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Evaluating PLM Implementations Using a Guidelines-based Approach

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Abstract

Product Lifecycle Management (PLM) is an information technology-based concept bringing several benefits to product development organizations. However, it has been reported that PLM implementations in industry render unsatisfactory results. Hence, the overall aim of the work presented in this thesis is to develop new tools and methods that can lead to improved outcomes from future PLM implementations.

In-depth understanding of the operational aspects of PLM implementations is needed in order to develop methods and tools that can support practitioners. However, most of the existing discussions of characteristics and challenges in PLM implementations are provided without thorough case studies of the implementations from which they are drawn. In particular, the role of requirements management in PLM implementation is argued to be in need of clarification. The problem is approached by presenting an in-depth case study of a recent PLM implementation, focusing on operational requirements management issues.

In order to achieve improved outcomes from PLM implementations, being able to evaluate the outcomes is argued as being necessary. Furthermore, it is argued that it would be beneficial to be able to evaluate tentative PLM solutions during development and PLM implementations leading to the development and deployment of PLM solutions, rather than evaluating the effects resulting from having used a PLM solution. It is found that such methods and tools are currently lacking and need to be proposed, developed and evaluated.

The problem is approached by utilizing published experiences, in terms of guidelines, from previous PLM implementations. A guideline can be defined as a directional recommendation for what to do (or what not to do) in a specific context. Available guidelines are first summarized in a tool, followed by a discussion of their relevance and application in relation to the in-depth case study. It is found that most of the guidelines, though highly relevant to the case, were not fully applied, and that a better application of more of the guidelines would lead to better outcomes. It is furthermore demonstrated that PLM implementation guidelines can be used to identify weak spots associated with conducted PLM implementations. A subset of the summarized guidelines (those regarding the PLM solution) is then utilized in a proposed method to identify risks associated with a PLM solution. As such, the methods and tool serve as discussion-facilitating support and direct focus on areas in need of improvement. Future work includes developing a guidelines structure and seeking to expand the guidelines set to cover more areas.

Keywords: Product lifecycle management, PLM, PLM implementation, PLM solution, requirements management, evaluation methods, and guidelines

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Gothenburg, Sweden, 2012
Mattias Bokinge

Appended papers and distribution of work

Paper A

Bokinge, M. and Malmqvist, J. (2011) 'Challenging requirements management issues in PLM implementation - findings from a retrospective case study', *8th International Conference on Product Lifecycle Management – PLM11,* July 11-13, 2011, Eindhoven, Netherlands.

Mattias Bokinge and Johan Malmqvist planned and carried out the study. The paper was written by Mattias Bokinge and reviewed by Johan Malmqvist.

Paper B

Bokinge, M. and Malmqvist, J. (2011) 'PLM implementation guidelines – relevance and application in practice: a discussion of findings from a retrospective case study', *International Journal of Product Lifecycle Management,* Vol. 6, No. 1, pp.79-98.

Johan Malmqvist planned and Mattias Bokinge carried out the study. Mattias Bokinge wrote the paper, and Johan Malmqvist contributed as a reviewer.

Paper C

Bokinge, M., Levandowski, C., Malmqvist, J. and Johannesson, H. (2012) 'A method to identify risks associated with a PLM solution', *9th International Conference on Product Lifecycle Management – PLM12*, July 9-11, 2012, Montreal, Canada.

Mattias Bokinge and Christoffer Levandowski planned and carried out the data collection. Mattias Bokinge analysed the data and wrote the paper. Johan Malmqvist, Christoffer Levandowski and Hans Johannesson contributed as reviewers.

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Appended papers

1 Introduction

This thesis aims to contribute to the area of PLM implementation. As an introduction to the area, this chapter first introduces the concepts of product lifecycle and product lifecycle management. The potential value of PLM and results from PLM investments in industry are then discussed. Based on those concepts, value and results, the research purpose and aim are stated, together with the research goals. Last, the research scope is defined, and the structure of the thesis is outlined.

1.1 The product lifecycle and Product Lifecycle Management (PLM)

Any product has a lifecycle, from cradle to grave, meaning that it can be imagined, defined, realized, supported and eventually retired, to use the terminology from Stark (2005). Cars, software, pencils and books are all examples of products and, hence, have a lifecycle. Information about a product is created and used in all of its lifecycle phases. Conceptual solutions are used as a base for detailing the product design, process plans are used for producing the products, and information about spare parts from the factory is utilized in the aftermarket phase, to name a few examples.

Dutta and Wolowicz (2004) compare the task of information management for modern organizations with that for a local cobbler in a small village hundreds of years ago. Based on the cobbler's knowledge of customers' needs and preferences, the cobbler developed, manufactured, sold and repaired shoes in a small workshop and thereby had full responsibility for all phases of the shoes' lifecycle. The challenge of obtaining "*the right information, in the right context at the right time*", as phrased by Dutta and Wolowicz (2004), was very limited in this context; most of the knowledge was inside the cobbler's own head, and information necessary (for example, for manufacturing) was easily accessible when needed. They argue that the increase in product complexity (such as more functions) and organizational and process complexity (such as more geographically-spread organizations) in modern organizations has resulted in a situation where more information needs to be shared among more people. Hence, although the phrase "*the right information, in the right context at the right time*" is as valid now as it was for the cobbler, the challenge to achieve it has increased many fold.

