PRODUKTENTWICKLUNG 2014c, p. 70].

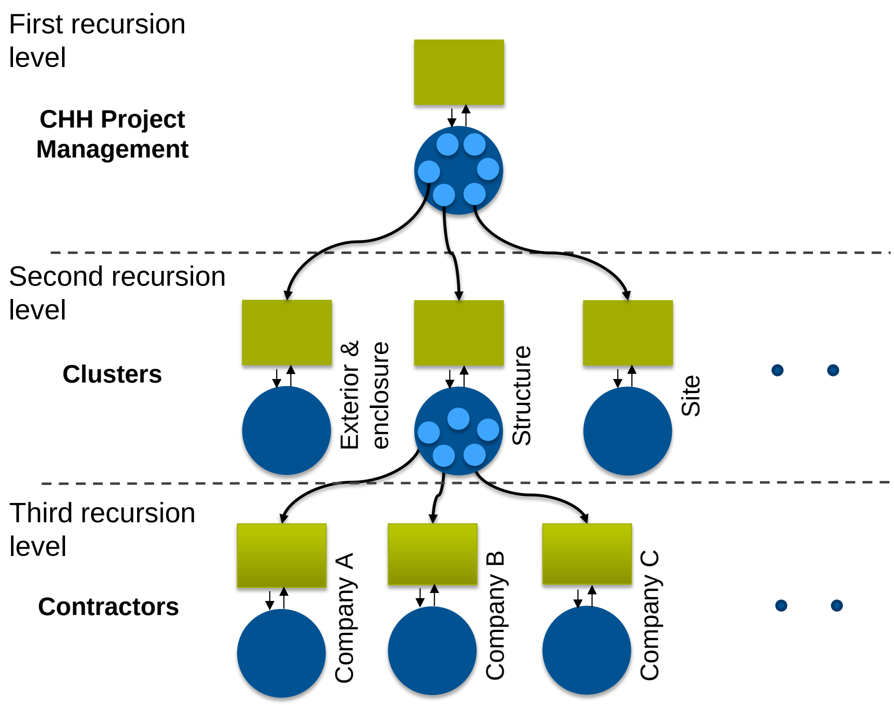

Figure 5-16: Recursion levels at CHH project

As seen in Figure 5-16, the highest recursion level represents CHH project management level. At this level, issues such as project norms, values and strategy are defined as well as the overall project control is performed. The second recursion level represents groups of contractors (clusters) working in particular types of work in the construction, such as exterior and enclosure, structural works, site works and so on. For this reason, this recursion level is referred to as the cluster level. This level is crucial for the ECM, since most of the engineering changes occur within these clusters and occasionally a single change involves many clusters. Third recursion level is consisted of particular contractor companies. This level is not as important for the case study because the focus lies in the ECM for the CHH project, not the ECM of particular contractor companies. The system in focus for this case study consequently covers the first and the second recursion levels depicted in Figure 5-16.

Step One – Analogy

According to the method described in chapter 4, the first step involves identification of the existing context-related functions of MCS and their categorization into VSM systems. In order to identify the functions of the ECM, existing general observations and informal interviews at the CHH project were employed as a first step. In addition, several cases of engineering changes of different scope were observed in order to identify context-related functions. This resulted in a preliminary list of functions for the first and second recursive levels that describe how the engineering changes are managed at CHH project. Next, the context-related functions were compared to the VSM functions. Based on the functional analogies, the context-related functions were assigned to VSM systems (see Appendix 9.5). In Figure 5-17, the outcome of this step is summarized.

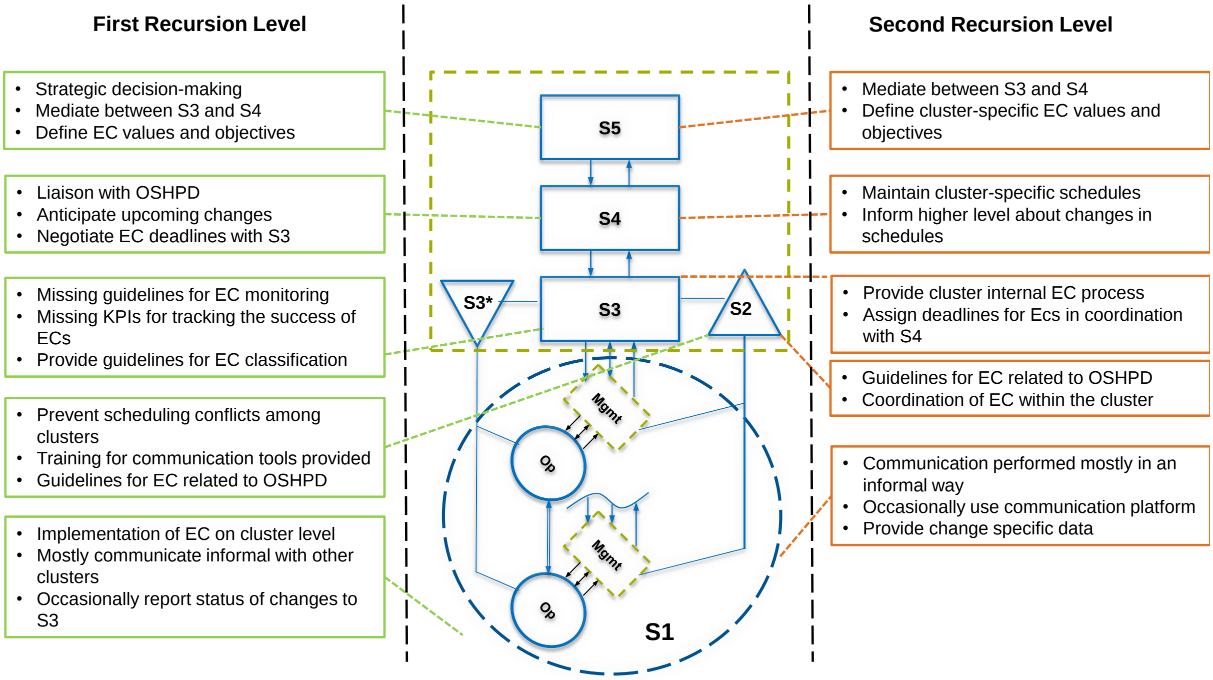

Figure 5-17: First and second recursive level as-is ECM functional model – an overview

First recursion level:

In relation to ECM, system 5 at the CHH project is involved in strategic decision-making. As an example, system 5 endorsed a semi-formal ECM process. In addition, system 5 is involved in mediating system 3 and 4 negotiations (project planning, negotiations with clusters, etc.) in relation to project deadlines. The functions of system 5 are mainly performed by project executive and the senior project manager.

Core responsibility of system 4 in CHH project is project planning. In relation to ECM, system 4 negotiates with system 3 about the engineering change deadlines. In addition, system 4 serves as the liaising agent with the OSHPD and other regulatory bodies and anticipates the engineering changes required by these regulatory bodies. Once these changes are performed, it ensures that the changes are approved by the regulatory bodies. System 4 functions are performed mainly by senior project manager and OSHPD and commissioning manager.

System 3 at CHH project is used mainly for setting the deadlines for the cluster level (second recursive level). This is because the functions of system 3 are performed by the same managers as for system 4. No system of information to assess the performance of operations is established. Most of the required functions of system 3 are missing, which will be discussed more closely in step 2 of the method.

System 3* functions related to ECM were not apparent in CHH project, at least not formally.

A software platform for communication - project inertia - is used mainly for transparency of project planning and for setting the planned deadlines of engineering changes (function of system 2). In the framework of system 2, training and guidelines for clusters on using project inertia is provided. A formal engineering change process for coordination with OSHPD and a memorandum of understanding as a reference document for classification of engineering changes is provided. Occasionally, coordination meetings with clusters are organized. Other than that, system 2 is practically nonexistent.

System 1 represents the clusters described in the beginning of this section. These clusters are responsible for implementing changes (from the project management perspective). As this case study was performed in the course of design phase, the engineering changes were contained only in changing the digital model or the plans. In the CHH project, there are a total of 6 operational units within system 1 – exterior and enclosure, structure, site, interior, CUP/MEP/IT[3], and productions. In case of changes that affects more than one cluster, there are was no formal coordination mechanism. Project inertia was occasionally used for this purpose and mostly in an informal way. No information was transmitted to system 3 about the progress of engineering changes.

<u>Second recursion level</u>:

System 5 in the cluster level is mainly confined in supporting the negotiation of system 3 and 4 in case there is a disagreement on how the changes should be implemented. This function of system 5 is performed mainly by cluster-specific senior project manager.

System 4 is in charge of creating and maintaining a cluster-specific engineering change schedule. This is performed by considering the overall project plan and current ongoing operations within the cluster (the latter information comes from system 3). The role of system 4 is performed by cluster-specific senior project manager and cluster project manager.

System 3 is in charge of operations control. In the cluster level this is limited to setting a formal engineering change process. System 3 uses information from system 4 about the planning of engineering changes based on which sets up the operational deadlines. As the engineering process lacks performance indicators, the information on progress from system 1 is received mainly by direct contact with system 1 units on ad-hoc basis.

System 3* functions related to ECM were not perceived as present at cluster level.

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[3] CUP/MEP/IT stands for: mechanical, electrical, plumbing engineering and information technology

Similarly to the first recursion level, project inertia is used as communication platform – a function of system 2. The OSHPD coordination process and MoU (memorandum of understanding) from the first recursive level is also maintained at the second recursion level. Regular meetings within clusters are organized to discuss the coordination of engineering changes within clusters. The functions of system 2 at cluster level are performed mainly by the cluster assistant and cluster project manager.

System 1 represents the group of the operational units (companies) that comprise each cluster. The operational units are responsible for implementing changes. This occasionally is performed together with suppliers. The communication between system 1 units is accomplished with emails or informal meetings, whereas project inertia is used only occasionally with the purpose of requesting information on engineering changes.

Step Two – Transfer

The second step of the method involves identification of the missing context-related functions based on the general VSM functions. It was performed with the help of two workshops (one for each recursion level). In the first recursion level workshop, the general manager of the CHH project and the OSHPD and commissioning manager were present. In the second recursion level workshop, the structural cluster manager and his assistant were present. In both these workshops, first the output of step one (the list of context-related functions) was verified by the managers, then the missing context-related functions were identified by transferring analogically the generic VSM functions into context-related functions. This way, additional context-related functions were identified, and several existing context-related functions were adapted. The following is a summary of this step for each recursive level (detailed list of should-be functions can be found in appendix 9.6).

First recursion level:

As seen in the previous step, the as-is functions of system 5 are limited to supporting negotiations between systems 4 and 3. However, one of most important functions of this system is to ensure that ECM objectives are in compliance with overall strategy of the project. In addition, system 5 must ensure that these objectives are understood and accepted by all the other systems in the project.

System 4 in CHH project is focused on general project planning from which the engineering changes are scheduled. The missing context-related functions of this system include the anticipation of possible changes by analyzing trends in engineering changes. Furthermore, system 4 should inform system 5 of possible impact of these trends into the overall project planning and update this plan accordingly. In addition, system 3 should be informed about any change of the engineering change plan.

System 3 is seen as one of the most underdeveloped systems, as most of the necessary functions are missing. System 3 should control the operations (clusters) by receiving information from system 2 about the progress of initiated changes. In case of unanticipated problems, system 3 should trigger auditing system (system 3*) to make enquiries about what went wrong. Another important function of system 3 is to design system 2 in such a way that the coordination of the operation units (system 1) is performed in an autonomous manner. How this should be performed is described in the paragraph below that describes system 2.

System 3* is nonexistent, therefore it should be created for the should-be ECM. Functions allocated to this system include auditing function such as verifying the compliance with the formal engineering change process, verifying the proper creation and update of engineering change documentation and so on.

Same as in system 3, system 2 is also underdeveloped from the ECM perspective. Although the communication channels that support the coordination of system 1 units exist, there are no clear guidelines on what coordination steps should be taken in case of, for example, an engineering change affecting many clusters. As mentioned before, the only formally defined process is the one concerning the OSHPD. All other changes are conducted in more or less informal manner. In addition, system 2 does not serve as variety attenuator for system 3, as no performance indicators are used for that purpose.

System 1 entities are responsible for actual implementation of the engineering changes. In order that this system is well integrated in the ECM, it needs to inform system 2 about the status of the engineering changes. System one needs to deal also with the feedback from external stakeholders, such as OSHPD. Based on the recursive property of the VSM, system 1 of the first recursive level comprises of all the VSMs in the second recursive level. Therefore, it is logical that the missing functions of system 1 are analyzed by unfolding the second recursive level.

Second recursion level:

One of the main functions that is lacking in system 5 is the definition of the values and norms in relation to ECM. Based on this internal strategy, cluster internal strategy should be set.

Besides being in charge of creating and maintaining a cluster-specific engineering change schedule, system 4 should closely inform system 5 about the trends and planning that could affect internal ECM strategy. In addition, system 4 should inform system 5 about important external changes, such as new regulations enforced by OSHPD or other relevant agencies and possible problems with trade partners.

Same as in the first recursion level, system 3 of the second recursive level is also underdeveloped. Here belongs the control of the operations (trade partners within clusters) by receiving information from system 2 about the progress of initiated changes. In case of unanticipated problems, system 3 should trigger auditing system (system 3*). Another important function of system 3 is to intervene in system 2 in order to improve the coordination of the operation units (System 1). Lessons learned should be continuously updated and reflected into system 2.

Same as in the first recursion level, system 3* is nonexistent. Functions allocated to this system include auditing function such as verifying the compliance with the formal engineering change process within clusters, verifying the proper creation and update of engineering change documentation and so on.

Same as system 3, system 2 is also underdeveloped from the ECM perspective. Although the communication channels that support the coordination of system 1 units exist, there are no clear guidelines on what coordination steps should be taken in case of, for example, an engineering change affecting many trade partners. As mentioned before, the only formally defined process is the one concerning the OSHPD. All other changes are conducted in more or less informal fashion. In addition, system 2 does not serve as variety attenuator for system 3, as no performance indicators are used for that purpose.

System 1 in the second recursive level represents trade partners and contractor companies that perform operations within the scope of the clusters. For the purpose of cluster level, this system should constantly report to system 3 (through system 2) about the progress of engineering changes. As such, system 1 is expected to inform system 3 about unexpected events that delay the execution of the changes.

Step Three – Transfer

Once the missing context-related functions are identified, the next step is to assign these functions to the actual functional entities in the organization. As input for this step serves the list of should-be functions obtained in step two and the organizational vertical unfolding. The assignment of the functions was done by using domain mapping matrix (DMM) as shown in Appendix 9.6. In this case study, no further concretization of the assignments (as in first case study) was required by the management of the CHH project.

5.3.4 Evaluation Results of the Third Case Study

Consistent to the previous case studies, the evaluation of applicability, usability and usefulness was performed with the help of a questionnaire as data-collection method. The full questionnaire used for this case study can be found in Appendix 9.4. The closed questions of the questionnaire again employ a six-point Likert scale, with 1 being “strongly disagree”, 2 – “disagree”, 3 – “disagree somewhat”, 4 – “agree somewhat”, 5 – “agree”, and 6 - “strongly agree”. The questionnaires were filled out by overall four managers that participated in the application of the method in both recursive levels (two in first recursive level, two in second recursive level).

<u>Applicability:</u>

The VSM was regarded as not so easy to understand by the managers as it scored quite low (scored 3,75 out of 6). In the same manner, the recursive character of the VSM was not so clear to the managers (scored 4). Further, the managers somewhat agree that the VSM functions are applicable to the specific context of the ECM and that the VSM as a model provides new perspective (both questions scored 4,25). In relation to the applicability of the method, one of the managers commented that the VSM is seen as a rather bureaucratic model in comparison to the more informal way of conducting engineering changes in CHH project. It is worth noting that the average score of the applicability differs between managers from the first and second recursion levels. First recursion level managers gave much higher grades than the second recursive level managers (4,5 compared to 3,6). This means that first recursive level managers find the method more applicable than the second recursive level managers.