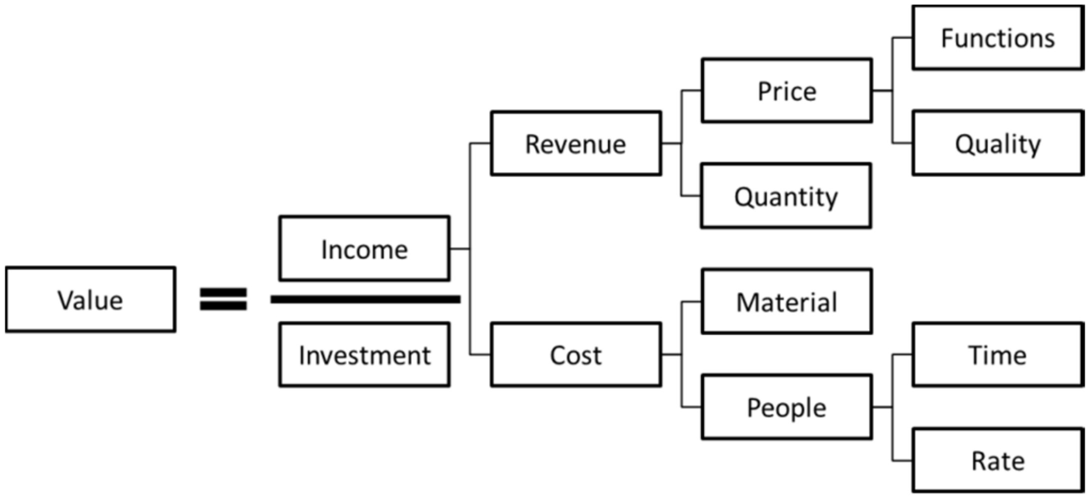

Figure 1-1: Return on investment (adapted from Grieves, 2006)

Product Lifecycle Management (PLM) is an information technology (IT) concept whose aim is a more effective and more efficient flow of product definition information through all phases of the product lifecycle. The use of computers, with virtual reality descriptions and simulations, and databases containing information of real products, enables organizations to develop products in ever shorter times, at ever lower costs and of ever increased product quality. As

Grieves (2006) puts it, PLM *"…allows us to capture and represent information as we move along in the product's life, but also allows us to simulate various actions to the product that would be prohibitively costly, if not destructive, in real life."*

1.2 The potential value of PLM

The value of PLM can be expressed as the return on investment, as seen in Figure 1-1. The value is the sum of all positive and negative changes to the income parameters divided by the PLM investment. Income can be gained by either increased revenue or decreased cost. Revenue in its turn may be increased by increasing price or quantity, and price may be increased due to improved functions or increased quality. Cost, on the other hand, may be decreased by decreased cost of material or people. Finally, the cost of people can be decreased by decreased time or decreased rate.

PLM may have a positive effect on several of these factors. For example, more effective searches for virtual product information may reduce the time for product development. Improved quality of virtual product information can lead to improved virtual reality simulations and for more effective and more efficient information sharing. An improved PLM solution may also reduce the environmental load occurring in the development process, for example due to less CO_2 emissions from travel to meetings and less material consumed to produce physical prototypes.

1.3 Terminology

The following terms are fundamental for the work presented in this thesis.

> ***Product Lifecycle Management (PLM):*** *A strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information, supporting the extended enterprise (customers, design and supply partners, etc.), spanning from concept to end of life of a product or plant, integrating people, processes, business systems, and information (CIMdata, 2002).*

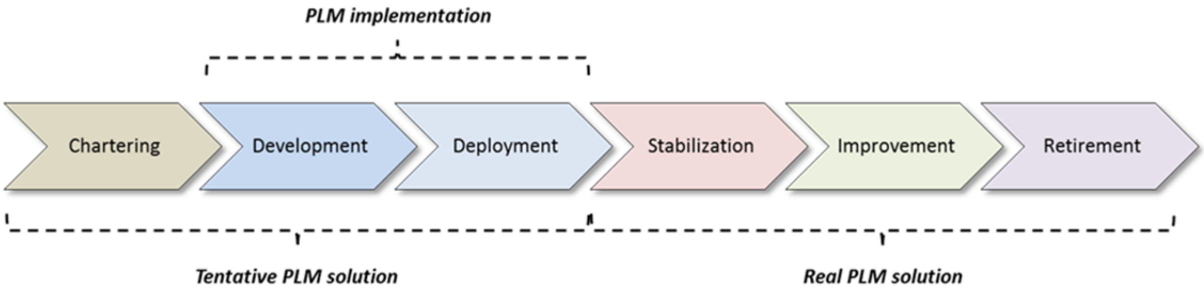

Figure 1-2: Framing PLM implementation activities and PLM solution artefact in the PLM solution lifecycle (Source: inspired by Marcus and Tanis, 2000, and Ross, 1999).

The four most important components of the definition are the following: PLM is a concept that focuses product definition information; PLM concerns product definition information throughout the complete product lifecycle, from concept to end of life; product definition information is created, managed, disseminated and used; and this is done in order to integrate people, processes, systems and information.

> ***PLM implementation:*** *The activity of developing and deploying a PLM solution.*

> ***PLM solution:*** *The artefact, either intended (prior to deployment) or real (subsequent to deployment), realizing the PLM concept.*

The term PLM implementation comprises the activities of developing and deploying a PLM solution. PLM implementations are commonly done through one or several projects. The result from these projects is the PLM solution, which is tentative prior to deployment, and real subsequent to implementation. The terminology is put in relation to the rest of the PLM solution lifecycle in Figure 1-2.

A PLM solution is a coherent combination of business objectives and strategies, processes and methods, as well as engineering applications such as Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM) and Computer-Aided Engineering (CAE), and Product Data Management (PDM) systems.

Chartering occurs prior to the activities of implementation. That is where the business case is constructed, vendors and software are usually selected, and the budget is established (Marcus and Tanis, 2000). Subsequent to implementation is the stabilization activity, which is where bugs are removed and employees get acquainted with the solution. A PLM solution may later on go through a number of improvements until it finally is retired.

1.4 Results from PLM implementations in industry

As early on as a decade ago, it was reported that PLM initiatives had been initiated by many organizations (Diepstraten et al, 2002) in several different industries, such as automotive industry, process industry, and life science to name a few (Burkett et al, 2002).

Benefits from PLM investments have been reported (e.g., Alemanni et al, 2008), and some claim even to have exceeded their expectations (e.g., CIMdata, 2008). Siddiqui et al (2004) report from an e-mail survey, sent to project champions and managers, where they asked how successful the project champions' and managers' PDM was. Respondents from 12 of 15 companies replied that their investment in PDM had been "*very successful*", and three replied that they had received a "*reasonable return*".

Others report from only partly successful investments (e.g., Rangan et al, 2005). Wognum and Kerssen-van Drongelen (2005) identified cases where cost-reductions, time-to-market reduction, increased design re-use, and increased design collaboration were all lower than anticipated. Their conclusion was that although PLM had generated benefits, the expectations were even higher. For most of the companies participating in the study, it was a first try with PLM.