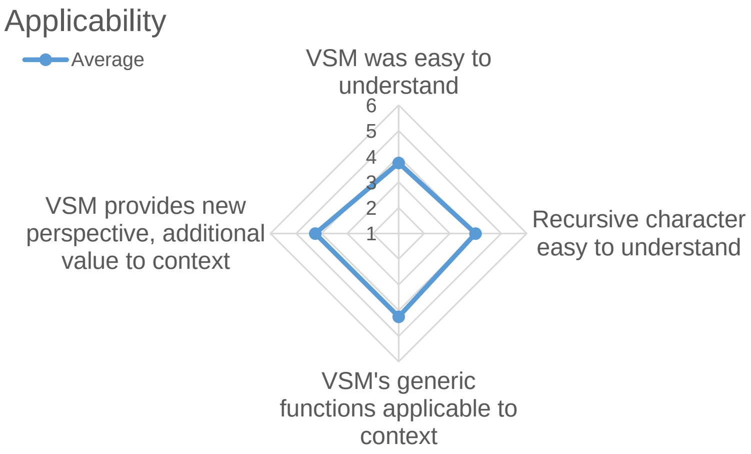

Figure 5-18: Evaluation of the applicability of the method in the third case study

<u>Usability:</u>

Based on the questions related to usability of the method, the managers found it quite difficult to identify the context-related functions based on the VSM functions (scored 3,75 out of 6). This means that it was difficult for the managers to perform functional analogies during the workshop. This outcome will be treated in the discussion of cross-case evaluation in subchapter 5.4. During the method application workshop, the managers were asked to think about the context-related function in their particular recursive level. The existence of two recursive levels was potentially a source of confusion, therefore two question addressed this issue. The managers found that the existence of two recursive levels caused only little confusion (scored 4,25), and it was not so difficult to differentiate the functions in this setting (scored 4,5). In addition, the managers mainly agree that the context relation of the VSM functions is generally feasible (scored 4,75).

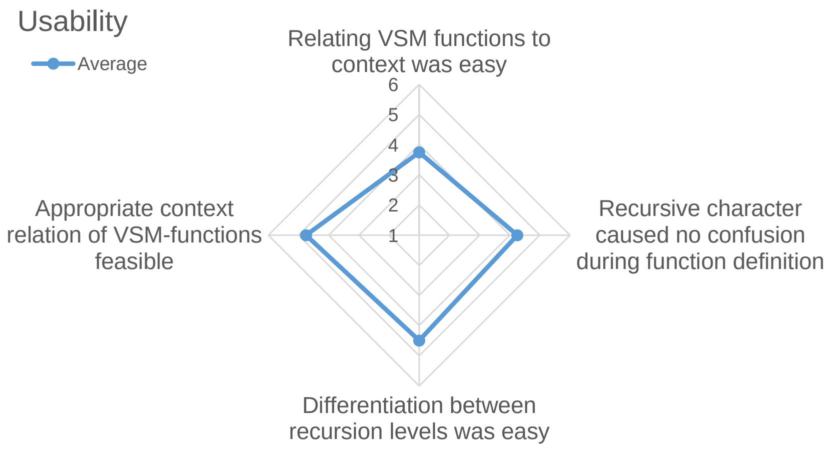

Figure 5-19: Evaluation of the usability of the method in the third case study

Comments provided by the managers reveal that the VSM and its underpinning theory was not so clear and that they would prefer to see examples of context-related functions rather than general (VSM) functions. Of course, this would be easier for the participants, but at the same time it would bias the outcome of the functional analogies. Another manager commented that the language used in the CHH do not correspond to the language of VSM functions, therefore the identification of the context-related functions was challenging.

Usefulness:

The managers evaluated the usefulness of the results generated by the method as quite high. The main result of the method, which is the "should-be" functional description, was seen as useful for setting up the ECM in the context of CHH project (scored 5 out of 6). In addition, the managers agree that the context-related functions are comprehensive (scored 4,8). The managers are also of the opinion that the consideration of two recursive levels brings additional value for properly implementing ECM (scored 4,8). In addition, context-related functions are seen as helpful to identify problems or challenges that would not be identified otherwise (scored 4,3).

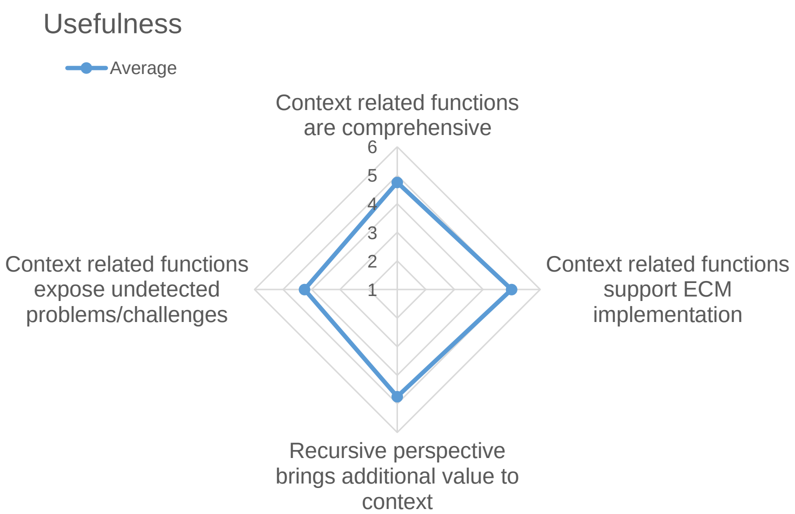

Figure 5-20: Evaluation of the usefulness of the method in the third case study

One manager additionally commented that the context-related functions are comprehensive but according to him, there are too many of them, and that a high number of context-related functions could lead to confusion among the stakeholders in setting up the ECM.

5.3.5 Summary of the Third Case Study

The method described in chapter 4 was applied to identify the necessary context-related functions for improving the responsiveness of the ECM in CHH project. The evaluation of the method application, as with other two cases, was performed as an initial descriptive study II (DS-II). For this type of evaluation, at least three criteria must be assessed: applicability, usability and usefulness [BLESSING & CHAKRABARTI 2009, p. 195]. The evaluation was performed with the help of questionnaire that was designed to tackle the three abovementioned evaluation criteria.

The application of the method in this case study revealed some interesting issues. These issues can be grouped into two categories: organizational and functional issues.

Organizational issues

Organizational issues include the problems that were observed in how different systems of the VSM are distributed in the project organization. Namely, in the first recursion level only three managers are involved in the ECM: project executive, senior project manager and OSHPD commissioning manager. Moreover, the senior manager is observed to be involved in performing the (as-is) functions belonging to three systems (systems 5, 4, and 3). This can be dangerous in the sense that system 5 needs to act sometimes as mediator to the negotiation efforts between systems 3 and 4. In this particular case, this mediation is not possible. This could lead to different management problems, such as inability to reach a decision that concerns system 3 (current operations) and system 4 (future trends), or biased decision-making.

In the second recursive level, the same problem is present, as cluster project manager performs functions belonging to three systems (systems 5, 4, and 3). Same as above, this represents a bad VSM practice since it can lead to inefficient and biased decision-making.

Functional issues

In terms of functional issues, there are numerous inconsistencies identified. First of all, it was realized that ECM in CHH project lacks system 3* - the auditing system in both recursion levels. The auditing system is extremely important for the adaptability of the ECM, as it activated whenever something goes wrong with an engineering change. For example, there could be systemic errors in how engineering changes for certain cluster are processed. These errors will not be identified unless system 3 delegates system 3* to perform an audit and discover what causes the errors.

Other incongruities include underdevelopment of all other systems in both recursion levels. Many functions missing in these systems are identified and listed in red in Appendix 9.6. In order that ECM is correctly embedded in current management system, the functions identified as missing need to be incorporated as suggested. This however was not performed by the CHH in the course of this study.

Based on the feedback from four managers belonging to two recursive levels, all three evaluation criteria were rated moderately high. Highest average score (4,7 out of 6) was given to the usefulness of the method. The questions in the questionnaire related to the usefulness were designed to find out whether the results generated from applying the method are useful or not.

The applicability of the method, scored lowest (4,1 out of 6). Although the result is still on the positive side, it should be mentioned that the lower score of the applicability criteria comes mainly from the scoring of the managers of the second recursive level. These managers were faced with the VSM for the first time during the application of the method and they did not see right away the potential of the VSM in derivation of ECM related functions. This factor contributed to a somewhat lower score of applicability in comparison to the other two case studies.

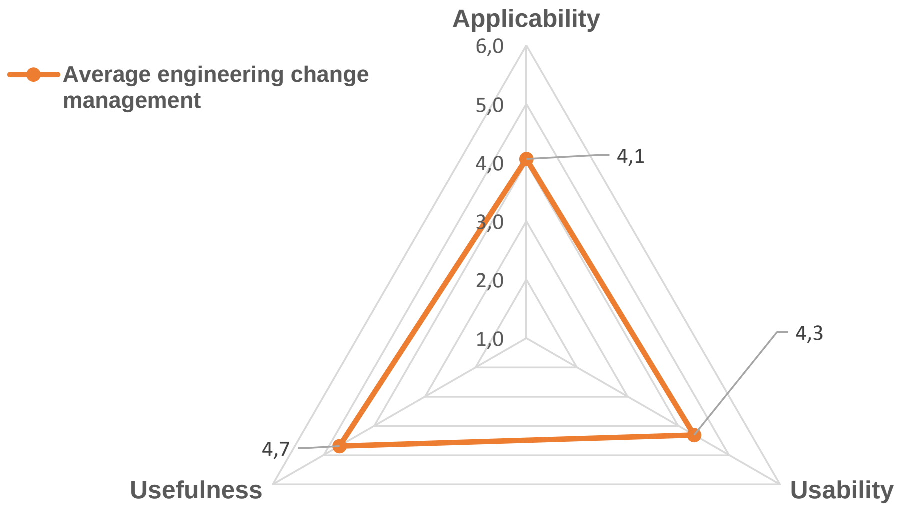

Figure 5-21: Aggregated results for three evaluation criteria in the ECM case study

The usability criterion also scored relatively low (4,3 out of 6). The managers did find it not so easy to perform the functional analogies for obtaining the context-related ECM functions. This is probably due to the high number of context-related functions that needed to be derived in the workshop and the tight schedule of the managers.

Finally, the evaluation results of the third case study indicate that the method is appropriate for functional design of ECM. This case study is unique in the sense that the method was applied for diagnosing an existing MCS, and improvement suggestions based on the observations in applying method were generated.

5.4 Cross-Case Evaluation of the Method

According to design research methodology (DRM), the initial evaluation of the support (in this case the method described in chapter 4) includes an indication of the applicability, usability and usefulness of the support. In addition, an indication of the issues, factors and links that need detailed evaluation should be presented [Blessing & Chakrabarti 2009, p. 195]. In this thesis, the evaluation of the method is performed on the basis of cross-case analysis along these three evaluation criteria. Cross-case analysis increases the generalizability, which assures that the results of the analysis are not bounded to a single case study [Miles & Huberman 1994, p. 172]. Although the number of case studies in this work is not high, cross-case analysis provides the chance to address the differences and similarities between them with an inter-case comparison. The conclusions of the evaluation conducted in this way are therefore stronger and can point to important issues. As input for the cross-case evaluation serve all the questionnaires obtained from all three case studies. The evaluation questions were designed based on the suggestions by ROSSI et al. According to them, the evaluation questions should be [ROSSI et al. , p. 71-73]:

- Reasonable and appropriate – the questions are designed to evaluate the method within scope that is defined by the method requirements (criteria provided in Table 4-1).
- Answerable – the questions use unambiguous terms and are focused only in the experience of the mangers in applying the method.

The questionnaires contain closed questions that use a six-point Likert scale for answering, with 1 being "strongly disagree", 2 – "disagree", 3 – "disagree somewhat", 4 – "agree somewhat", 5 – "agree", and 6 - "strongly agree". It was decided to pick this scale, to avoid giving the participants a neutral option as it would be the case with a five-point Likert scale. After each closed question, a space for comments is given, in order that the managers can provide further information as needed. The questionnaires used in all three case studies can be found in Appendixes 9.2, 9.4, and 9.7. The individual results of evaluation questionnaires from each case study were provided within the case study subchapters, whereas in this subchapter the cross-case evaluation of the method will be provided.

In the first part of the cross-case evaluation analysis, the average results along the three evaluation criteria will be presented and discussed. In the second part, the results will be compared with the method requirements set in chapter 4 and based on this comparison, suggestions on how to further improve the method will be provided.

5.4.1 Cross-Case Analysis of the Evaluation Results

As seen from Figure 5-22, all three evaluation criteria scored more or less equally. The cross-case scores of the evaluation criteria range from 4,4 to 4,7. This means that in general all evaluation criteria scored well.

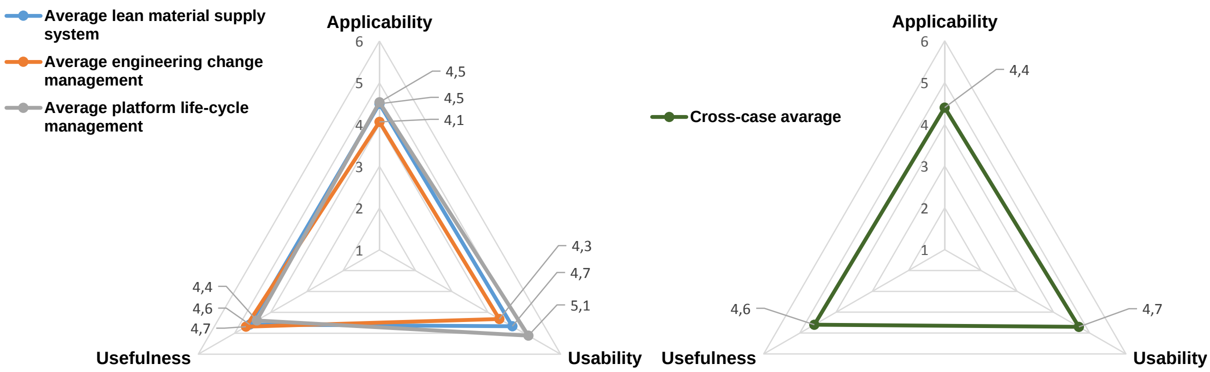

Figure 5-22: Average scoring of the three evaluation criteria for each case study (left), and cross-case average (right)

Applicability criterion

Applicability criterion has slightly lower score compared to other evaluation criteria (average score 4,4). The reasons for this appears to be the difficulty mangers faced in understanding the underpinning theory behind the method, the VSM. In addition, the recursive character of VSM further contributed to the perception of theoretical basis of the method as more difficult. This could be observed especially in managers belonging to lower recursive levels (for example cluster managers in engineering change management case study). These managers are closer to operations and are part of core engineering processes. They understood VSM as a model that imposes bureaucratic control that limits their operational freedom. Consequently, these mangers did not see VSM providing new functional insights and additional value to their operating efforts. The opposite was observed in higher recursive-level managers. While only few of them considered the VSM difficult, most of them are of the opinion that VSM and its functions are very well applicable in their case-specific contexts and provide new valuable perspectives. Therefore, the only problem that the evaluation results in relation to the applicability of the method reveal is the difficulty of the method that users face in sufficiently understanding the VSM. Otherwise, the method seems to be applicable for the purpose that it was designed, which is supporting the managers in conceptualizing the MCS at functional level.

Usability criterion

In terms of usability, the cross-case evaluation results are the highest among the evaluation criteria (scored 4,7 out of 6). Consequently, the managers agree that the method supports effectively and efficiently the design of MCS on functional level. In relation to effectivity, the managers are of the opinion that context-related functions were appropriately deduced from the VSM functions. In addition, the allocation of context-related functions to functional entities of the organization was also evaluated as feasible. In relation to the efficiency, the managers found it relatively easy to differentiate the context-related functions and their classification into VSM systems (step one – functional analogies). Also the second step (transfer), which is about analogic relation of VSM functions to context-related functions (should-be functional model of the MCS), was considered easy. Third step, embedding the "should-be" functions to functional entities of the organization was found easy as well. It is to be noted however, that lower scores for this evaluation criterion were given again by lower recursive-level managers. For example, one of them found step two very difficult, and commented that he would prefer to see few alternatives of context-related functions rather than only VSM functions. This suggestion would probably make the workshops more efficient, but the danger is that the resulting context-related functions can be biased by the workshop moderator (or by whoever is responsible for preparing these alternatives). In addition, important ideas from managers could be hampered by "leading" them to context-related functions implied by the moderator.

Usefulness criterion

Usefulness evaluation criterion is an indicator of how successfully the method delivers the expected results. In cross-case evaluation, usefulness achieved a respectable score (4,6 out of 6). This means that, in general, the managers are satisfied with the results achieved by the method. In this regard, the mangers stated that they are content with the "should-be" functional model generated by the method, and they think that the functional model is appropriate for conception of their respective MCS. The allocation of context-related functions to functional entities was also seen helpful for understanding and implementing the MCS. In addition, most of the managers agree that the method exposes some problems and challenges in MCS design that would not be identified otherwise. Two lower level recursive-level managers from two case studies (platform life-cycle management and ECM case study) do not agree with this statement and the reasons for this were not provided.

In summary, it can be stated that the cross-case evaluation reflects a positive experience of the managers in applying the method along all three evaluation criteria. However, there are some issues exposed that can serve as basis for method improvement. In order to do so, the results will be compared with the method requirements set in chapter 4 and based on this comparison, suggestions on how to further improve the method will be provided.

5.4.2 Comparison of Cross-Case Evaluation Results with the Initial Requirements of the Method

In subchapter 4.2, the requirements that guided the method design were presented (summarized in Table 4-1). Now after the method is evaluated using the three evaluation criteria, the assessment of the fulfillment of these requirements can be presented. For guiding the discussion, this assessment is structured in three parts. First, the application evaluation will be presented. This evaluation focuses on the ability of the method to address the application requirements, target requirements and general requirements of the method. Second part relates to success evaluation, which reflects the ability of the method to provide the results as required in objectives and desired output requirements. At the end of this section, the implications and suggestions for improvement are provided.

Application evaluation

The evaluation results indicate that all the managers involved in method application find it relatively easy to perform the functional analogies required to categorize the MCS functions into the VSM functions and the transformation of VSM functions into the MCS functions (for obtaining the should-be MCS functional description). However, the results show that the VSM theory in general and the recursive property was not very clear to the participants as for most of them it was the first contact with this topic. From the three case studies performed in industrial settings, it can be inferred that the method is well suited for engineering MCS. The method is also suitable for large scope MCS, such as engineering change management and life-cycle platform management, as well as for smaller scope MCS, such as kanban system or BiQ. The method is required to support all sizes of the organization. This requirement could not be comprehensively evaluated since the case studies involved relatively large engineering companies and engineering projects. What can be said in this regard however, is that the method proved to be well suited for the two large engineering organizations and it could be selectively used in smaller business units. In addition, the method was described as easy to be applied by most of the participating managers. Lower recursion-level managers however, found the application of the method not as easy as the higher recursion-level managers.

Success evaluation

The main objective of the method is to support the identification of necessary functions for MCS design in engineering companies. Based on the evaluation results from all three case studies, the method supports this objective by providing comprehensive list of MCS functions and allocates these functions to the appropriate functional entities of the organization. This output of the method provides the basis for the next design stage (the social level). As described in the previous section, the higher recursion-level mangers agree that the method exposes some problems and challenges that would not be identified otherwise, whereas the lower recursion-level managers generally find the method less value-adding.

Implications and suggestions for improvement

In general, it can be stated that the method meets the requirements set in the subchapter 4.2, with few exceptions.

First exception is the applicability of the method in small-sized organizations. Namely, all three case studies presented in this thesis took place in large organizations. Inherently, the applicability of the method could be evaluated only for large organizations. The applicability of the method for middle to small size organizations therefore remains unassessed. Case studies in middle- and small-sized organizations are sought.

Another clearly identified issue is the difficulty of the managers to have an overview of the VSM theory. Namely, in all three case studies the managers remarked that the VSM theory was not very clear to them and they had difficulties to fully grasp the recursive character of VSM. Before the application of the method, in all case studies first an introduction of the VSM theory was conducted. The introduction was held short (approximately 45 to 60 minutes – including questions) since the managers had lack of free time. Apparently, this time slot should be expanded in order to allow for better absorption of the VSM theoretical fundamentals. Another alternative could be to include the vertical complexity unfolding in the methodology, so it is performed together with the mangers in the workshops. This could better engage the managers into seeing their organization from the VSM perspective, and in combination with theoretical introduction, a better understanding of the underlying theory can be achieved. This could be of a particular benefit for lower recursion-level managers, who as shown by the evaluation results, have more difficulties in grasping the VSM theory. This could in addition help them to understand the value added that VSM brings into the MCS design in their recursion level.

Third issue relates to supporting the functional analogies by providing functional alternatives that the managers can choose from. Although this support is not required by the higher recursion-level managers, it might be necessary for supporting the lower recursion-level managers. As stated in section 5.4.1, supporting the mangers by providing alternative context-related functions bears the risk of “leading” them into biased solutions. Therefore, this support should be done only when absolutely necessary and with high precaution. It is assumed that, once the lower recursion-level managers have a better understanding of the VSM theory, this support will not be necessary.

6. Summary and Conclusions

This chapter closes the main research in this thesis and summarizes the problem description, objective, developed support and its evaluation results. After the summary, a conclusion in form of a reflection on the academic and industrial implications is provided. At the end of this chapter, an outlook for building up on the research presented in this thesis is given.

6.1 Summary

Today, engineering companies operate in extremely dynamic and turbulent market conditions. In order to thrive in such an environment, the companies need to be highly responsive and adapt quickly to the changes. To achieve this, engineering companies need to develop dynamic capabilities in order to ensure competitive advantage. Developing dynamic capabilities is not an easy task, as it requires not only flexible resources but also processes that help operationalize these resources. Typical engineering processes, such as product development and manufacturing, could be regarded as processes that operationalize flexible resources with the condition that they are performed effectively and efficiently. The management mechanisms that are crucial for achieving the effectiveness and efficiency of engineering processes are known in literature as management control systems (MCS). Current literature describes MCS as systems that make possible the continuous adaptation to the changing environmental conditions and therefore, contribute to the viability of the organizations. Despite their importance, there is a lack of generic guidelines on how MCS should be designed. Current MCS frameworks (such as [MERCHANT & VAN DER STEDE 2012, OTLEY 1994, SIMONS 1995]) help to achieve a better understanding of MCS, but are of limited use to managers, who require tailor-designed MCS for their particular engineering companies. The main reason for this is that given frameworks take a limited cybernetic perspective on the MCS. All of these frameworks recognize that cybernetic control systems are an important theoretical backbone of MCS, but only in the sense of homeostatic regulation. In other words, these frameworks use cybernetic theory on feedback control systems to describe the part of the MCS that is responsible to achieve a desired (static) state of a process output. As a consequence, contemporary MCS frameworks presume cybernetics to be helpful in describing only the rigid feedback control systems that are not intrinsically adaptable.

This thesis tackles this issue by expanding the cybernetic perspective on MCS. It argues that management cybernetics, and in particular, the viable system model (VSM) provide a systemic foundation not only for homeostatic regulation, but also for adaptable mechanisms required in contemporary MCS. Therefore, the objective of this thesis is to explore the extent of the theoretical support that management cybernetics can provide to the topic of MCS in general, as well as enquire the potential benefits for practitioners in engineering companies. In chapter 3 of the thesis, the possibility that the VSM serves as theoretical underpinning for the design of contemporary MCS at functional level is explored. The analysis in this chapter shows that the VSM incorporates all the functions required for contemporary engineering

MCS. The results from the analysis of this chapter were used to formulate the requirements for developing a method which provides a systematic support to managers in engineering companies for design of MCS at the functional level. The method comprises of three steps: analogy, transfer, and instantiation step. The analogy step makes possible the alteration of the MCS description into the VSM meta-systemic domain. In the transfer step, missing functions of the MCS are identified. Based on VSM functions, the missing functions are deduced and transferred into the "should-be" functional model of the MCS. In the instantiation step, the "should-be" functional MCS model is further detailed and embedded into the functional entities of the organization's structure. In this way, the obtained functional description of MCS contains not only the functions for homeostatic regulation, but also the functions that enable the adaptability in MCS. The method as such is designed to support the first level of MCS design – the functional level. The design at the social level is not supported by this method. However, once the method is executed and as a result, all the necessary functions for adaptable MCS are identified and embedded into the functional organizational structure, the preconditions are fulfilled to start with the MCS design at the social level.

The method is applied and evaluated in three industrial case studies (described in chapter 5). In the first case study, the method is applied in context of lean pull-based material supply. The second case study takes place in the context of life-cycle management of platform systems and the third case study shows results of applying the method in the context of engineering change management. Evaluation of the method in all these case studies is performed along three evaluation criteria: applicability, usefulness and usability of the method. For data collection purposes, questionnaires were developed and employed. The participating managers are of the opinion that the method is well developed for its purpose and brings additional value to the design of MCS. Based on the evaluation results, it is noted that higher recursion-level managers found the method more useful than lower recursion-level managers. Based on the evaluation results, suggestions on improvement are provided, which include minor modifications to the method, such as including the vertical complexity unfolding in the method in order that a better understanding of the VSM perspective is achieved.

6.2 Conclusions and Outlook

In this subchapter, a reflection on the initially set research questions is presented, followed by the implications to research and industrial application. At the end of the subchapter, an outlook for further research is provided.

6.2.1 Reflection

The research presented in this thesis was guided by three research questions. The **first research question** tackles the scope of the theoretical support that management cybernetics, in particular the viable system model (VSM), provides in understanding and designing of contemporary MCS. In this regard, it is shown that the state of the art MCS frameworks utilize a limited cybernetic perspective. These frameworks exploit only the homeostatic feedback systems to describe the rigid control systems required for maintaining desired states of the organizational processes (described as diagnostic control systems by [SIMONS 1995]).

This thesis explores in chapter 3 an extended cybernetic perspective that includes other important parts for adaptability of the MCS. For this purpose, the VSM is used as functional "skeleton" on which all the parts of MCS were embedded. For example, the interactive control system as a key system for adaptation could be embedded in the functions of systems 3 and 4 of the VSM. Similarly, the belief and boundary system that set the values and purpose of the MCS could be embedded in the functions of system 5 of the VSM. Hence, the MCS and VSM functions were found to be analogical. The difference is that the VSM is a meta-systemic functional model of the organization and is general in description, whereas the MCS functions are context-specific and convey a specific objective of the MCS. Therefore, in order to relate these two types of functions (at different abstraction levels) functional analogy as the main cognitive effort should be employed. This effort also helps in locating the right functional entities of the organization where the MCS functions should be embedded. MCS however, are complex control systems that are operationalized in organizations that represent purposeful systems. Their design is therefore multi-layered and involves not only the design at the functional level, but also the design at the social and the organizational level (see Figure 4-2). Hence, the support of the VSM to the understanding and design of the MCS is contained at the functional design level. This limitation is the outcome of the analysis in chapter 3 and addresses the **second research question**. For addressing the **third research question**, a method is developed for supporting the design of MCS at the functional level that uses the VSM as theoretical underpinning. The method represents an effort for systematic MCS design that according to evaluation results, leads to new valuable insights in the design of MCS. However, the method presented in this thesis is only the first step in the systematic design of MCS. Further research should be undertaken in order to develop a set of step-by-step guidelines for MCS design. In the outlook section this issue will be further elaborated.

The design procedure and the method presented in this thesis represent a **systemic approach** for design of MCS. One could dispute this statement by reminding that the subject of enquiry is the design of single MCS which ultimately represents a **reductionist approach**. Several MCS could be implemented in an organization and a true systemic design approach would address these MCS as undividable parts. In other words, the outcome of the design of a single MCS is different from the outcome of the design of all MCS at once, which ultimately leads to different behavior of MCS package designed through a reductionist approach from the MCS package designed through a systemic approach. Although it is true that the procedure and the method in this thesis support the design of single MCS, the final outcome (when a package of MCS is implemented in an organization) should support a systemic goal: the viability of the organization. Viability is the overarching goal that should be supported by the MCS, therefore the design of MCS contains all the functions necessary for viability of the organization. The method presented in this thesis ensures that these functions are incorporated into the MCS (by deriving viability-relevant functions from VSM) and are distributed to the right functional entities. Therefore, all MCS designed through this method, will have a meta-systemically similar structure that enables the system (organization in this case) to reach the overarching goal although MCS separately have their own purposes and goals. This is the main reason why the first design level in the design procedure is the functional level – to ensure that the ability of the organization to attain the systemic goal is preserved in the functional structure.

6.2.2 Implications for Research

This thesis contributes to the MCS body of knowledge in two aspects. First, this research proposes a new general procedure for designing MCS. This procedure comprises three levels. At the first level, the functional modeling of the MCS to be designed is conceptualized. This functional model should in essence convey "what" functionally needs to be achieved in order for MCS to meet its objective. The other two levels of design comprise of social and organizational levels. At the second level, "how" this functionality is conceptualized by means of social structures is detailed. In the third level, the embodiment of the MCS into the organization is performed.

This thesis is focused on the first design level, the functional level, which represents thesis' second and main contribution aspect to research. Namely, at this level of MCS design, it is proposed to use the VSM perspective in order to identify and assign all the necessary functions required for a specific MCS. This perspective distinguishes itself from existing MCS frameworks that use hierarchical structure of the organization as the structural framework for the embodiment of the MCS in organizations. Hierarchical structures of organizations are unnatural to complex adaptable systems [ESPINOSA et al. 2007, p. 334] since they support the direct supervision of lower level constituents of the system but disregard adaptable processes. For this reason, the existing MCS frameworks fail to successfully incorporate the adaptable mechanisms into their MCS models. In contrast to existing MCS frameworks, the proposed VSM perspective is based on the viable meta-systemic functional structure. This structure provides the functions and communication channels that are necessary for the adaptation of the organizations to the environment. As such, it is suitable to be used as a framework for the embodiment of adaptable MCS. Consequently, the VSM perspective makes it possible to functionally model all levers of control necessary for contemporary MCS.

In addition to these contributions, this thesis has an implication on the research of VSM application. Namely, the VSM so far has been used mainly as a diagnosing tool for assessing the viability of organizations. Despite successful VSM applications in industry, VSM is still regarded as an exotic management concept and is still not part of management mainstream research. This is partly due to the difficulty to fully grasp the underlying theory and partially because the scope of restructuring that the VSM diagnostics entail are often of organization-wide proportions. This thesis opens a new facet for VSM application in organizations by identifying the VSM as the canonical model for the functional design of MCS. Thus, in this thesis the VSM is used to tackle a problem that is of smaller scope and therefore can potentially contribute to the embracement of the VSM in the mainstream management research in future.

6.2.3 Implications for Industry

Managers of engineering companies still lack clear design guidelines for engineering MCS. This thesis is an attempt to bring clarity on this issue by providing a top-down view of the possible MCS design process. In this regard, three necessary levels of design are suggested (the functional, social and organizational levels). The new VSM perspective facilitated development of a method that enables the identification of the necessary functions for adaptable MCS in a systematic manner. This method can be utilized by the managers of engineering companies in two possible scenarios.

First, managers can employ the method for diagnosing already implemented MCS that are not functioning as expected. In this scenario, the method helps in identifying missing functions necessary for the proper functioning of the MCS. Support of the method in this scenario is limited only to functional pathologies (defects in MCS that are caused by inappropriate or missing control functions). The third case study of this thesis (subchapter 5.3) is an example of the method being applied for such a purpose.

Second, the method supports the design of new MCS. This scenario requires that the managers have a clear vision of what the new MCS needs to achieve in order to identify and extract the context-related functions of the MCS. As emphasized already, the support of the method in such scenarios is limited to the functional modeling of the MCS. The application of the method in such scenarios is described in the first and the second case studies of this thesis. In both scenarios, the method supports the assignment of the identified functions to the proper functional entities of the organization.

Based on the results of the evaluation, the method provides managers a distinct support for design of the MCS at functional level. However, it should be noted that design of the MCS incorporates other design levels that are equally important for proper embedding of MCS into organizations. These design levels were not part of this research, therefore they remain a subject of further research that will be described in the next section.

6.2.4 Outlook

Research presented in this thesis opens many areas of inquiry for researchers. These inquiries can be classified in two categories: further empirical research on evaluating the method presented in this thesis and further research steps to be undertaken to complete the research initiated by this thesis.

Because of the time constraint, the method presented in this thesis could be evaluated in only three case studies. In all these case studies, the method was applied in relatively large engineering organizations. Researchers are strongly encouraged to further evaluate the method in large organizations to potentially come to new insights about the applicability and usefulness of the method. It would be of particular interest to evaluate the method also in small- to medium-sized engineering organizations in order to assess the applicability of the method in these subjects. Based on the evaluation results, modifications of the method could be suggested. In addition, the applicability of the method could be assessed in other industries (other than engineering) and governmental/non-governmental institutions, since the underlying theory of the method is not limited only to engineering organizations but rather to viable organizations in general. Particular importance to research and industry would have a study on the application of the method for implementation of several MCS into an organization. This way, the applicability of the method for designing MCS package would be assessed.