It has been argued that the value gained from investments made in PLM can and should be questioned, and claims have been made that many failures are due to inabilities in implementation (e.g., Hewett, 2010). Reporting from industry, Baker (2002) states that "*nobody could have foreseen how big, messy, and tough this project would turn out to be.*" In an attempt to describe the complexity of PLM implementation, Grönvall (2009) compares PLM implementation with heart transplantation and states that both are considered "*one of the vital organs,*" both are "*complex with many parameters, dependencies and uncertainties*" and both carry a "*high risk.*"

To conclude, the area of PLM implementation has potential for improvement and is, hence, the focus in this thesis.

1.5 Purpose, aim and research goals

The overall aim of the work is to develop new tools and methods that can lead to improved outcomes from PLM implementations in industry. A solid understanding of the characteristics and challenging issues in contemporary PLM implementations, as well as the contexts in which they occur, is needed in order for the likelihood that such new tools and methods can be used to address real issues in future PLM implementations to increase. Hence, the first research goal is to:

> ***Research goal 1:*** *Clarify the characteristics of and challenging issues in real contemporary PLM implementations, as well as the contexts in which they occur.*

Subsequently, the tools and methods need to be proposed, developed and evaluated. Hence, the second research goal is to:

> ***Research goal 2:*** *Propose, develop and evaluate tools and methods that can be used to improve the outcomes of PLM implementations.*

The research goals stated above guide the conceptual framework presented in Section 2, which subsequently leads up to specific research questions and the corresponding scientific research approach in Section 3.

1.6 Scope

The research presented in this thesis focuses on the activity of implementing PLM, including the development and deployment of a PLM solution. The initial chartering activity, albeit an important part of any PLM investment, is not considered in this thesis. Likewise, the subsequent activities' stabilization, improvement and retirement are also excluded from the scope.

Although PLM as a concept concerns products of any combination of all engineering disciplines, the scope of the PLM implementations studied in this research is delimited to the area of mechanical engineering.

1.7 Outline of the thesis

The thesis is structured as follows: in this section, the research area has been described, concluding with the general purpose, the aim and the research goals to be fulfilled.

Section 2 presents the frame of reference, starting with a summary of areas of relevance and contribution, includes sections discussing those areas, and concludes with a statement of the research needs.

In Section 3, research questions are formulated, based on the research goals in Section 1 and the identified research needs in Section 2. Subsequently, a categorization of the research problem is made and relevant research models are presented. Last, the process, methods and validation strategies applied in the appended papers are specified.

Section 4 summarizes the results from the appended papers.

In Section 5, answers to the research questions are provided, contributions made in relation to the stated research goals are summarized, and the validity of the contributions are discussed.

Section 6 contains the conclusions drawn from the conducted research.

Last, Section 7 proposes future work in the area.

2 Conceptual framework

This chapter presents the conceptual framework employed in this thesis. The chapter starts with a roadmap of the chapter with areas of relevance and contribution, followed by sections discussing those areas. Last, the research needs are stated.

2.1 Areas of relevance and contribution

The areas of relevance and contribution to the work presented in this thesis are depicted in Figure 2-1, together with references to sections in which the areas are discussed. The areas of relevance are either essential to the work (marked in blue, or dark grey if printed in black and white) or provide a useful context (marked in green or light grey). Some of the essential areas are also the areas to which the work aims to contribute (marked with thick borders).

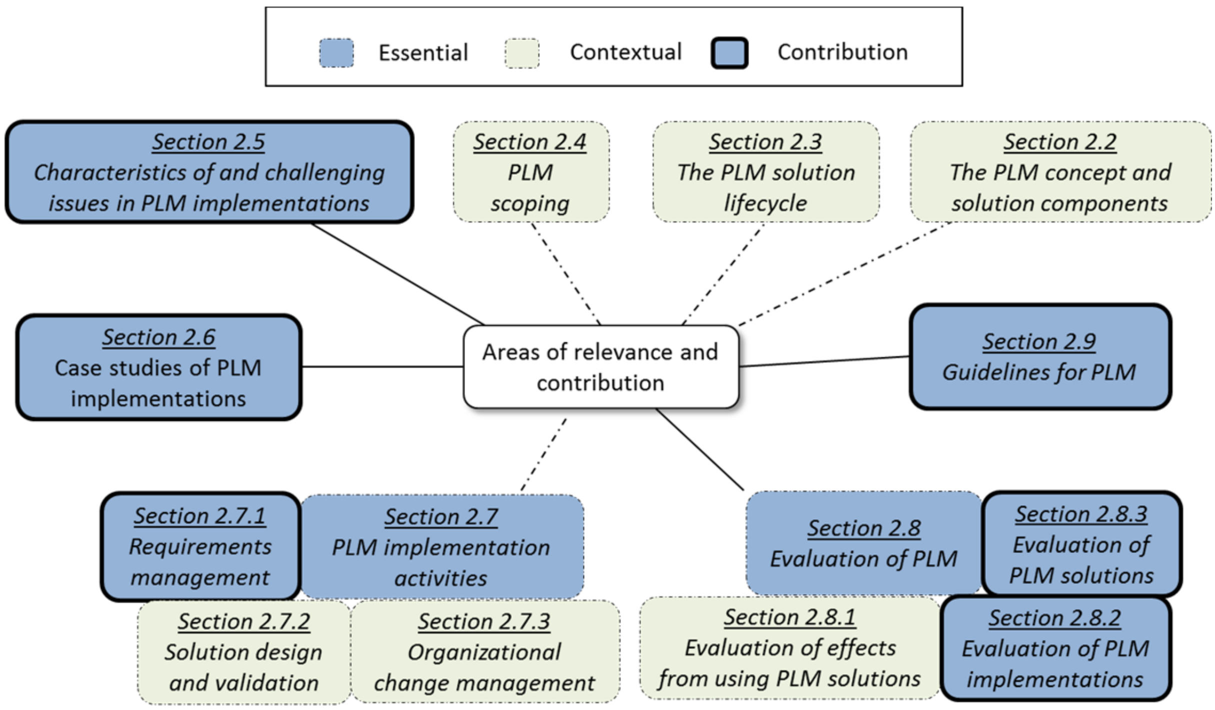

Figure 2-1: Areas of relevance and contribution to the work presented in this thesis (Source: inspired by Blessing and Chakrabarti, 2009).