In regard to the further research steps to complete the research initiated by this thesis, the author encourages readers to direct their enquiries towards the two remaining MCS design levels.

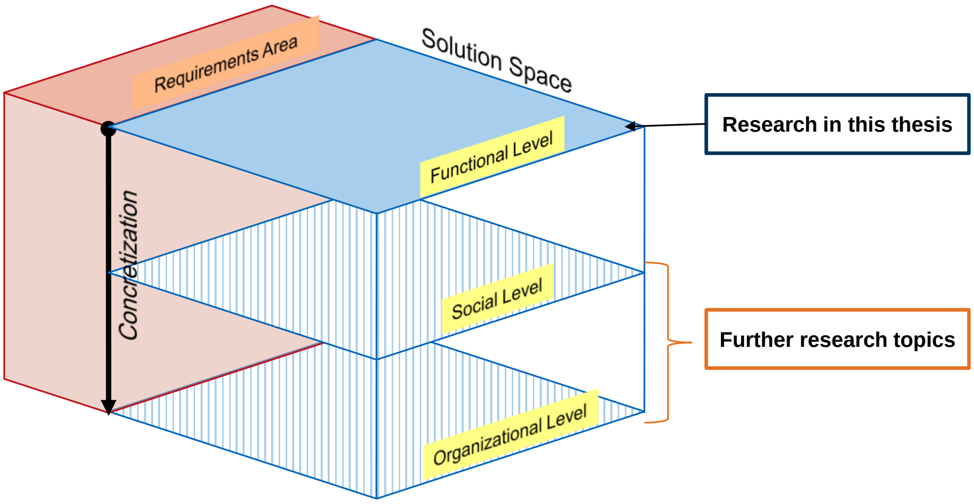

Figure 6-1: Research topics to be undertaken to complete MCS design procedure

As seen in Figure 6-1, two levels of MCS design procedure remain for further research – the social and the organizational level. For these design levels the existing MCS frameworks can be adapted to provide a methodological support for practitioners to design the MCS. At the social level, the functional model of MCS should be enriched by taking into account social aspects such as the organizational structure, responsibility hierarchies, cultural issues, interests and purposes of certain departments or groups and so on. In addition, the necessary formal communication channels within the social entities are also modeled based on the functional model (obtained by the previous design level – the functional level). From systemic thinking, the interpretative and emancipatory paradigms could provide support at this design level.

At the organizational level, the functional and social models obtained from previous design levels should be used to plan clear guidelines and job descriptions for the concerned organizational stakeholders that include the requirements to learn and adapt. In addition, the incentives for the stakeholders are identified. The stakeholders should be provided with necessary tools and techniques to achieve the operational requirements of the MCS. At this stage the bottom-up issues should be considered and matched with requirements descending from the functional and social levels. This could potentially lead to an agreed MCS that is properly embedded (implemented) into the organization.

As stated in the beginning of this section, this thesis opens many areas of further research. Some of these areas that relate to the VSM perspective and could potentially have a significant impact on engineering management are elaborated in the next chapter.

7. Extended Outlook of Management Cybernetics in Engineering Management

In this chapter, an extended outlook is provided with the objective to illustrate some important implications of VSM perspective on engineering management. The first topic presented in this chapter relates to a system used for coordinating operational scheduling with management planning in construction engineering – the Last Planner® System (LPS). Coordination management systems such as LPS are very important in engineering management, therefore in subchapter 7.1, LPS will be analyzed from VSM perspective. Next topic presented in this chapter is the implication of the VSM perspective on continuous improvement (kaizen). The VSM perspective views an organization as a recursive system comprised of self-contained viable autonomous subsystems. Some implications of this view on continuous improvement process will be presented in subchapter 7.2. At the end of the chapter (subchapter 7.3), some further requirements for viability in organizational context will be presented.

7.1 Last Planner® System

In the following subchapter the subject of study is the Last Planner® System (LPS), as one of most prominent lean production control systems in construction engineering. In difference with the three MCS described in chapter 5, LPS's is designed to coordinate operational scheduling with the higher levels of management planning. The objective of the study in this subchapter is to provide first indications of the applicability of the method described in chapter 4 in management coordination systems such as LPS. To reach this objective, it is crucial to understand whether LPS and VSM share the same functional structure. If this is the case, then the method developed in this thesis could be applied to management coordination systems without or with minimal modifications.

7.1.1 Introduction to Last Planner® System

Last Planner® System (LPS) was introduced to improve construction project management performance [BALLARD 2000]. LPS contains the logic of lean principles such as not passing on defective products to the next customer, pulling, and striving for continuous improvement. Detailed guidelines exist for implementation of the LPS's control mechanisms [BALLARD et al. 2007], however industry experience shows that challenges remain, such as incomplete implementation of coordination efforts required between the various planning levels [BORTOLAZZA et al. 2005, CHOO & TOMMELEIN 2001, PORWAL et al. 2010].

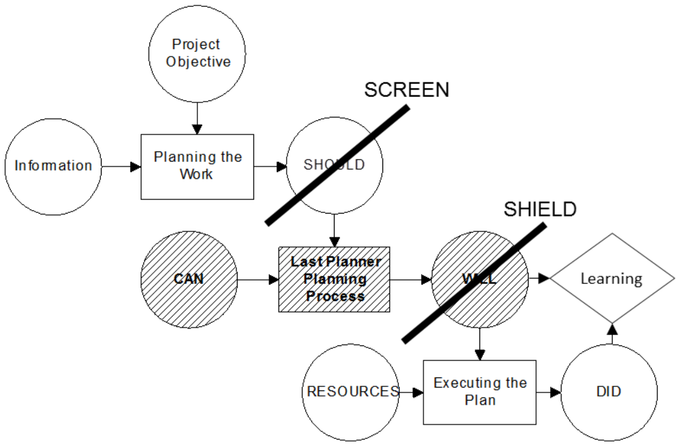

Figure 7-1: Last Planner® System – as in [ELEZI et al. 2014b, p. 1], based on [BALLARD 2000]

As seen in Figure 7-1, LPS consists of four (sometimes fewer or more, as needed) levels of schedules forming a hierarchical structure [BALLARD 2000, BALLARD et al. 2007]. At the highest level of the hierarchy, the master schedule represents what SHOULD be done. It shows the project phases with their corresponding milestones and serves to provide a complete overview of the project, from start to finish. At the second level, each phase in the master schedule gets detailed as a phase schedule to highlight activities and hand-offs between those responsible for doing the work. At the third level, each phase schedule gets further detailed as lookahead schedules. These form a rolling sequence of schedules each covering some time window (typically several weeks) long enough so as to afford planners the time to remove constraints and make work ready prior to execution (i.e., to "pull" in lean parlance) so the work CAN be done. Activities in the lookahead are screened (i.e., assessed for feasibility of making them ready in the time available until their scheduled execution time) and get expanded into operations and then detailed into tasks, which ultimately are to become work assignments. At the fourth level, weekly work plans get derived from the lookahead schedule to detail the immediately following week of work. They show tasks assessed (shielded) by the Last Planner for feasibility (CAN) and committed to (WILL) by matching work load to work crew capacity. Tasks on the weekly work plan that were completed as planned (DID) then count towards Percent Planned Complete (PPC). PPC is the number of tasks in DID that were in WILL, divided by the number of tasks in WILL. It is a metric to gauge plan reliability. As opposed to traditional, push-based scheduling systems, the LPS incorporates feedback loops (e.g., to support the constraints removal process) between operational working crews and higher level management as well as the environment (e.g., suppliers), thereby pulling tasks. The LPS also uses feedback to even out the work load of crews. Finally, the LPS promotes continuous improvement by having Last Planners compare actual completed work (DID) to the assigned work (WILL) and deduce lessons learned.

7.1.2 Last Planner® System from VSM Perspective

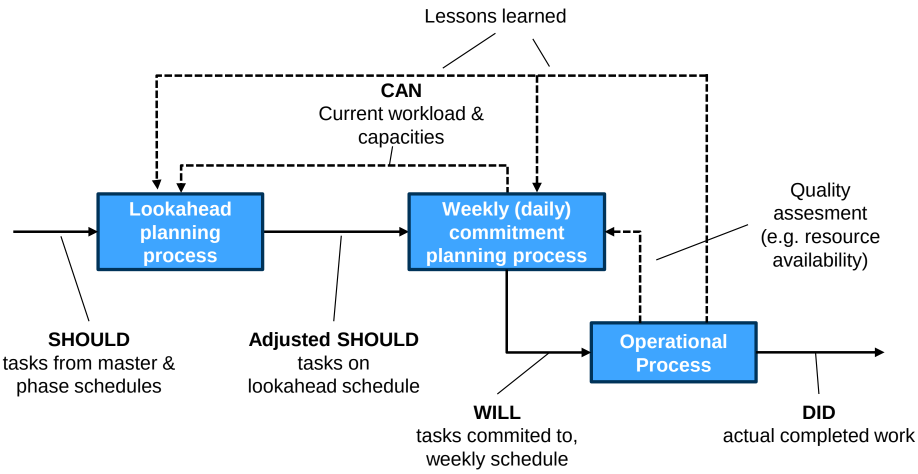

Figure 7-2: LPS feedback mechanisms

By analyzing the structure of information channels and the flow of information, it can be seen that LPS consists of several feedback loops. In addition, LPS has input information that appear to come from the environment and there are several stages of the coordination and synchronization of the schedules. For example, the master schedule (as input to the control system) is attuned to adjusted SHOULD, based on what CAN be done by operations (see Figure 7-2). This resembles to the same functionality as that of the homeostat between system 4 and system 3 in VSM. This hints that management coordination systems have the same functional structure as MCS and that they represent in fact a type of MCS.

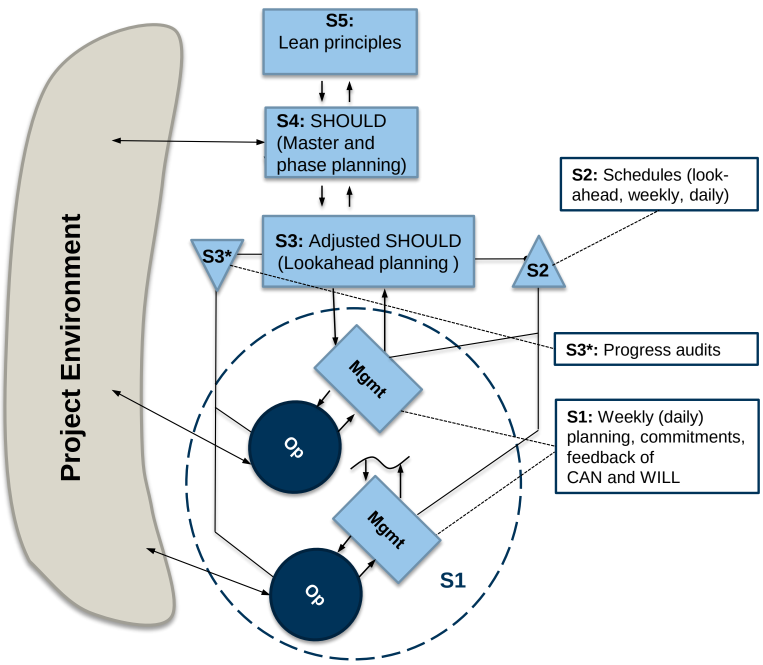

Figure 7-3: LPS functions in relation to VSM systems

To confirm this statement, the LPS will be put into the VSM perspective, in order to understand whether LPS consists of functions that correspond to all five systems of VSM. The result of the VSM perspective on LPS is shown in Figure 7-3.

LPS supports several lean principles such as pulling and continuous improvement (Kaizen). Therefore, the purpose and goals of LPS are defined by these principles (system 5). Master and phase scheduling are part of strategic adaptive processes vested in system 4. In this level, the strategic adaptation of the schedule phases is performed in order that the influences from project environment are considered. By taking into consideration these influences, system 4 elaborates the lookahead planning and refers it to system 3. System 3 then takes this information and informs operations through system 2. At this point there are two scenarios that can ensue. First scenario is the case when operations (system 1) provides feedback to system 3 that based on schedule deviations and capacity issues in operations the lookahead planning need to be adjusted. The second scenario is when operations deem as realistic the lookahead planning and system 3 has the green light to generate weekly (or daily) work planning that is communicated to system 2. In the second recursive level, the management in operational level is in charge of performing the production operations based on the weekly (daily) plan. System 3* utilizes sporadic audit to check the progress of work committed to by system 1. The information generated by system 3* can be used for lessons learned and/or Kaizen by the higher management.

Based on the discussion above it can be deduced that LPS contains functions from all five systems of VSM, which indicates that LPS as management coordination system represents a type of MCS and as such is a subject of the design procedure and the method presented in this thesis. Further research should be performed in order to assess exactly the level of applicability of the method suggested in this thesis in case of coordination management systems such as LPS.

7.2 Implications of Recursion in Continuous Improvement

In this thesis, the VSM perspective was shown to be a powerful perspective for understanding and designing MCS. This perspective however, can be expanded to include analysis of other important managerial processes in engineering companies. In this subchapter, the continuous improvement will be put into VSM perspective and some initial conclusions will be drawn. Of particular importance is the implication of recursion on Plan-Do-Check-Act (PDCA) cycle, one of the most prominent processes used for implementing continuous improvement. These implications are than related to the further research to be performed in this direction.

7.2.1 Introduction of Continuous Improvement and Plan-Do-Check-Act Cycle

Continuous improvement, also referred as kaizen in Lean Thinking [LIKER 2004, WOMACK & JONES 1996], in general terms is a continuous effort to improve processes, products, methods or tools in an organization. It is a cornerstone of several engineering management approaches such as lean production, lean development, total quality management, and six sigma, that have proven to be highly successful in engineering companies [BHUIYAN & BAGHEL 2005].

Initially applied mainly in a production context as an approach to increase quality, continuous improvement has evolved into a management principle ideally involving the whole organization [IMAI 1986]. One of the most prominent processes to implement continuous improvement is the Plan-Do-Check-Act (PDCA) cycle. The PDCA cycle originates from Plan-Do-Study-Act (PDSA) cycle, first described by Walter Shewhart in the 1930s. In the 1950s Deming introduced the PDSA to Japanese companies including Toyota [SOBEK & SMALLEY 2008]. Later Toyota integrated it to its management philosophy and the PDSA evolved to PDCA. Toyota integrated this cycle to support one of their key Lean principles - continuous improvement, also known as kaizen [IMAI 1986, LIKER 2004].

PDCA cycle in its abstract description contains four phases. “Planning” phase includes problem analysis and identification of one or several solutions. In addition, the action plan is defined within this phase. “Doing” involves implementation or realization of the action plan. “Checking” includes examining the outcomes of the previous phase, whereas “acting” involves the analysis and comparison of the real outcomes with the desired outcomes. In case of a difference in the comparison, the cycle is repeated. PDCA is a scalable procedure, which means that it can be performed in any level of an organization. For example, it can be applied in very specific problem that a single employee faces, or to a large teams such as in design, production, or even in high management structures [BHUIYAN & BAGHEL 2005]. Basically, PDCA enables continuous learning by constant checking and controlling the results of planning decisions and by employing subsequent corrective measures. In this way, a learning curve effect is made possible. Besides the iteration needed for continuous improvement, previous research shows some elements of the recursive nature of the PDCA cycle [CHARANTIMATH 2003].

7.2.2 Relating Plan-Do-Check-Act with Viable System Model Perspective

Several researchers previously tried to bring the continuous improvement into the systemic perspective. For example ESPEJO & SCHWANINGER put the learning cycle in the context of VSM which appears as a loop between management (system 2 to system 5 of the VSM) and operations (system 1) [ESPEJO 2000, ESPEJO et al. 1996]. Figure 7-4 shows how they mapped the OADI cycle (another similar cycle to PDCA) to the VSM. In the same figure, the PDCA cycle steps are superimposed. As system 5 of the VSM is in charge of defining the organization’s identity and values and balances system 4 future plans against system 3 present management efforts, all of these three management systems contribute to the “plan” step of the PDCA cycle. “Doing” step is obviously an act of operations (system 1).

System 2 takes part in the “Do” step of PDCA cycle since its main function is to coordinate and support the elements of system 1. On the other hand, system 3* incorporates sporadic auditing functions to support special information requirements and decision-making of system 3, therefore it is periodically involved in the “Check” step.