2.2 The PLM concept and solution components

Starting with the PLM concept, let us first return to the definition of PLM, as proposed by CIMdata:

> ***Product Lifecycle Management (PLM):*** *A strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information, supporting the extended enterprise (customers, design and supply partners, etc.), spanning from concept to end of life of a product or plant, integrating people, processes, business systems, and information (CIMdata, 2002).*

From the definition, the term product definition information can be identified as the object. The definition thereby seems to exclude other domain types of information than those regarding the product itself, such as employees, customers and suppliers. More problematically, the definition also seems to exclude information regarding resources needed for the production of the product. However, whether the exclusion of information of other domain types is beneficial can be questioned. For the product definition information to be used in practice, certainly a fair amount of context information is also needed. For example, in order to estimate product cost, we need to know in what manufacturing process and system the product is to be produced.

One view of how the area of PLM relates to adjacent areas has been suggested by Grieves (2006) and is shown in Figure 2-2. The horizontal axis is divided into four domains of knowledge: product, supported by PLM; customer, supported by Customer Relationship Management (CRM); employee, supported by Enterprise Resource Planning (ERP); and supplier, supported by Supply Chain Management (SCM). The vertical axis is divided into different functions in the product lifecycle, whereof PLM supports the complete life cycle. According to Grieves (2006), ERP supports several domains, but focuses on the functions production and sales & service. Other views of how PLM relates to adjacent areas also exist (e.g., Garetti et al, 2005), and it is not clear-cut where to draw the line between different concepts. Rather, the areas can be seen as intersecting each other.

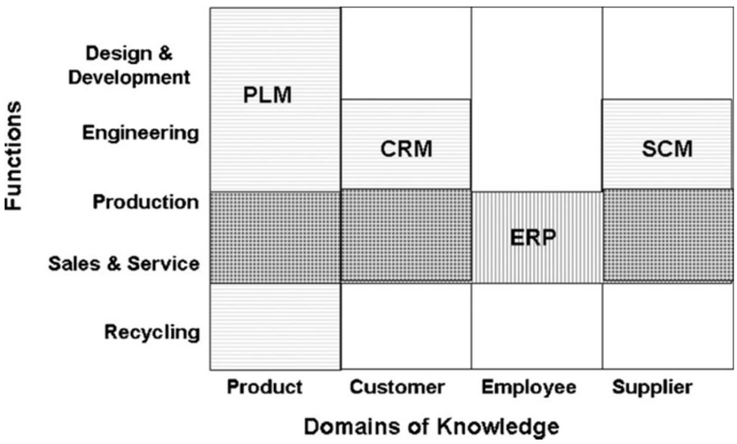

Figure 2-2: How PLM interrelates with other domains, such as Customer Relationship Management (CRM), Enterprise Resource Planning (ERP), and Supply Chain Management (SCM) (Source: Grieves, 2006).

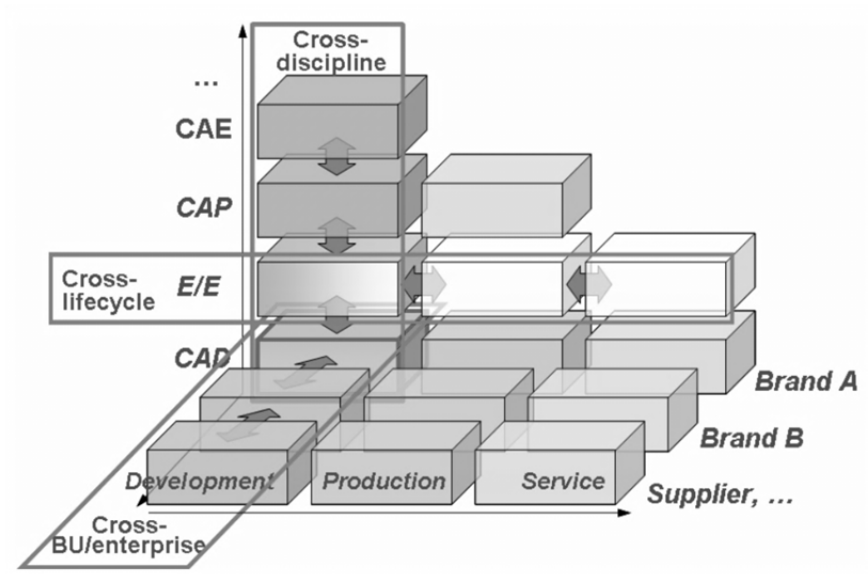

Figure 2-3: PLM supports across x: across lifecycle; across organizations; and across engineering disciplines (Source: Bergsjö et al, 2007).

The definition from CIMdata also implies that PLM supports across the complete lifecycle of a product. That it supports not only its own organization, but also customers and suppliers is also implied. Bergsjö et al (2007) offer a model with three dimensions, as seen in Figure 2-3. In it, they highlight how PLM also supports across different engineering disciplines, such as mechanical engineering, electrical engineering, and IT.

From the definition by CIMdata, it can also be identified that PLM, as a business approach or concept, aims at *"integrating people, processes, systems and information"* through the use of a *"consistent set of business solutions."* The same four aspects have also been recognized as important by Svensson et al. (1999), who propose a framework for engineering information systems comprising the views of processes, information, roles and systems (see Figure 2-4).

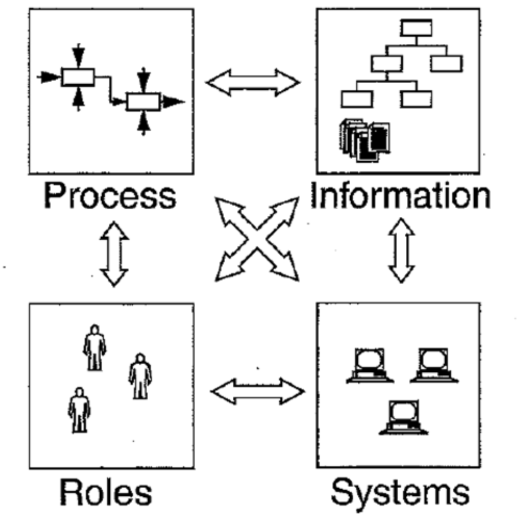

Figure 2-4: Four views of an engineering information management system (Source: Svensson et al, 1999).