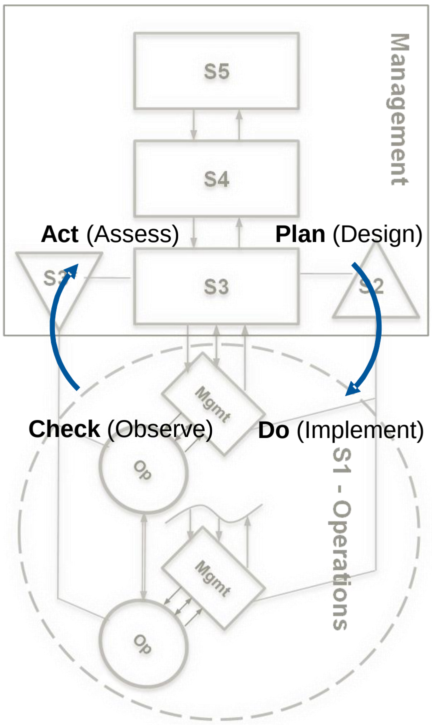

Figure 7-4: OADI and PDCA superimposed on VSM (adapted from [ESPEJO et al. 1996])

It is important to mention, that the “check” step can be performed by system 1 and then system 3 is directly informed, thus the employment of system 3* is avoided. The decision making and preparation of the next cycle as part of the “Act” step is a matter of system 3 (operations control) including decisions on corrective action if the results of operations (“Doing”) require so. This can be performed by initiating changes in system 2 guidelines or by direct intervention in system 1. System 4 and system 5 may be involved in the “Act” step as well, depending from the scope of the changes incurred.

PDCA cycle is conventionally believed to be iterative. By superimposing the PDCA cycle on VSM as in Figure 7-4, another property emerges – namely, the PDCA cycle can also be recursive. According to CHARANTIMATH the “Do” step of the PDCA cycle encompasses another PDCA cycle [CHARANTIMATH 2003, p. 47, 48]. This statement can be based on the recursive property of the VSM, which is manifested by the fact that every entity within system 1 itself comprises all five VSM systems. As the “Do” step takes place in one or more entities of system 1, it can trigger another PDCA cycle at the lower recursion level. How and why this can happen, can be explained through the law of requisite variety.

The VSM’s recursive property can be explained by Ashby’s law, also known as Law of Requisite Variety (explained in section 2.2.3) and amplification and attenuation of variety (explained in section 2.2.4). As the management levels (system 3 to system 5) in an organization cannot handle the complexity of the operational entities, system 2 is introduced to amplify/attenuate this complexity. In other words, system 2 serves as interface between operations and management. Consequently, for system 1 entities, system 2 represents a set of rules/guidelines. For system 3, system 2 represents an attenuation element since it prevents the complexity of operation to proliferate in higher management structures. On the other hand, system 1 entities have to amplify the information coming from system 2 in order to keep operations ongoing. In other words, system 3 serves as "good regulator" (described in section 2.2.3) for essential parameters coming from operations. Now, let's imagine that a PDCA is initiated by system 3. This cycle propagates through system 2 where it is attenuated and enters system 1's entities. The propagation of the cycle into system 1 triggers another PDCA, but now one recursion level below the initial recursion level. This concept extends the idea of cycles within cycles [CHARANTIMATH 2003, p. 47, 48]. Triggering another PDCA cycle at the next lower level of recursion within every "Do" step ensures maximum effectiveness of PDCA-based improvement in an organization that is obviously a top-down driven improvement effort.

To illustrate what has been said so far, let's take an example from manufacturing. Assume that production planning (system 3) of a manufacturing site triggers an improvement initiative concerning material flow in production. Goals are set and plans are made at a rather high level of management. Using system 2, the initiative is communicated to all entities of system 1 that are held to conduct PDCA cycles within their expert fields, e.g., work routines at single assembly stations, work cells, or commissioning routes. This continues as far down the recursion levels as necessary to meet the complexity implied by the goals of the initiative and the operational system under consideration. This way, improvements are likely to be made at levels of detail that could not have been anticipated by overall production management in the first place. The PDCA cycles within cycles ensure access to in-depth expert knowledge, thereby fully unleashing improvement potential.

Another example coming from lean thinking is the "5 whys" problem-solving tool. This tool prescribes asking five times why a problem occurred, thus going deeper into recursion levels of the organization to find the causes of a problem and relentlessly reflecting on actions at any level for continuous improvement [LIKER 2004, SHINGO 1986]. The VSM in such cases can provide structured planning of such tools as it provides a functional and systemic view of these different recursion levels of the organization.

The improvement initiatives can emerge not only from management, but also from operational levels too. In these cases it is said that the improvement efforts propagate in a bottom-up manner. The VSM in bottom-up improvement efforts supports transparency of processes across recursion levels and can contribute in diffusion of incremental improvements throughout the organization. In terms of the VSM's requirements, such transparency and diffusion are necessary since this enables cohesion between the autonomous operational units, for example to prevent conflicts over shared resources [BEER 1972, PÉRES RÍOS 2012]. Therefore, as opposed to the top-down driven PDCA cycle, exercising spontaneous, bottom-up driven improvement procedures requires monitoring or sensing functionality of system 3 at the corresponding recursion level. Management should not be blind to what happens "in the trenches." In terms of lean thinking, this notion corresponds for example to "gemba gembutsu" or the practice to "go and see for yourself at the work face." This control function is not included in the list of VSM functions (see Table 3-1). It is suggested to add such control function to S3 so it will be able to communicate and detect any type of improvement, subsequently triggering diffusion of that improvement across operations and recursion levels as far as required in a PDCA cycle. Especially for less standardized processes, this type of bottom-up triggered improvement holds great potential if integrated in the organization's operations.

7.2.3 Implications for Further Research

VSM provides a holistic view of organizations and helps in understanding continuous improvement methods such as the PDCA cycle. Use of the model shows that its underlying cybernetic principles and laws support the notion of a recursive approach to continuous improvement, both in top-down and bottom-up cases of proliferating improvements. Thus it provides a sound theoretical basis for corresponding aspects of management approaches such as Lean, which suggest adoption of continuous improvement throughout an organization and involving everyone regardless of their level in the hierarchy. However, both the top-down unfolding of improvement cycles and the diffusion of bottom-up driven improvements require adaption to any individual application case, especially in terms of the depth of the unfolding or diffusion. Guidelines for implementation of corresponding communication channels and processes running within PDCA are necessary to make use of the VSM's theory in industrial practice. Furthermore, when using the VSM for organizational design at a functional level, the model needs to be enhanced by a system 3 function that senses improvements at lower levels of recursion, i.e., within the operational entities of system 1, and regulates introduction of improvements to other system 1 entities via system 2.

Sustaining the continuity of improvements in complex organizations requires a systemic view of the structures that support improvement procedures. As discussed above, VSM meets this requirement. Based on previous research as well as the underlying cybernetic principles and requirements, it could be shown that organization-wide learning and improvement implies a recursive understanding of improvement procedures at lower levels. Maximum effectiveness of improvements can be ensured only if the improvement procedures are unfolded to the required degree of complexity, i.e., if they reach all organizational levels (upwards for holistic views or downwards for access to expert input) as appropriate for the organizational system to be improved. Differentiation into top-down and bottom-up driven improvement initiatives identified a gap within the VSM's set of organizational functions. This highlighted the need for a function in system 3 to allow for diffusion of spontaneous improvements from operations to the whole organization, especially in organizations with a low level of standardization.

Further research based on the VSM perspective is required to identify how continuous improvement in organizations can be better understood and managed. Research could expand on the definition of functions specific to continuous improvement, derived from the VSM's generic functions. Subsequently, a methodology could be developed that supports identification of relevant organizational units to be integrated in continuous improvement initiatives. The increased understanding as a result of VSM perspective, can provide advantages for implementing continuous improvement on an organizational scale since not only operations with their processes and primary activities can be chosen for improvement, but also the management functions at any recursion level of the organization.

7.3 Additional Requirements for the VSM Perspective on MCS

As described earlier in this thesis, VSM is a model of organization that incorporates necessary functions for a system to be viable. In the initial study presented in this subchapter, the author will argue that when using this model, other requirements are necessary to be taken into account for ensuring the viability of engineering companies. By enriching the VSM with these additional requirements, the VSM perspective expands from being only a functional perspective and provides a more realistic insight on what needs to be undertaken in order that the viability is ensured. Additional requirements listed in this study pinpoint to important systems or characteristics of living organisms that contribute to their viability but are not considered explicitly in the VSM theory. These requirements have an impact on MCS design also, especially on social and organizational level. Therefore, these requirements are described in the following in order to serve as reference for the researchers that decide to direct their research efforts toward these two MCS design levels.

As described in section 2.2.6, VSM has been used for diagnosing and organizational redesign of viable organizations. For example, it allows for analysis of appropriate scaling of operational units (compared to the organizations environment that has to be dealt with) and for examination of clarity in responsibilities of controlling units [BROCKLESBY & CUMMINGS 1996]. The outcome of such diagnosis and organizational redesign according to the functional prerequisites derived from the VSM were increases in efficiency, better communication and reaction times as well as better adaptability of corporate strategy [BROCKLESBY & CUMMINGS 1996, SCHWANINGER 2006, SCHWANINGER 2009]. However, there are several authors that criticize VSM for not considering some important issues, such as for example the organizations being social and purposeful systems [CHECKLAND 1980, ULRICH 1981]. These critics are taken into consideration to formulate five additional requirements for viable systems (in addition to the ones originating from VSM itself).

7.3.1 Requirement 1: Dedication

The first requirement is derived from the cohesion of natural viable systems. For example, in the human body, all organs and tissues are dedicated to the survival of the whole system and their existence depends on it. Although this is taken for granted in natural viable systems, in organizations the dedication does not come automatically. The dedication of employees to their firm is a prerequisite for organizational success. According to the VSM, the identity of an organization and also its subsystems at lower recursion-levels needs to be clear, diffused, and accepted [ESPEJO et al. 1999]. This, however, addresses only one dimension of employee dedication. Limited to the formal perspective, personnel development and management of operational tasks in a bilateral relationship (lead-member-dialogue and bilateral feedback) build the other dimensions that result in higher productivity of employees and thus in higher viability of the whole organization [VAN MARREWIJK & TIMMERS 2003]. Accordingly, additional requirements for the viability of an organization are appropriate motivation of employees (for example, by personnel development, appropriate incentives etc.) and management styles that build upon intensive bilateral communication between operational (System 1) and controlling systems (Systems 2 and 3) [FREY & OSTERLOH 2002]. This requirement is crucial and should be addressed in the social and organizational level of the MCS design procedure.

7.3.2 Requirement 2: Real-Time Feedback

Another difference between an organization and the human body is (near) real-time feedback between the brain, sensory, and motor systems and the perceived environment. The VSM states that a viable system must be able to meet the requisite variety of its environment and continuously adapt to the changes. Also, the internal connections need to meet the requisite variety inherent to the organization, e.g., labor demand for more accurate payment calculation, etc.

Beer's original VSM described only generically the need for the ability to cope with external and internal variety, e.g., through adequate design of communication channels and information systems [PÉREZ RÍOS 2010]. He did not specify quantitative aspects of reaction to changes in variety such as reaction speed [WALKER 1990]. However, Beer did warn on harmful effects of delays in communication for overall coordination [BEER 1979].

The suggested requirement in this regard is to strive for implementation of the fastest-possible feedback loops to enable high respond rate for adaptability to external or internal changes. A possible realization may be a system for market monitoring, implemented in System 4 to provide near real-time modeling of the environment. For an internal reporting system, the definition of performance measurement indices and an implementation in a correspondent information system would provide the requirement for real-time feedback [WALKER 1990].

The request for internal real-time feedback is not to be confused with the concept of algedonic[4] channels in the VSM, but shall be seen as a qualitative enhancement of communication and information channels between and within systems 1, 2 and 3.

7.3.3 Requirement 3: Complementary Sensory Systems

In natural VSMs, sensory systems such as sight, sound and touch complement each other in order to detect the environment and changes therein. In general, the body filters multisensory information and reduces it to necessary information by so-called sensory gating processes that prevent overloading the brain [CROMWELL et al. 2008]. This multisensory information gets integrated by the brain, creating a coherent image of the environment and making the body adaptable to changes and enabling it to react in near real-time to possible threats [LEWKOWICZ & GHAZANFAR 2009].

These mechanism can be transferred to organizations. Beer's original VSM requirements included a filtering and alerting function of System 4 in combination with System 3 and reactive processing and answering to these alerts by System 5 [BEER 1979]. Yet, he did not

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[4] Algedonic channels are part of the VSM and run straight from System 1 to System 5 delivering arousal signals like pain or pleasure (e.g., information about critical situations). These channels exist separately from the normal information channels.

detail how such requirement might be implemented. At this point, the analogy of complementary sensory systems in organizations leads to the conclusion that a subsystem must exist to realize necessary observation of the environment's relevant parts, filtering of unnecessary information, and detection of changes crucial for the organization's viability. These requirements can be implemented in a system analogously to the balanced scorecard. Balance scorecard uses defined key performance indicators (KPIs) to reduce system-immanent information to a limited number of factors related to business strategy and ultimately enables management techniques such as management by exception [KAPLAN & NORTON 1996, NORTHOUSE 2010]. Akin to this approach, it is proposed to define key viability indicators (KVIs) in all recursive levels of the organization. KVIs should be set-up in all interfaces where there is a variance leap, such as for example in the interfaces between the environment and system 4, between system 2 and system 1, as well as between system 1 and the local environments, to name a few. For example, in the interface between the environment and system 4, the KVIs need to cover all information within the environment relevant for viability, such as strategically-relevant market developments, and alert critical changes when detected. A definition of KVI categories dividing the environment into relevant subjects facilitates coverage of all necessary information, analogously to the complementary multisensory information in natural VSMs. The organization's management can thereby focus on strategic decision-making and reacting quickly based on the information provided by the KVIs. The importance of KPIs for MCS are well known in the literature (see for example [SIMONS 1995]). This requirement therefore, reinstates this importance that need to be addressed in design of MCS.

7.3.4 Requirement 4: Learning

The human body's nervous system consists of neurons as building blocks that are interconnected to other neurons via chemical interfaces, the synapses, and form neural networks. Specific information in forms of stimuli (e.g., by the sensory organs) gets transported within this network of neurons along specific pathways. Each set of information activates a characteristic pathway or pattern of neural connections [MCCLELLAND 2010]. The interconnections formed by synapses can be strengthened or weakened by increasingly or decreasingly use frequency. This phenomenon is called synaptic plasticity; it builds the basis of learning in highly developed and extremely adaptable natural VSMs such as human beings [KANDEL 2001]. Synaptic connections in the neural network can thus be stabilized by more frequent use which ultimately leads to an increase in viability due to learning and thereby more effective and efficient adaption to changes or disturbances in the environment.

This effect can be applied to organizations concerning their MCS and communication networks. For example, imagine a planner in an industrial organization facing problems with production or quality of certain product parts. A MCS enabling feedback to the designer of the problematic part is required in order to resolve the problem. If responsibilities are transparently assigned and documented, the planner is able to contact the right entity within the organization concerning the issue. If such problems or comparable ones occur more frequently, the communication paths underlie certain learning effects (such as shorter reaction time and more efficient problem solving due to increasingly familiar interconnections within or between the involved organizational systems).

From this context and example, the fourth requirement for viability can be derived, aiming at providing lean communication and coordination networks. This can be achieved by transparent assignment of responsibilities for process steps and their contents, and by additional preselection of the correct communication partners for every MCS. The first outcome of these measures is a requisite variety for the organization's subsystems achieved through increased regulatory potential of MCS. The second one is the increase in efficiency of MCS due to learning effects. Therefore, during the design of MCS, these two functionalities that make possible learning and adaptation should be addressed in the social and organizational design level.

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9. Appendix

9.1 Amended Responsibility Assignment Matrix[5] (RAM) from First Case Study

The following document represents the output of the method applied in the context of pull-based material supply (first case study). The entries in red represent the added functions and assignments. Because of the size, the responsibility assignment matrix is spread over two pages.

RAM Assignments Definitions (obtained from project documents):

Accountable (A): The accountable team member is answerable for the accurate and full completion of the deliverable, activity or task. He may delegate the work to other team members, who are then responsible for completion of the task. Usually there is only one accountable person specified for each deliverable, activity or task. Sometimes the accountable team member is at the same time responsible for completion of a task. If this is the case, than in RAM it is indicated as "AR" or simply "A" with no "R".