Zimmerman (2008) presents a generic model (Figure 2-5) of an organization's enterprise architecture, based on contributions from Zachman (1987) and Schekkerman (2003), and argues that a similar view can be applied to the PLM area. In addition to processes, systems and information, he also includes strategies and objectives in the PLM concept, which aligns to the definition by CIMdata (2002). In his model, the people dimension is not explicitly modelled but is implicitly understood to be included in processes. He states that elements of the upper layers in the pyramid require elements of the lower levels, while elements of the lower levels enable elements of the upper levels.

Comparing the PLM architecture model from Zimmerman (2008) with the four views model from Svensson et al (1999), several differences are apparent. First, the PLM architecture model has explicit layers of business objectives and business strategies that are missing in the four views model. Furthermore, the architecture model has a hierarchical structure emphasizing the superior status of, for example, business objectives over application architecture. On the other hand, the four views model has a roles view, emphasizing people and organizational structures as part of the system.

In the systems view of the four view model of Svensson et al. (1999), PLM can be said to be the combination of PDM systems and engineering applications (Brandao and Wynn, 2008). It is generally accepted by the PLM community that an organization's PLM concept cannot be fully supported by only one or a few software components (Sääksvuori and Immonen, 2008). Multiple engineering applications, such as CAD, CAM and CAE and at least one, but often several, Product Data Management (PDM) system are required to be able to create, manage, disseminate and use the different kinds of information needed throughout the product lifecycle. The model from Malmqvist (2009) visualizes the existence of various engineering tools (applications) and one PDM system in connection to the product lifecycle (see Figure 2-6).

To conclude, PLM is a broad concept without a clear-cut definition of its boundaries, focusing product definition information. The concept is realized with not only engineering applications and PDM systems, but also a range of other elements. Those elements include processes, people and the information as such. Having the concept and components of PLM defined, the next relevant area to discuss is the PLM solution lifecycle.

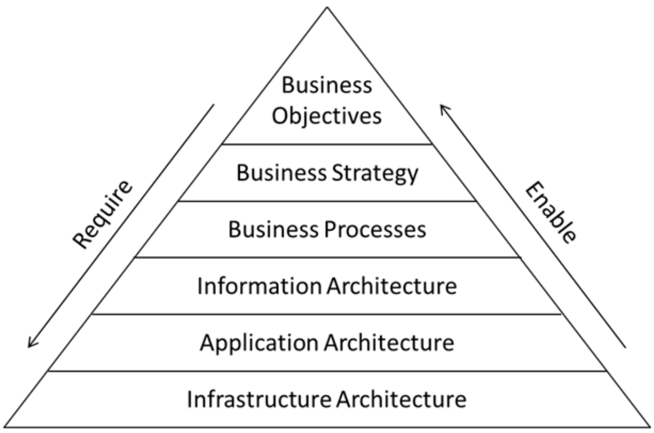

Figure 2-5: Layers of a PLM architecture (Source: modified from Zimmerman, 2008).

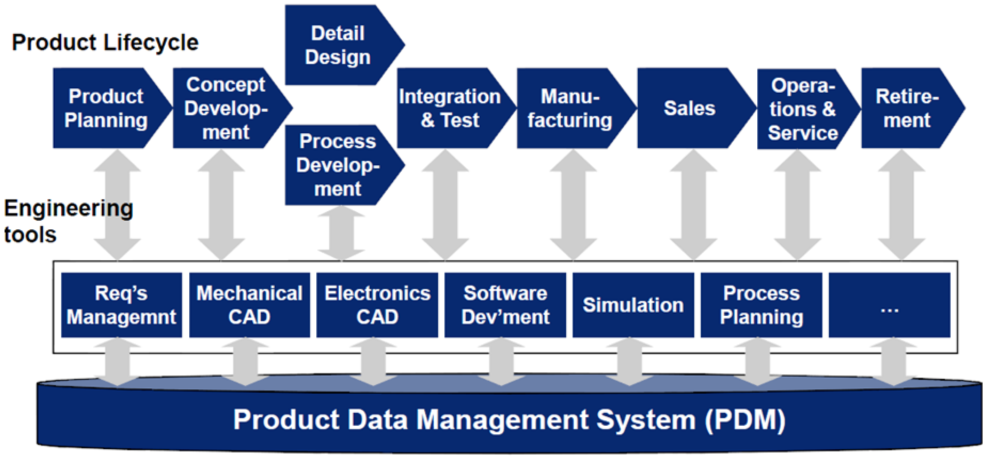

Figure 2-6: Multiple engineering applications (tools) and a PDM system and their connection to the product lifecycle (Source: Malmqvist, 2009).

2.3 The PLM solution lifecycle

Like any other product, a PLM solution can be said to have a lifecycle. Marcus and Tanis (2000) identify four phases from the view of organizations adopting them: the chartering phase; the project phase; the shakedown phase; and the onward and upward phase. During the chartering phase, the business case is constructed, vendors and software are selected, and the budget is established. During the project phase, the software is modified to fit the organization and is deployed. The shakedown phase is the phase between solution deployment and when the organization has returned to normal work again. The last phase, the onward and upward phase, starts from when normal work is achieved and continues until the system is retired.

Ross (1999) presents a similar model, focusing on ERP software. She identifies five phases: design; deployment (she uses the term implementation); stabilization; continuous improvement; and transformation.

There are some similarities and differences between the models. First of all, the model from Ross (1999) lacks the chartering phase, the steps of defining a business case, the selection of vendors and software, and the establishment of the budget. Those steps are all included in the design phase. Second, the next two steps of her model, design and deployment, correspond to the project phase in the model by Marcus and Tanis (2000): stabilization corresponds to the shakedown phase and continuous improvement and transformation corresponds to the onward and upward phase.

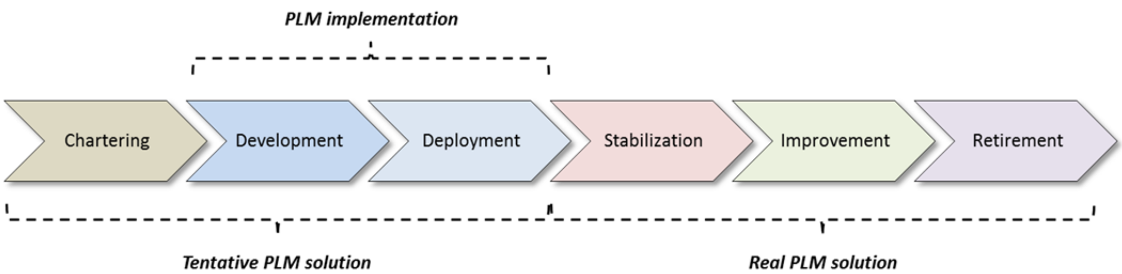

Figure 2-7: Recapitulation of Figure 1-2, the PLM solution lifecycle, seen from organizations adopting them (Source: inspired by Marcus and Tanis, 2000, and Ross, 1999).

In this thesis, the terms chartering, development, deployment, stabilization, improvement and retirement (none of the models identify retirement as a phase) are used to frame the PLM solution lifecycle (Figure 2-7). Although Marcus and Tanis (2000) as well as Ross (1999) focus on enterprise software, which is only one component of a PLM solution, both are relevant for framing the terms PLM implementation and PLM solution used in this thesis. The term PLM implementation includes both the development and the deployment of the PLM solution. The PLM solution can be said to be tentative until it is deployed and real from when it is deployed.

Prior to discussing the characteristics of and the challenging issues within PLM implementations, the next section focuses on the area of PLM scoping, which belongs to the PLM chartering phase. It is included in this thesis as orientation, since it has drawn much attention from the PLM research community.

2.4 PLM scoping

Support for PLM scoping has been provided by several authors (e.g. Stark, 2005; Sääksvuori and Immonen, 2008; Grieves, 2006; Batenburg et al., 2006; Pels and Simons, 2008). That support has derived from the Capability Maturity Model (CMM), developed at Carnegie Mellon University's Software Engineering Institute based on the work by Humphrey (1998; also see Humphrey, 1999) and Humphrey and Sweet (1987). The method builds on the theory that "*as an organization matures, the software process becomes better defined and more consistently implemented throughout the organization*" (Paulk et al., 1993).

The CMM model identifies five levels of maturity a process may have:

- Initial, meaning the process is not at all formalized
- Repeatable, meaning that the process is documented to the extent that some repeatability is possible
- Defined, meaning that the process is thoroughly documented
- Managed, meaning that metrics are applied to assess the process
- Optimized, meaning that the process is approved based on the metrics

Grieves (2006) states that several PLM software vendors and PLM consultants provide assessment tools based on the CMM model. An example can also be found in literature. Stark (2005) proposes a questionnaire based on the CMM concept that can be used by companies to make self-evaluations of their PLM maturity. The questions have pre-defined answers, and are divided in three different categories: those regarding the company as such; those regarding product development; and those regarding product data and product data management. Based on the answers, scores are provided that categorize the company at one of the maturity levels.

Grieves (2006) argues that the PLM maturity should be assessed for the different departments of the company, respectively. The rationale for doing so is that each department may have different PLM maturity and may therefore have different change needs. An example of such an assessment is seen in Figure 2-8. In the figure, the maturity level of each department has

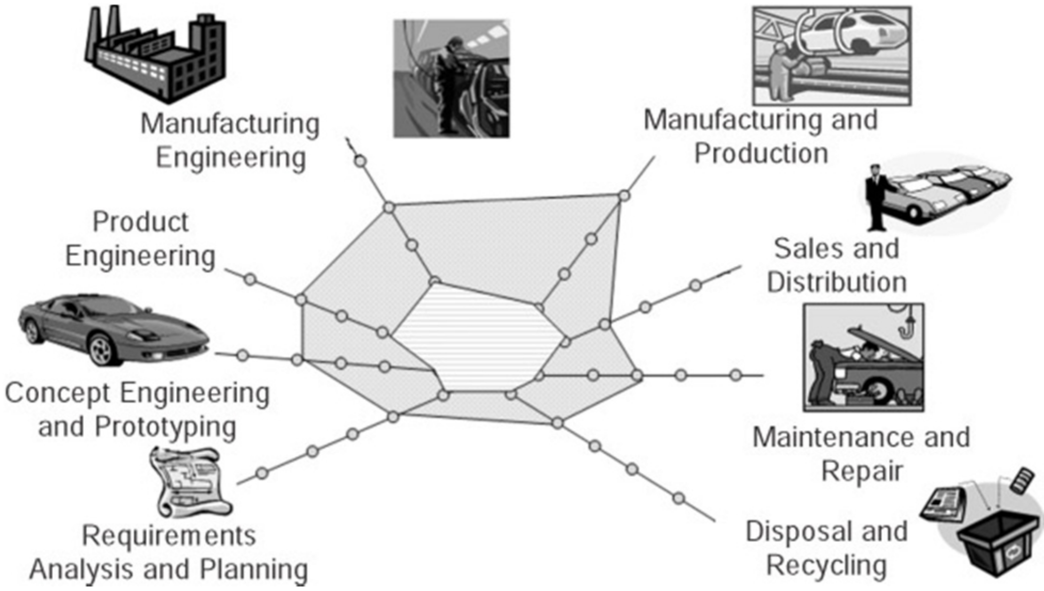

Figure 2-8 Example of results from a PLM capability maturity assessment divided into different company departments, including an assessment of the existing situation (inner circle) and a desirable to-be situation (outer circle) (Source: Grieves, 2006).

been assessed (inner circle) and plans for the future to-be state constructed (outer circle). Based on those two assessments, a plan can be developed for how to proceed with PLM.