Responsible (R): Team member who does the actual work (or part of the work) to complete the deliverable, activity or task. The accountable person approves the work that the responsible person provides.

Consulted (C): Team member who acts as a consultant for a specific deliverable, activity or task. Usually, consulted team members are subject matter experts (SMEs). Consulted team members may be customers of the deliverable, peers or leadership personnel. There is generally two way communication established between the responsible and consulted team members.

Supporting (S): Team member who provides support in the completion of specific part of the deliverable, activity or task. Usually, supporting team members are allocated to the responsible team member.

Informed (I): Team member who is periodically informed on progress to facilitate coordination but are not involved in the completion of a specific deliverable, activity or task.

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[5] Adapted from [PRODUKTENTWICKLUNG 2014a]

	Functions / **People**	Project Executive	Director, Business and Risk	Project Accountant CHC / SLC	Director of Project Management & Construction	Project Coordinator	Senior Project Manager Site & Structural	Project Engineer Site & Structure	Project Manager Enclosure	Project Engineer Enclosure	Senior Project Manager MEP	Project Engineer MEP	Project Engineer - MEP	Senior Project Manager Interiors	Project Engineer Interiors
	Production Values														
1.	Define Lean Principles to strive for, set overall expectations	AR			R										
	Strategic Planning, Production, Supply Chain														
2.	Daily Strategic Production Core Team Meeting				A	R	R								
3.	Built in Quality Process Construction						S		S		S			S	
4.	Detailing schedule complete with TP's						R		R		R			R	
5.	Trade Specific Production Plans														
6.	Constructability Planning														
7.	Information Flow -- Construction -						R		R		R			R	
8.	Jobsite Communication Plan														
9.	Risk Assessment - Production		A												
10.	Risk Mitigation - Production		A												
11.	Facilitate commissioning process						S		S		S			S	
12.	Close Out Planning														
13.	Commissioning Plan														
14.	Issue Resolution Construction						R		R		R			R	
	Supply Chain														
15.	Prefabrication Strategy						S		S		S			S	
16.	Prefabrication Process (Onsite/Offsite)						S		S		S			S	
17.	Prefabrication Matrix						S		S		S			S	
18.	Prefabrication Logistics						S		S		S			S	
19.	Create & Maintain Prefabrication Dashboard				I		S		S		S			S	
20.	Obtain and Assess Prefabrication Volume Information (WIP, Inventory Levels)				I		S		S		S			S	
21.	Trade Specific Supply Flow Plans														
22.	Kitting Plans						S		S		S			S	
	Production Schedule Planning, -Coordination and -Control														
23.	Scheduling Process - Adaptions to Master Milestone Planning (Overall Campus)				A		S		S		S			S	
24.	Last Planner System														
25.	Facilitate Weekly Last Planner Meeting (Lookahead)						R		R		R			R	
26.	Last Planner Engagement, Commitment and Execution Quality Control														
27.	Takt Time/Line of Balance Planning														
28.	Facilitate Daily Production Huddles														
29.	Financial and Schedule Risk Assessments		A		A		R		R		R			R	
30.	Trade Specific Production/Installation Plans														
	Production Control and Audit														
31.	Create & Maintain Production Rules (translate lean principles, set expectations, assess necessity of adaptions)				I										
32.	Audit Compliance to Production Rules														
33.	Create & Maintain Visual Production Dashboard														
34.	Create & Maintain Logistics Dashboard														
35.	Production Tracking and Analysis														
36.	Productivity Tracking and Analysis (TP info consolidation)														
37.	Production & Productivity Dashboard														
38.	Daily Production Progress Analysis & Feedback				I										
39.	Rework Tracking & Improvement														
40.	Production Controls						S		S		S			S	
41.	Set up Central Resources (including hoisting & equipment) Plan						R								
42.	Production Information Flow						S		S		S			S	
	Installation and Workspace Optimization														
43.	Game Tape Process														
44.	5S Plan														
45.	First Run Studies														
46.	Housekeeping Plan														
47.	Value Stream Mapping														
48.	Production Innovation Ideas - Pii						S		S		S			S	
49.	Material Consolidation Plan														
50.	Equipment Consolidation Plan														
51.	Medical Equipment Design & Install Coordination														
	Site Coordination														
52.	Communicate Production Rules														
53.	Site Logistics Plan														
54.	Site Layout Plan														
55.	Logistics and Site Coordination														
56.	Coordinate Deliveries (Delivery Calendar)														
57.	Crane & hoist Plan														
58.	Set up & Communicate Inventory Dashboard														
59.	Maintain Inventory Dashboard (consumables, tools)														
60.	Mobilization Plan (includes equip & mtl)						R		R		R			R	
61.	Construction Execution Plan						S		S		S			S	

Project Engineer Interiors	Project Manager Interiors	Project Engineer Interiors	Project Manager Interiors	Project Engineer - Interiors	General Superintendent	Superintendent Site Logistics	Project Engineer Logistics	Project Engineer Operations	Area Supt Site & Structure	Area Supt Enclosure	Area Supt CUP/MEP/IT Infrastructure	Area Supt Interiors	Area Supt Interiors	Area Supt Interiors	Area Supt Interiors	Area Supt Interiors	Senior Manager Const. Operations & Innovation	Production Core Team	Production Manager	Production Superintendent	Production Engineer	Production Engineer	Built in Quality Manager	BIQ Engineer	Safety Manager	Safety Engineer	Tradepartners (Sups, Foremen, Crews)	Owner's Representatives
					I												I		I									
					R	R											R	R	R									
	S		S		S														A				R	S				
	R		R		A													C	R									
																	I	R	A								R	
					A																							
	R		R		R												A	R										
					A																							
					R												R		S									
					R												R		S									
	S		S		R														S				S					
	R		R		R												A	R										
	S		S		S												A	C	R									
	S		S		S												A	C	R		S	S						
	S		S		S												A	R	R									
	S		S		S												A		R									
	S		S		S												I	C	A		R	R						
	S		S		S		R										I	C	A		R	R						
					A	R	S		S	S	S	S	S	S	S	S											R	
	S		S			I												S									R	
	S		S																R									C
					S				R	R	R	R	R	R	R	R	A		R	R							R	
	R		R		R				R	R	R	R	R	R	R	R	I		A									
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					S												I	S	A									
					A				R	R	R	R	R	R	R	R	I		S								R	
	R		R		R												R		S									
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					S	S	S	S									I		A	S	R	R						
					I	R	R										I		A									
					S												I	C	A	R	R	R						
					S												I	C	A	R	R	R						
					S												I	C	A	R	R	R						
					R	S	S	S	R	R	R	R	R	R	R	R	I		A	R	R	R						
					R												A		R									
	S		S		S												A		R									
					A	I	I											C	C	I								
	S		S		S												A		R									
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						A			S	S	S	S	S	S	S	S											R	
	R		R		A												S		S									
	S		S		A				R	R	R	R	R	R	R	R			S	S			S					

9.2 Questionnaire Used for the First Case Study Evaluation

Technische Universität München

Evaluation Sheet: Viable System Model at CHH

10/22/14

Please support our research on **lean implementation supported by the Viable System Model (VSM)** with your feedback and comments. To identify room for improvement, please share your opinion about: **applicability** of the VSM-based approach, **usability** of a) the translation process for general functions of the VSM into specific ones for your lean material supply system, and b) the process of refining the RASCI-chart based on the created VSM, as well as **usefulness** of the final results.

It is important for the research project to have your personal opinion. Please rate the following questions according to the given scale and comment shortly, if you like, at the end of each block.

Please feel free to also provide written feedback to questions that don't have special comment fields!

Thank you very much for your support!

1. Applicability of the VSM-based approach

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The **VSM** in general is **easy to understand** and **describes my experience** in real projects.	☐	☐	☐	☐	☐	☐
The **recursive character** of the VSM is **easy to understand** and **describes my experience** in real projects.	☐	☐	☐	☐	☐	☐
In my experience, the **general functions** (provided by the literature) of the VSM **describe** the functions required in this project.	☐	☐	☐	☐	☐	☐
From my understanding, the **VSM** provides a new perspective that **brings additional value** for lean material supply systems**.**	☐	☐	☐	☐	☐	☐
After reading the general functions of the VSM during the workshop, it was easy **to relate** them to functions **specific** to **lean production systems and material supply**.	☐	☐	☐	☐	☐	☐

Comments on applicability of the VSM in the context of designing and structuring a lean material supply system for CHH.

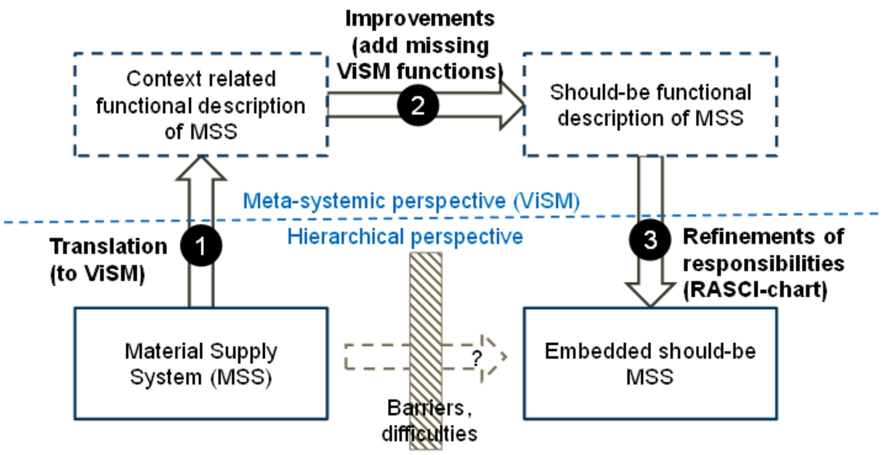
____

____

2. Usability of the approach (function translation and RASCI-refinements)

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **recursive character** of the Viable System Model was **clear** and **caused no confusion** in identifying the correct functions for each recursion level.	☐	☐	☐	☐	☐	☐
The **general VSM-functions** were **appropriately brought** into lean material supply system context.	☐	☐	☐	☐	☐	☐
It was **easy to differentiate** the context related **functions and their clustering** into the 5 VSM-systems	☐	☐	☐	☐	☐	☐
It was easy to **identify the existing structures** that perform (some of) the VSM-functions.	☐	☐	☐	☐	☐	☐
It was **easy to refine responsibilities** (RASCI-chart) based on the context related VSM-functions.	☐	☐	☐	☐	☐	☐

The approach (as reminder and overview):



Comments on usability of the approach followed for a) function translation and b) refinements of the existing RASCI-chart in the context of designing and structuring a lean material supply system for CHH:

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3. Usefulness of the results

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
From **my point of view** and **experience,** the list of context related functions is **comprehensive**.	☐	☐	☐	☐	☐	☐
The **context related functions** are **essential to** implement adaptable lean material supply in CHH's organization structure.	☐	☐	☐	☐	☐	☐
The **context related functions** are **useful to set up** communication and control for adaptable and lean material supply at CHH.	☐	☐	☐	☐	☐	☐
The **context related functions** can be **useful to refine** CHH's existing organization structure.	☐	☐	☐	☐	☐	☐
The context related functions of the VSM **expose** some **problems and challenges** in this project I haven't thought about.	☐	☐	☐	☐	☐	☐
The **recursive perspective** of the context related functions **brings additional value** (e.g. efficiency, better coordination) for lean material supply systems in practice.	☐	☐	☐	☐	☐	☐

Comments on usefulness of the produced results, e.g. further application of the refined RASCI-chart, enhancement of job descriptions, transparency about responsibilities among production system managers and field workers:

____

____

Please **indicate** which of the following topics from lean construction **could** or **could not** be **supported** with the VSM approach.

	Could be supported	**Could not be supported**	**Not applicable**	**Comments**
Integrated form of agreement	☐	☐	☐	
Continuous improvement	☐	☐	☐	
Smaller lean control mechanisms (such as poka-yoke, built-in quality etc.)	☐	☐	☐	
Document/information management	☐	☐	☐	
Value stream mapping and waste elimination	☐	☐	☐	
Other:	☐	☐	☐	
	☐	☐	☐	
	☐	☐	☐	
	☐	☐	☐	

Thank you very much for your feedback!

9.3 Should-be MACS Functions – Second Recursion Level[6]

VSM System	Modular Architecture Control System (MACS) context-related functions (after the workshop) - second recursion level	To be performed by
S5 - Policy	Define and update strategic goals of the platform management	VM Policy Board
	Decide on strategic issues concerning platforms (e.g. hunting fields)	
	Receive information about future changes concerning platforms from S4 and the capabilities of operations from S3 (for updating strategic goals)	
	Ultimate decision about platform changes, if S3 and S4 cannot agree	
	Know how update if certain competences are missing (e.g. invest in new technology)	
	Through its strategic goals, it should serve as basis for making decisions on R&D projects	
	Check acceptance and understanding of the platform strategy across the whole BUR	
S4 - Intelligence	Monitor environmental factors (competitors, customer demand, legislation, political changes, economic changes, SCM issues, technology changes, organizational changes etc.)	Regional/Central Marketing Portfolio Management
	Analyze the environmental changes and prioritize them based on the impact on platform management	
	Inform S5 about detected changes and the impact on the platforms and portfolio strategy	
	Analyze the impact of environmental changes on platform strategy with S3, evaluate if the platform is still able to handle future requirements	
	Discuss with S3 why and when platform functions should change	
	Provide an outlook for future functional requirements and the impact on market of the platforms based on the observed environmental trends	
S3 - Control	Get status updates from S1 about what functions of products are affected due to the new variant requests	Product Management
	Receive information from S2 about problems related to platforms (e.g. higher cost or delays in designing and manufacturing certain variants)	
	Design and update the autonomous platform management and embed it in S2 (operational platform management guidelines)	
	Initiate schedule changes based on the information received from S4 (update the platform roadmap)	
	Initiate sporadic audit by engaging S3* for addressing problems not covered by S2	
	Analyze the impact of operational issues on platform strategy with S4, evaluate if a new platform strategy is feasible from the operational point of view	
	Set key performance indicators (KPIs) to enable autonomous platform management	
	Ensure that S1 follows the functional planning of modules (platform and modular roadmap)	
	Identify possible synergies between and within S1 entities (for increasing the efficiency of platform management)	
	Act directly (only in extreme cases) on S1 for solving platform management operational problems	
S3* - Auditing	Ad-hoc monitoring of S1 for assessing the compliance of S1 entities to operational platform management guidelines	Product Management
	Ad-hoc special assignments for trouble-shooting problems in S1 related to non-compliance of platforms (e.g. certain variants cannot be produced with the current platform)	
S2 - Coordination	Provide communication tools to S1 entities for synchronization of information (e.g. communication network, regular meetings, special templates etc.)	Project Office
	Provide guidelines and rules to S1 entities for reporting continuously on the health of current platform systems (in form of KPIs)	
	Based on the information received from S1 entities, report to S3 about the current status of platform systems (serve as variance attenuator)	
	Provide guidelines to S1 entities on possible changes in module and platform roadmaps	
S1 - Operations	Work on the design and development of platform modules as scheduled in the modular and platform roadmaps	Development Centers
	Work on unpredicted platform system changes as requested by S3	
	Communicate with other S1 through S2 entities about platform systems' changes on functions, materials, tools, interfaces, etc.	
	Follow instructions coming from the guidelines for the reporting to S2	
	Report current status of the roadmaps (schedule and necessary changes) to S2	
	Provide information to S3 concerning resource capacity requirements for following module and platform roadmaps	
	Receive goals from S3 through S2 (e.g. planned output, functional changes of platforms, etc.)	

[6] Adapted from [PRODUKTENTWICKLUNG 2014b]

9.4 Questionnaire Used for the Second Case Study Evaluation

Workshop Evaluation Sheet

21. August 2014

Viable System Model into Lifecycle Management of Platforms context

Please support our research on **Lifecycle Management (LCM) of Platforms** with your feedback and comments. To identify room for improvement, please share your opinion about: the **Viable System Model (VSM)**, the translation process of the general functions of the VSM into the ones related to LCM of Platforms, the final results, and the workshop execution.

It is important for the research project to have your personal opinion. Please rate the following questions according to the given scale, or simply answer the questions.

Please feel free to also provide written feedback for questions that don't have special comment fields!

Thank you very much for your support!

Expectations

Given my research on Lifecycle Management of Platforms and the use of the Viable Systems Model, what are your **desired outcomes** of our research collaboration at the T1 project?

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What **challenges** do you see and where do you see them concerning our **research collaboration** in supporting Lifecycle Management of Platforms at the T1 project?

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The Viable System Model (VSM)

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The general **VSM** is **easy to understand** and **describes my experience** on real projects.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **recursive character** of the VSM is **easy to understand** and **describes my experience** in real projects.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
In my experience, the **general functions** (provided by the literature) of the VSM **describe** the functions required for LCM of platforms	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
From my understanding, the **general VSM** provides a new perspective that brings additional **value** for Lifecycle Management of Platforms**.**	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree”, “Disagree”, or “Disagree somewhat”, please indicate why you think the VSM **does not provide a new perspective** that brings additional value for Lifecycle Management of Platforms.

____

____

____

Process of translating the Viable System Model (VSM) functions

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
After reading the general functions of the VSM during the workshop, it was easy **to relate** them to functions **specific** to **Lifecycle Management of Platforms**.	☐	☐	☐	☐	☐	☐

If your answer was "Strongly disagree", "Disagree", or "Disagree somewhat", please indicate why you had **difficulties to relate** the general functions to Lifecycle Management of Platforms specific ones.

____

____

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The **size of the team** during the workshop was **adequate** to discuss the functions specific to Lifecycle Management of Platforms.	☐	☐	☐	☐	☐	☐

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
During the workshop the **required experts** were **present** to discuss the context related functions of the VSM.	☐	☐	☐	☐	☐	☐

If your answer was "Strongly disagree", "Disagree", or "Disagree somewhat", please indicate which **experts** or **persons were missing** in order to discuss the context related functions of the VSM**.**

____

____

____

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **provided examples** for each context related function were **useful** for a better understanding of ways how to implement them.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The idea of the **approach** for the sequence of actions in LCM of platforms **(flowchart)** is **appropriate**.	☐	☐	☐	☐	☐	☐

If your answer was "Strongly disagree", "Disagree", or "Disagree somewhat", please indicate what **part** of the approach was **not understandable** or **needs** further **improvement**.

____

____

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **sequence** (proposed approach) for the LCM of Platforms **can be integrated** in the **existing process**.	☐	☐	☐	☐	☐	☐

If your answer was "Strongly disagree", "Disagree", or "Disagree somewhat", please indicate why **the approach for the sequence** cannot be integrated in the current process.

____

____

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **scheduled time** for the workshop sessions was **adequate** to reach the objectives of the workshop.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **slides** and **handout** used during the workshop were **adequate** to support the identification of the context related functions.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree”, “Disagree”, or “Disagree somewhat”, please indicate how the discussion could have been **supported more adequate**.

____

____

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **allocation** of VSM-**functions** to responsible departments/persons was **possible**.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree”, “Disagree”, or “Disagree somewhat”, please indicate where you had **problems allocating** the **LCM of platform functions to responsible persons**.

____

____

Workshop result

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
From **my point of view** and **experience,** the list of context related functions is **comprehensive**.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree”, “Disagree”, or “Disagree somewhat”, please indicate why you **don’t** see the list of functions as **comprehensive.**

____

____

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **general functions** were **appropriately brought** into Lifecycle Management of Platforms context.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree”, “Disagree”, or “Disagree somewhat”, please indicate why you **don’t think** that the functions were **brought appropriately** into Lifecycle Management of Platforms context**.**

____

____

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **context related functions** can be **useful to set up** Lifecycle Management of Platforms processes.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree”, “Disagree”, or “Disagree somewhat”, please indicate why you **don’t think** the translated functions are **useful** to set up Lifecycle of Platforms processes.

____

____

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The proposed approach for a **flowchart** containing the context related functions **brings additional value** (e.g. clear procedure, better coordination) for LCM of Platforms in practice.	☐	☐	☐	☐	☐	☐

If your answer was "Strongly disagree", "Disagree", or "Disagree somewhat", please indicate why you **don't think** the **flowchart** would bring **additional value** for setting-up the LCM of Platform processes.

____

____

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **allocation** of functions to existing structures/ responsible persons **helps for understanding** and **implementing** the approach.	☐	☐	☐	☐	☐	☐

If your answer was "Strongly disagree", "Disagree", or "Disagree somewhat", please indicate why you **don't think** the **allocation of function** helps to understand and implement the approach.

____

____

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The need of **KPI**s for LCM of platforms is comprehensible and **KPI**s will be investigated to track **platform performance**.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree”, “Disagree”, or “Disagree somewhat”, please indicate why you **don’t think** that **KPI**s help to improve the LCM of platforms.

____

____

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The translated functions of the VSM **expose** some **problems and challenges** in this project I haven’t thought about.	☐	☐	☐	☐	☐	☐

Please feel free to **mention** the problems and challenges that the discussion of the context related functions **revealed**.

____

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Please **indicate** which of the following challenges and problems **could** or **could not** be **tackled / solved** with the Lifecycle Management of Platforms specific VSM.

	Could be tackled/ solved	Could not be tackled/ solved	Not applicable	Comments
Adaptability of Lifecycle Management of Platforms	☐	☐	☐	
Continuous improvement	☐	☐	☐	
Coordination of disturbance factors	☐	☐	☐	
Prediction of disturbance factors	☐	☐	☐	
Assessment of the LCM of platforms impact	☐	☐	☐	
Process safety for the LCM of platforms process	☐	☐	☐	
Measurement of platform performance	☐	☐	☐	
Involvement of different departments	☐	☐	☐	
Identification of solutions	☐	☐	☐	
Communication of control mechanism	☐	☐	☐	
Schedule management	☐	☐	☐	
Tracking of platform change decisions	☐	☐	☐	
Clarification of roles within the control mechanism	☐	☐	☐	

Workshop execution

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The workshop moderator **introduced** the VSM and its characteristics in an **understandable** and **structured way**.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **objectives** of the workshop were **clear** to me through the introduction of the moderator.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **pace** of the **workshop** was **adequate** and I was able to **follow** the **discussion**.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
It was possible for me to **communicate** my **point of view** during the workshop.	☐	☐	☐	☐	☐	☐

	Very poor	Poor	Fair	Satisfactory	Good	Very Good
Finally, please **evaluate** the workshop as a whole.	☐	☐	☐	☐	☐	☐

Please share any other comments and suggestions you may have:

____

____

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Thank you very much for your feedback!

9.5 As-is ECM Functions

9.5.1 As-is ECM First Recursion Level Functions[7]

VSM System	First recursion level ECM functions	Degree of fulfillment
S5 - Policy	Set strategic objective for project management (e.g. handle changes without bureaucracy, balance risk and opportunity of ECs)	No formal strategy set
	Define the overall values of ECM within the project management	Integrated project delivery influences how costs of EC are shared or allocated. EC should be executed in lean manner
	Receive information about the planning in engineering change management from S4 (e.g. deadlines for the clusters) and current status of changes	Only large scale ECs are entered in vPlanner software and their progress is discussed once weekly. The discussion provides a limited overview over the time planning and the current status of the ECs
	Decide on ECM issues in which project planning and project operations cannot agree on	Nonexistent
	Ensure that ECM respects the project planning and the regulatory requirements	Existent only in relation to OSHPD and ADA
	Discuss project management strategy with cluster managers	Nonexistent
S4 - Intelligence	Ensure that vPlanner and EC work plans stay updated	Planning performed only for the overall project. No ECM planning performed
	Talk with the owner to anticipate engineering changes due to changes in the requirements. Stay in close contact with OSHPD and ADA	Existent
	Define mile stones and deadlines for the ECs	Nonexistent
	Occasionally report to S5 about current state of ECM planning	Existent only for large impact ECs
	Inform clusters about an updated planning	Nonexistent in relation to ECM
S3 - Control	Receive occasional updates on ECs coming from the clusters	No rules were defined on how S3 should be kept updated
	Occasionally receive updates about the status of changes vial E-Mail or Project Inertia (software)	Nonexistent
	Receive audit information from S3* (Beer 1972, p.178 ; Pérez Rios 2012, p.38) - inexistent	Nonexistent
	Receive updates from the project planning that affect ECM	Most of information received relates to the whole project rather than ECM
	Receive strategic level goals concerning the ECM (e.g. coordination with OSHPD, project management guidelines, IPD rules, etc.)	Only goals related to the communication with OSHPD and ADA are received
	Decide about direct intervention based on the provided information from clusters	In special cases meetings are organized to discuss about certain strategic ECs
	Inform project planning about changes that miss deadlines or cause a delay of the project	Not observed as existent during the case study
	Assign deadlines for the ECs based on the project planning	Nonexistent
	Define accountability mechanisms for S1 (e.g. keep informed about how the ECM complies with the goals)	Nonexistent
	Monitor that the ECs fulfill the quality requirements	Performed only for certain strategic ECs
	Ensure that the clusters inform each other about engineering changes and work together on solutions	Partially existent

[7] Adapted from [PRODUKTENTWICKLUNG 2014c]

As-is ECM First Recursion Level Functions (cont.)

VSM System	First recursion level ECM functions	Degree of fulfillment
S3* - Auditing	Audit clusters (e.g. quality audits, compliance with OSHPD standards, etc.)	Nonexistent
	Ensure that ECM instructions are complied by the clusters	Nonexistent
	Report on problems arisen in clusters that require update of ECM instructions for solving them	Nonexistent
S2 - Coordination	Provide a common EC communication platform to the clusters	Mostly informal communication between clusters
	Common communication platform forwards comments and information between clusters	Nonexistent
	Use OSHPD approval process and memorandum of understanding for change classification	Partially existent
	Mediate between clusters concerning the selection of EC solutions	Partially existent
	Inform S3 or higher levels about ECs which exceed self-regulatory capacity and require direct action by the management	Nonexistent
	Forward clusters relevant project changes to be incorporated in ECM (e.g. updated OSHPD approval process)	Performed in an informal way
	Contain a set of KPIs for assessing the performance of ECM	Nonexistent
S1 - Operations	Plan, design and erect the hospital building. Implementation of changes initiated internally or externally	Existent
	React to changes that occur in the particular environment (e.g. comments from OSHPD, new requirements from the owner, etc.)	Existent
	Ensure that the clusters finish the engineering changes on time. Support open discussions on changes among the operational units	Only particular ECs are monitored closely
	Inform other clusters about changes in the deadlines or discuss possible solutions for engineering changes	Mostly informal
	Utilize ECM coordination/communication system provided by S2	Nonexistent
	Provide EC status updates to S2	No rules or KPIs for reporting the status are defined
	Receive information about strategy updates in relation to ECM	Nonexistent
	Negotiate resource allocation with S3 affecting ECs	Nonexistent

9.5.2 As-is ECM Second Recursion Level Functions[8]

VSM System	Second recursion level ECM functions	Degree of fulfillment
S5 - Policy	Define the cluster internal strategy for ECM (e.g. cooperation with District Structural Engineer at OSHPD)	Partially existent only in relation to OSHPD and ADA
	Receive information from S4 about the EC planning (e.g. deadlines for the different parts of the building)	No rules defined when and to which extent information is provided
	Facilitate a compromise between cluster planning and operations in case of disagreements	No guidelines are provided clarifying in which cases S5 should intervene
	Ensure that the legal requirements are respected	Partially existent only in relation to OSHPD and ADA
S4 - Intelligence	Update the cluster-related EC schedules in vPlanner. Maintain the deadlines until the fabrication of the structural parts starts	Excel file containing only some ECs and their status is maintained
	Communicate with the cluster-related detailer and suppliers to anticipate ECs	Performed occasionally in an informal way
	Create and maintain an cluster-internal schedule with all important EC deadlines	No separate EC scheduling and progress monitoring is performed for most of ECs.
	Update S5 about the changes in EC plan	No rules or guidelines set for updating S5
	Communicate adjustments of the cluster-internal planning to other clusters	No formal process for communication between clusters established
S3 - Controlling	Continuously receive updates about the status of changes via E-Mail or Project Inertia (software)	No reporting guidelines available
	Receive audit information from S3* in case of problems in EC execution	Nonexistent
	Receive an updated schedule for the cluster-internal planning	No updates concerning ECs is provided
	Receive instructions from the project level and from cluster-internal S5 (e.g. updated project management rules, change in OSHPD legal requirements)	No ECM specific instructions are provided
	Decide about updating the cluster-internal ECM process based on S2 information	Nonexistent
	Inform the cluster-internal planning about ECs that can't be finished on time	Only in few cases this information is provided
	Negotiate and set the EC deadlines with cluster-internal planning	Nonexistent
	Decide on indicators to monitor the progress of ECs	Nonexistent
	Maintain and update the EC process	Nonexistent
	Ensure that the operational units answer the RFIs and work together on solutions	Existent

[8] Adapted from [PRODUKTENTWICKLUNG 2014c]

As-is ECM second recursion level functions (cont.)

VSM System	First recursion level ECM functions	Degree of fulfillment
S3* - Auditing	Audit the EC operations (e.g. quality audits, compliance with cluster-internal ECM guidelines)	Nonexistent
	Ensure that ECM instructions are complied by the operational teams	Nonexistent
	Report on problems arisen in operational teams that require update of cluster-internal ECM instructions for solving them	Nonexistent
S2 - Coordination	Provide a common EC communication platform to the operational teams within the cluster	Mostly informal communication
	Define the cluster internal EC process	Partially existent only in relation to OSHPD and ADA
	Schedule meetings to ensure coordination among the EC operational teams. Set priorities for engineering changes	Partially existent only in relation to OSHPD and ADA
	Inform S3 about EC which exceed the scope of decision-making of operational teams and require attention of the management	No formal process established
	Contain a set of KPIs for assessing the performance of EC operational teams	Nonexistent
S1 - Operations	Implement the cluster-specific ECs	Existent
	Suggest changes in cluster-specific ECM process based on for example, new owner requirements, new technologies, from the regulatory bodies, etc.	Nonexistent
	Inform other operational units about changes that arise from ECs.	Performed in an informal way
	Utilize coordination/communication system provided by S2	No coordination/communication system provided by S2 in this recursion level
	Receive information about updated cluster-internal strategy	Nonexistent
	Discuss and receive deadlines for changes with S3	Nonexistent

9.6 Should-be ECM Functions[9]

VSM System	First recursion level ECM functions	Performed by	Second recursion level ECM functions	Performed by
S5 - Policy	Define the strategic objectives for the ECM (e.g. involvement of the owner, coordination and cooperation with the legal bodies, efficiency, etc.)	Office of Project Executive and Senior Project Manager	Define the cluster internal strategy for ECM (e.g. cluster-level cooperation with District Structural Engineer at OSHPD)	Office of Structural Senior Project Manager
	Define the strategic values that should be incorporated in the ECM (e.g. integrated project delivery, lean principles, quality, safety, etc.)		Define the values (reflected from the first recursion level) that are required for the cluster-level ECM (e.g. communication and cooperation within the cluster, quality requirements, lean principles, etc.)	
	Receive information about the ECM planning (e.g. ongoing ECs, anticipated ECs, schedules, deadlines, specific problems in relation to S3 and S4 homeostat)		Receive information on ECM planning on cluster level (e.g. performance of ECM, specific problems in execution of ECs)	
	Act as mediator to settle disputes between S3 and S4 and negotiate between future and current ECM operations (e.g. deadlines for changes, timetables, costs, work plans and schedules)		Act as mediator to settle disputes between S3 and S4 on cluster level and negotiate between future and current ECM operations	
	Ensure that the ECM is well integrated in the overall project planning. The owners requirements and legal requirements have to receive special attention in the ECM process.		Ensure the integration of intra-cluster ECM planning with the overall ECM inter-cluster planning	
	Ensure that the ECM strategy is understood and respected by all clusters		Ensure that the cluster ECM strategy is understood and accepted by the cluster stakeholders	
S4 - Intelligence	Anticipate upcoming ECs and analyze the impact of these changes to the overall project planning (e.g. new requirements from owner or regulatory bodies, delays caused by changes, longer lead times, wrong previous assumptions, problems during construction, delayed approval process, available labor, economic changes, changes in technical equipment etc.)	Office of Senior Project Manager, OSHPD and Comm. Manager	Analyze the cluster specific environment to anticipate changes arising from first recursion level planning and impact the cluster EC planning (e.g. new regulatory requirements, problem with suppliers, changes of trade partners, etc.)	Office of Structural Senior Project Manager and Structural Project Manager
	Synchronize the ECM planning with the planning of other operational processes (material supply, design and construction phases, etc.). Create and maintain documents for easier synchronization. Provide suggestions when changes should be implemented or phased in depending on the synchronization analysis.		Use the first recursion ECM planning as an input to maintain a cluster-specific EC planning. Feedback information to the first recursion level planning in case the cluster plans deviate and a solution has to be found	
	Inform S5 about important deviations in future planning (schedules, important mile stones, and deadlines)		Inform S5 about important changes of cluster-level EC planning (schedules, important mile stones, and deadlines)	
	Inform S3 about changes in schedules or plans that effect the current ECM or the processes. Negotiate with S3 about these changes		Forward changes and adaptations to S3 that impact the work of the operational teams (e.g. new deadlines, cost planning, schedules)	

[9] Adapted from [PRODUKTENTWICKLUNG 2014c]

Should be ECM Functions (cont.)