2.5 Characteristics of and challenging issues in PLM implementations

Much has been reported on the characteristics of and the challenging issues within PLM implementations. In an attempt to characterize and rank the challenges, Bowler and Rohde (1995) refer to an equation of success that is known in General Motors as Bryant's law:

$$\boldsymbol{S} = 100E + 10P + T$$

The equation indicates that the success (S) of a PLM implementation is mostly affected by empowered people (E), then defined processes (P), and least by suitable technology (T). Most authors agree that technical issues exist in PLM implementation, although the more severe issues are related to processes and people (e.g., Wognum and Kerssen-van Drongelen, 2005; Batenburg et al, 2006; Garetti et al, 2005; Eigner and Schleidt, 2008; Rangan et al, 2005; Bowler and Rohde, 1995). Similar statements also exist from the field of enterprise systems in general (Leonard-Barton and Deschamps, 1988; Orlikowski, 2000; Davenport, 2000). In the sub-sections below, the characteristics and challenging issues within each of the three categories are summarized.

2.5.1 Technical characteristics and challenges

Technical issues have been reported. Many can be traced to the fact that the software components of PLM solutions (in other words, engineering applications and PDM systems) are commonly complex systems composed of Commercial Off-The-Shelf (COTS) component software (Sääksvuori and Immonen, 2008). Hewett (2010) argues that existing PLM software packages are immature and consist of support for multiple complex functionalities that are only weakly integrated with each other. Furthermore, he claims that an organization's total

PLM support might require several different software packages from several different vendors, which in turn are more or less integrated with each other.

2.5.2 Process characteristics and challenges

PLM implementations are not about automating existing processes. The whole idea with PLM is to change the process to achieve business benefits (Siddiqui et al, 2004; Batenburg et al, 2006). Many companies develop standardized engineering processes, such as for new product development or for engineering change. There are several reasons for doing so. A unified process is easier to survey than multiple different processes. Furthermore, one standardized process requires only one technical solution to support it. However, although a standardized process may look fine for everybody on a high level, it is in the details important differentiators appear (Hewett, 2010). A company may produce some products of purely mechanical character, while other products may also include electrical components and software. Some products may be more complex than others, and some products may have unique legal requirements placed on them. In such situations, one standardized process is a compromise that may be unable to effectively and efficiently support, and may even be destructive for, the development of some products. The challenge is then to find the optimal balance between standardization and differentiation.

2.5.3 Organizational characteristics and challenges

Regarding empowerment, it has been argued that the large scope of PLM (Batenburg et al, 2006) or the complexity and unawareness of its meaning (Schuh et al, 2008) are reasons for PLM implementation failures. Unawareness of where to start such long endeavours and the challenge to maintain the interest from all stakeholders until the benefits start to show have also been put forward (Bryan and Sackett, 1997). Siddiqui et al (2004) found that a lack of support from users and senior management was a critical issue in PDM implementations, and (Rangan et al, 2005) reported that they found several implementations that failed due to a lack of communication with the user community. Eigner and Schleidt (2008) claim that PDM/PLM implementations have a critical phase (as conceptually seen in Figure 2-9) where the costs are high while drawbacks rather than benefits are visible, until a point of breakeven is reached. It is not difficult to imagine the difficulties that may exist in convincing stakeholders to continue while still in that critical phase.

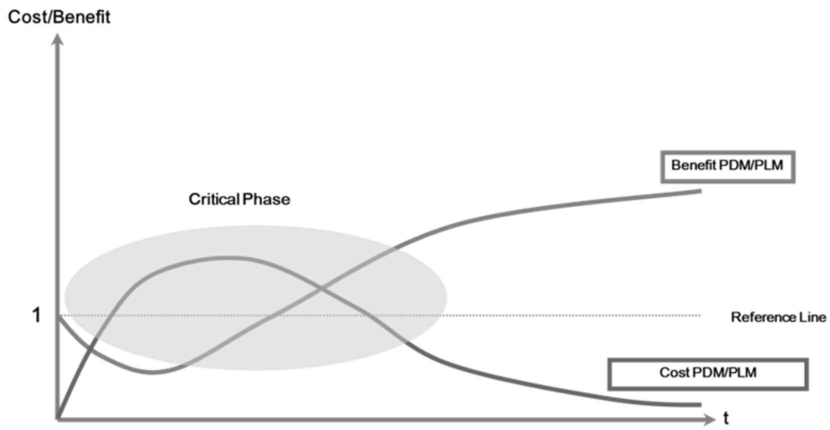

Figure 2-9: Costs and benefits over time for a PDM/PLM endeavour (Source: Eigner and Schleidt, 2008).

Also, while the benefits from investing in PLM are on a high level aimed at upper management, solutions achieving those benefits do not necessary make the everyday work easier for the product engineers. Such conflicts of interest may result in a resistance to change.

Wognum et al (2004) discuss issues regarding enterprise system implementations and identify the project form for conducting them as a source for failures. Not all organizations are used to the project the form for conducting business, and proficiency in project management might be lacking. Furthermore, they find that such implementations are done irregularly, with substantial time in between projects. Although sets of lessons learned are likely to be acquired from PLM implementations (Hartman and Miller, 2006), there is often an inability to pass lessons learned from one project to the next (Wognum et al, 2004). This is in line with the statement by Rangan et al (2005) that the main body of knowledge of how to develop and implement PLM solutions resides in the heads of individuals who lack the incentives to share their experiences.

2.5.4 Conclusions

Challenging issues in PLM implementations include, but are not restricted to, the following: the concept of PLM is not well understood and agreed upon; the scope of PLM is very large, and it is not known where to start such endeavours; it is difficult to maintain stakeholders' interest and support during such long endeavours; it requires understanding of and changes to business processes; it requires understanding of and changes to commercial software, and it requires people to change. Although technical issues exist, the main challenges relate to changes to business processes and organizational structures. All in all, these issues require a highly competent PLM implementation team.

However, it has also been argued that PLM implementations in many cases are performed irregularly, in a project organization, and in many cases with substantial time in between projects. Furthermore, it has been argued that each new project is populated with new team members, and that lessons learned from past projects are not utilized in following projects. This implies obstacles for improving the outcomes of PLM implementations and, ultimately, PLM investments.