VSM System	First recursion level ECM functions	Performed by	Second recursion level ECM functions	Performed by
S3 - Control	Maintain schedules for inter-cluster ECs and ensure that they are synchronized with the project plan (work plans, mile stones, lead times of the suppliers and production planning). Inform the clusters about changes in the overall project plan that could impact their work	Office of Senior Project Manager, OSHPD and Comm. Manager	Maintain a cluster-internal schedule with all the EC important deadlines, lead times and constrains. Inform S4 in case of schedules clashes that impact the overall project planning	Office of Structural Senior Project Manager and Structural Project Manager
	Receive direct information from the clusters concerning ECs and their status. S3 is directly informed by S1 in case an EC becomes or is about to become a risk for the entire project		Receive information from S2 about ECs and their status. The operational teams within the cluster inform S3 in case problems in executing an EC	
	Receive information from S2 for assessing the performance of ECM (e.g. KPIs, status updates, current changes)		Receive information (reports) from S2 concerning the ECM performance within the cluster (e.g. KPIs, status updates, ongoing changes)	
	Receive audit information concerning the ECM at cluster level (e.g.. compliance with the formal EC process, OSHPD approval process, coordination among the clusters, EC documentation, specific problems, suggestions for improvement, etc.)		Receive detailed information from the audit about problems in execution of EC within the cluster (e.g. compliance with the formal engineering change process, change documentation and coordination within and outside the cluster)	
	Discuss with S4 about anticipated ECs and changes in the EC planning. Based on this information adjustments of EC work plans, EC deadlines, EC costs and schedules should be performed		Receive information about future planning from S4. In addition to the cluster specific objectives also implement also the strategic changes coming from the first recursion level (e.g. schedules, deadlines, etc.)	
	Receive strategic goals and instructions concerning the ECM (e.g. coordination with OSHPD and other regulatory bodies, efficiency). Based on these goals, a formal standardized ECM process on project level is suggested		Receive strategic goals and instructions concerning the ECM on cluster level (e.g. coordination with OSHPD and other regulatory bodies, efficiency). Based on these goals, a formal standardized ECM process on cluster level is suggested	
	Based on the information provide by S2 and S3*, update and maintain the ECM process, such as modification of the rules and guidelines (rules for RFIs, document management, definition of responsibilities, creating new rules, adjusting communication platform, etc.)		Based on the information from S2 and S3*, update and maintain the cluster-internal ECM process, such as modification of the rules and guidelines (MRU material/ non-material changes, rules for RFIs, document management, maintenance of the models and drawings), definition of responsibilities, etc.)	
	Inform S4 about changes that might impact the future planning of the project (e.g. EC delays, long waiting times, approval problems, miles stones that will not be met). Also report conflicts between current operational EC plan and the future plan		Inform S4 about changes that impact the future planning of the cluster (e.g. unrealistic deadline planning of the ECs).	
	Inform and instruct the clusters about decisions and changes concerning the ECM process (approval rules or future planning of the project, approaches for OSHPD coordination and approval process or cooperation with other legislative bodies etc.)		Inform and instruct the operational teams about decisions and changes concerning the ECM process (e.g. future planning of the cluster, objectives etc.)	
	Ensure that the overall project management strategy is reflected in the ECM process (e.g. IPD, coordination with legal bodies, project goals).		Reflect the cluster strategy into ECM cluster-level process (e.g. IPD rules, coordination with legal bodies, etc.)	
	Assign EC deadlines and target costs. Set requirements concerning constructability, quality and inter- and intra-cluster change propagation.		Assign EC execution deadlines, and target costs for cluster level changes.	
	Define performance measures to evaluate the performance and allow for autonomous operation of the clusters in terms of ECM (e.g. KPIs, guidelines for cost calculations, time spend on ECs)		Define performance measures to evaluate the performance of the EC execution by operational teams (e.g. KPIs)	
	Allocate personnel to certain clusters for critical ECs		Negotiate the allocation of personnel in case the operational units cannot cope with the scope of the ECs	
	Define a common communication platform for ECM. Provide rules or guidelines to the clusters for using the communication platform. At this recursion level, a special attention should be give to inter-cluster ECs		Enforce the use of common communication platform for ECM within the cluster. Provide specific rules or guidelines to operational teams for using the communication platform	
	Monitor the EC performance of clusters and act if the performance is not satisfactory		Monitor the performance of EC execution. Ensure that all changes are documented correctly	
	Make sure that there is a coordination between clusters on inter-cluster ECs		Ensure that operational teams communicate and work together on ECs that require cooperation (e.g. information sharing, collaborate on solutions, provide status updates, make knowledge and experience accessible)	

Should be ECM Functions (cont.)

VSM System	First recursion level ECM functions	Performed by	Second recursion level ECM functions	Performed by
S3* - Auditing	Audit (ad-hoc) the ECM process within the clusters (compliance with the formal ECM process, documentation of the change, coordination among clusters, etc.). Ask the clusters for feedback concerning the ECM (e.g. problems with the current ECM process, conflicts with other clusters, suggestions for improvement of the communication platform). Create reports to obtain more detailed insights about the ECM performance (e.g. causes of long processing time)	Office of Senior Project Manager, OSHPD and Comm. Manager	Audit (ad-hoc) the ECM process performed by operational teams (compliance with cluster-intern ECM process, documentation of the change, coordination among operational teams, etc.). Ask the operational teams for feedback concerning the ECM (e.g. problems with the current ECM process, conflicts with other teams, suggestions for improvement of the communication platform). Create reports to obtain more detailed insights about the ECM performance	Cluster Assistant
	Ensure that rules, processes and procedures for ECM set by S3 are correctly applied		Ensure that rules, processes and procedures for ECM set by S3 are correctly applied by operational teams	
	Enlarge the insight and information basis for S3 in case of specific problems that cannot be autonomously solved within clusters		Enlarge the insight and information basis of S3 in case of specific problems that cannot be autonomously solved within operational teams	
S2 - Coordination	Provide a communication and coordination platform to all clusters to allow a project-wide ECM. Ensure that the coordination platform meets the requirements of all clusters to facilitate efficient ECM	Office of Senior Project Manager, OSHPD and Comm. Manager	Make project wide the communication and coordination platform accessible for all member of the cluster. In addition, offer a medium or platform for cluster internal coordination and communication	Office of Structural Project Manager and Cluster Assistant
	Transmit information about changes in the commitments, deadlines, requirements of ECs to S3		Transmit information about changes in the commitments, agreed solutions, and execution problems to S3	
	Provide a formal ECM process to ensure that clusters execute autonomously ECs (e.g. provide rules for coordination with OSHPD and the approval process)		Ensure that operational teams use the formal ECM process for autonomous execution of ECs	
	Mediate conflicts between clusters that arise during the execution of EC process.		Mediate conflicts between operational teams that arise during the execution of EC process.	
	Inform the cluster management about ECs that require special attention or coordination (e.g. due to time constraints, number of impacted clusters, conflict with a regulatory body, high cost for a change, risk for the project, or quality issue).		Inform the operational team management about changes that require special coordination and attention in execution of ECs (e.g. problem finding a solution, missing information or problems with coordination)	
	Send updated project-wide process rules, guidelines and legal requirements in relation to the ECM to the clusters (e.g. process maps, responsibilities, OSHPD process, documentation rules, maintenance of the models and drawings, responsibilities, communication platform)		Forward updated cluster-internal rules directly to local S2s (e.g. internal process maps, guidelines for internal communication) directly to the local S2s	
	Forward to S3 the information needed to assess the performance of ECM at cluster level (e.g. KPIs, reports, etc.).		Forward to S3 the information needed to assess the performance of EC execution at operational team level (e.g. KPIs, reports, etc.).	
S1 - Operations	Execute ECs initiated internally or externally on cluster level	Cluster and Cluster Management	Execute ECs on operational team level	Operational Teams
	Implement the changes to ECM process initiated by S3 (e.g. new requirements, problems that occur during planning and construction, feedback from regulatory bodies)		Incorporate the changes to ECM process initiated by S3 on operational team level	
	Ensure that the ECM on cluster level is performed efficiently (e.g. EC implementations meet the deadlines, budget and quality requirements).		Ensure that the ECM on operational level is performed efficiently (e.g. EC executions meet the deadlines, budget and quality requirements).	
	Communicate and coordinate EC implementation with other clusters (e.g. finding a feasible solution for all involved clusters, discussion on deadlines and requirements)		Communicate and coordinate EC execution with other operational teams (e.g. finding a feasible solution for all involved clusters, discussion on deadlines and requirements)	
	Use the communication and coordination platform for ECM provided by S2		Utilize the standardized communication and coordination platform for ECM	
	Keep the communication and coordination platform updated (e.g. status of the cluster-level ECs, progress, required decisions and possible problems). This information is attenuated by S2 to match the requisite variety of S3		Keep the communication and coordination platform updated (e.g. status of the individual ECs, stage, progress, required decisions and possible problems).	
	Inform S3 directly in case a problem in an EC occurs that requires full attention (e.g. critical EC delay, unpredicted cost, time or labor requirements, safety issues, quality problems)		Bring a critical EC to the attention of cluster-internal S3 in case problems occur (e.g. critical EC delay, unpredicted cost, time or labor requirements, safety issues, quality problems)	
	Discuss directly with S3 about anticipated problems in relation to ECM (e.g. insufficient resources, budget, etc.)		Discuss with the cluster-internal S3 about anticipated problems in relation to execution of ECs (e.g. insufficient resources, budget, etc.)	

9.7 Questionnaire Used for the Third Case Study Evaluation

Technische Universität München

Workshop Evaluation Sheet

Translation of the Viable System Model into Engineering Change Management Context

Please support our research on **engineering change management (ECM)** with your feedback and comments. To identify room for improvement, please share your opinion about: the **Viable System Model (VSM)**, the translation process of the general functions of the VSM into ECM specific ones, the final results, and the workshop execution.

It is important for the research project to have your personal opinion. Please rate the following questions according to the given scale, or simply answer the questions.

Please feel free to also provide written feedback for questions that don't have special comment fields!

Thank you very much for your support!

Expectations

Given my research on engineering change management and use of Viable Systems Model, what are your **desired outcomes** of our research collaboration at the CHH project?

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Where and what **challenges** do you see concerning our **research collaboration** in supporting engineering change management at the CHH project?

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The Viable System Model (VSM)

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The general **VSM** is **easy to understand** and **describes my experience** in real projects.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **recursive character** of the VSM is **easy to understand** and **describes my experience** in real projects.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
In my experience, the **general functions**, (provided by the literature) of the VSM **describe** the functions required in this project.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
From my understanding, the **general VSM** provides a new perspective that brings additional **value** for engineering change management**.**	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree,” “Disagree,” or “Disagree somewhat,” please indicate why you think the VSM **does not provide a new perspective** that brings additional value for engineering change management.

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Process of translating the Viable System Model (VSM) functions

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
After reading the general functions of the VSM during the workshop, it was easy **to relate** them to functions **specific** to **engineering change management**.	☐	☐	☐	☐	☐	☐

If your answer was "Strongly disagree," "Disagree," or "Disagree somewhat," please indicate why you had **difficulties to relate** the general functions to engineering change management specific ones.

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	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The **recursive character** of the Viable System Model was **clear** and **caused no confusion** in identifying the correct functions for each recursion level.	☐	☐	☐	☐	☐	☐

If your answer was "Strongly disagree," "Disagree," or "Disagree somewhat," please indicate the **reasons for confusion** caused by the recursive character**.**

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____

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
It was **easy to differentiate** between the **context related functions** of the *first* (CHH project) and the *second* (Cluster of the project) recursion level.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree,” “Disagree,” or “Disagree somewhat,” please indicate why you had **difficulties to differentiate** between the two recursion levels.

____

____

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The **size of the team** during the workshop was **adequate** to discuss the functions specific to engineering change management.	☐	☐	☐	☐	☐	☐

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
During the workshop the **required experts** were **present** to discuss the context related functions of the VSM.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree,” “Disagree,” or “Disagree somewhat,” please indicate which **experts** or **persons were missing** in order to discuss the context related functions of the VSM**.**

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	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The **provided examples** for each context related function were **useful** for a better understanding of ways, how to implement them.	☐	☐	☐	☐	☐	☐

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The **scheduled time** for the workshop sessions was **adequate** to reach the objectives of the workshop.	☐	☐	☐	☐	☐	☐

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The **slides** and **handouts** used during the workshop were **adequate** to support the identification of the context related functions.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree,” “Disagree,” or “Disagree somewhat,” please indicate how the discussion could have been **supported more adequate**.

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Workshop result

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
From **my point of view** and **experience,** the list of context related functions is **comprehensive**.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree,” “Disagree,” or “Disagree somewhat,” please indicate why you **don’t** see the list of functions as **comprehensive.**

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	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **general function** were **appropriately brought** into engineering change management context.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree,” “Disagree,” or “Disagree somewhat,” please indicate why you **don’t think** that the functions were **brought appropriately** into engineering change management context**.**

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	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **context related functions** can be **useful to set up** engineering change management processes.	☐	☐	☐	☐	☐	☐

If your answer was “Strongly disagree,” “Disagree,” or “Disagree somewhat,” please indicate why you **don’t think** the translated functions are **useful** to set up engineering change processes.

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	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The **recursive perspective** of the context related functions **brings additional value** (e.g. efficiency, better coordination) for engineering change management in practice.	☐	☐	☐	☐	☐	☐

	Strongly disagree	**Disagree**	**Disagree somewhat**	**Agree somewhat**	**Agree**	**Strongly agree**
The translated functions of the VSM **expose** some **problems and challenges** in this projects I haven't thought about.	☐	☐	☐	☐	☐	☐

Please feel free to **mention** the problems and challenges that the discussion of the context related functions **revealed**.

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Please **indicate** which of the following challenges and problems **could** or **could not** be **tackled / solved** with the engineering change management specific VSM.

	Could be tackled/ solved	Could not be tackled/ solved	Not applicable	Comments
Adaptability of engineering change management	☐	☐	☐	
Continuous improvement	☐	☐	☐	
Coordination of engineering changes	☐	☐	☐	
Prediction of engineering changes	☐	☐	☐	
Assessment of the engineering change impact	☐	☐	☐	
Process safety for the engineering change process	☐	☐	☐	
Document management	☐	☐	☐	
Involvement of different stakeholders	☐	☐	☐	
Identification of solutions	☐	☐	☐	
Communication of engineering changes	☐	☐	☐	
Schedule management	☐	☐	☐	
Tracking of engineering changes	☐	☐	☐	
Clarification of roles within the change process	☐	☐	☐	

Workshop execution

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The workshop moderator **introduced** the VSM and its characteristics in an **understandable** and **structured way**.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **objectives** of the workshop were **clear** to me through the introduction of the workshop.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
The **pace** of the **workshop** was **adequate** and I was able to **follow** the **discussion**.	☐	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Disagree somewhat	Agree somewhat	Agree	Strongly agree
It was possible for me to **communicate** my **point of view** during the workshop.	☐	☐	☐	☐	☐	☐

	Very poor	Poor	Fair	Satisfactory	Good	Very Good
Finally, please **evaluate** the workshop as a whole.	☐	☐	☐	☐	☐	☐

Please share any other comments and suggestions you may have:

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Thank you very much for your feedback!

10. List of dissertations

Lehrstuhl für Produktentwicklung
Technische Universität München,
Boltzmannstraße 15
85748 Garching

Dissertations under supervision of

- Prof. Dr.-Ing. W. Rodenacker,
- Prof. Dr.-Ing. K. Ehrlenspiel
- Prof. Dr.-Ing. U. Lindemann

D1 COLLIN, H.:
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D2 OTT, J.:
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D3 STEINWACHS, H.:
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D5 LUBITZSCH, W.:
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D7 BAUMGARTH, R.:
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