2.6 Case studies of PLM implementations

A prerequisite for being able to understand the characteristics and challenging issues in PLM implementations, and to develop tools and methods to support PLM implementations, is an in-depth understanding of the reasoning behind various operational modes of action and their effects in real and contemporary PLM implementations. Case studies of PLM implementations are thus needed.

As reviewed in the previous section, several contributions offer descriptions as well as discussions of characteristics and challenges in PLM implementations. Both Hewett (2010) and Sellgren and Hakelius (1996a; also Sellgren and Hakelius, 1996b) discuss identified challenges. Sääksvuori and Immonen (2008) contribute general descriptions of different dimensions of PLM implementation, such as project planning, group responsibilities and common problems. Other studies contribute descriptions of the PLM solution and effects the solution has brought (e.g., Rangan and Cadha, 2001; CIMdata, 2008). None of these contributions, however, provides any descriptions of PLM implementation efforts. Some short descriptions exist (e.g., Pikosz et al, 1997; Rangan et al, 2005; Baker, 2002; Stark, 2005). However, they are still not thorough enough to facilitate an in-depth understanding of the rationale for different modes of actions and their effects in reality. Zimmerman (2008) includes a long description of a 10 year long PLM implementation. In relation to the description, strategies for project governance, project management, change management, partner and supplier management and PLM architecture are discussed. Their description makes visible the influence time may have on organizational structures. However, since the description covers such a long effort, it is not in-depth enough to cover operational activities.

Descriptions of enterprise implementations from other areas, adjacent to the area of PLM, exist. Haug and Frederiksen (2009) contribute from the area of enterprise content management. Several examples can also be found from the ERP area (e.g., Khosrow-Pour, 2006; Yusuf et al. 2004; Al-Mashari and Al-Mudimigh, 2003; Deloitte and Touche, 1998). However, not knowing the full characteristics of PLM and other areas, it is difficult to know what experience can be generalized to the area of PLM.

To conclude, there is a general need for in-depth case studies of PLM implementation covering operational aspects. What areas such descriptions specifically should focus on depends on the need and available support for various PLM implementation activities. Relevant activities and available support for these activities are discussed in the next section.

2.7 PLM implementation activities

PLM implementations share some characteristics with software development projects. Sommerville (2007) argues that four activities are relevant for any software development: software specification; software design and implementation; software validation; and, software evolution. Since PLM solutions are more than software, the more general terms requirements management, solution design, and solution validation are used in this thesis. In relation to the PLM solution lifecycle, software evolution is comparable to the stabilization and improvement phases and is, therefore, beyond the scope of this thesis. In addition to the development phase, there is the deployment phase, where a key activity is organizational change management. These areas are discussed in the following sections.

2.7.1 Requirements management

Starting with requirements management, the two terms requirement and requirements management can be defined as:

> ***Requirement:*** *1) A condition or capability needed by a user to solve a problem or achieve an objective; or, 2) a condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed document; or, 3) a documented representation of a condition or capability as in 1 or 2 (Radatz, 1990; cross-referenced by Wiegers, 2003).*

> ***Requirements engineering (management):*** *the branch of software engineering concerned with the real-world goals for, functions of, and constraints on software systems. It is also concerned with the relationship of these factors to precise specifications of software behaviour, and to their evolution over time and across software families (Zave, 1997).*

The terminology regarding requirements management seems not to be agreed upon in literature. While Sommerville (2007) uses the term requirements management while referring to managing changes to requirements, Davis (2005) uses the term to refer to gathering requirements, including requirements elicitation, prioritization and specification. Zave's (1997) definition of the term requirements engineering fits best with the definition of requirements management used in the appended papers, as well as in this thesis. These two terms are therefore used interchangeably with the same intended meaning. Nuseibeh and Easterbrook (2000) state that requirements management activities include, but are not restricted to, the following: eliciting requirements, modelling and analysing requirements, communicating requirements, agreeing upon requirements and evolving requirements. As such, requirements management can be seen as a very broad concept. Nuseibeh and Easterbrook (2000) further note that software cannot work in isolation but is part of a system. Regarding the definition by Zave (1997), they claim that rather than being a branch of software engineering, requirements management should therefore be regarded as a branch of systems engineering.

The purpose of spending time and money on requirements management prior to solution development is to reduce the risk of making mistakes during development (Boehm and Basili, 2001). However, the amount of money that should be reserved for requirements management depends on the project characteristics. While too little focus on requirements management leads to increased project risks, too much focus on requirements management may result in an unnecessary long project. Hence, the goal is to have "*just enough requirements management*" (Davis, 2005).

Both Bryan and Sackett (1997) and Baker (2002) argue that requirements management based on the abilities COTS software offers is different in comparison to requirements management for developing a software solution from scratch, since such projects need to take into consideration the possibilities and constraints of the COTS software. Similar statements also exist from COTS investments in general (e.g., Perrone, 2004). Sommerville (2007) argues that development projects based on COTS software therefore need to function in a specific order. First, they need to specify requirements on a high level, having a flexible mind-set in order to not reject good candidates on unnecessary over-specification. They then need to select software and vendors and, subsequently, modify the requirements towards the possibilities and constraints in the selected software. Hence, requirements management is an activity that starts as early on as in the chartering phase and continues throughout the development phase.

The selection of software and vendors in the chartering phase is not solely based on the technical requirements. Baker (2002) briefly discusses other factors to consider, such as in what direction the COTS software is being developed and what kind of relationship is required or possible with different vendors. Sääksvuori and Immonen (2008) describe different activities companies may pursue in selecting a system. They are the following:

- Scan the market for available systems
- Benchmark companies using the available systems
- Test a subset of the available systems
- Decide upon scope and schedule
- Negotiate the terms with the vendors.

They argue that the "*mating rite*" may take a very long time, sometimes months or even up to several years for large companies.

Tools, methods and processes for requirements management in PLM implementation can be found for both the chartering and the development phases. Some authors propose methods to derive the needed software from needed technical capabilities through the utilization of Quality Function Deployment (QFD) (e.g., Bitzer et al., 2009; see also Bitzer et al., 2008; Kumar and Midha, 2006). The model from Bitzer et al. (2009) in Figure 2.10 provides a typical example contributing to early requirements management efforts, leading to systems being selected.

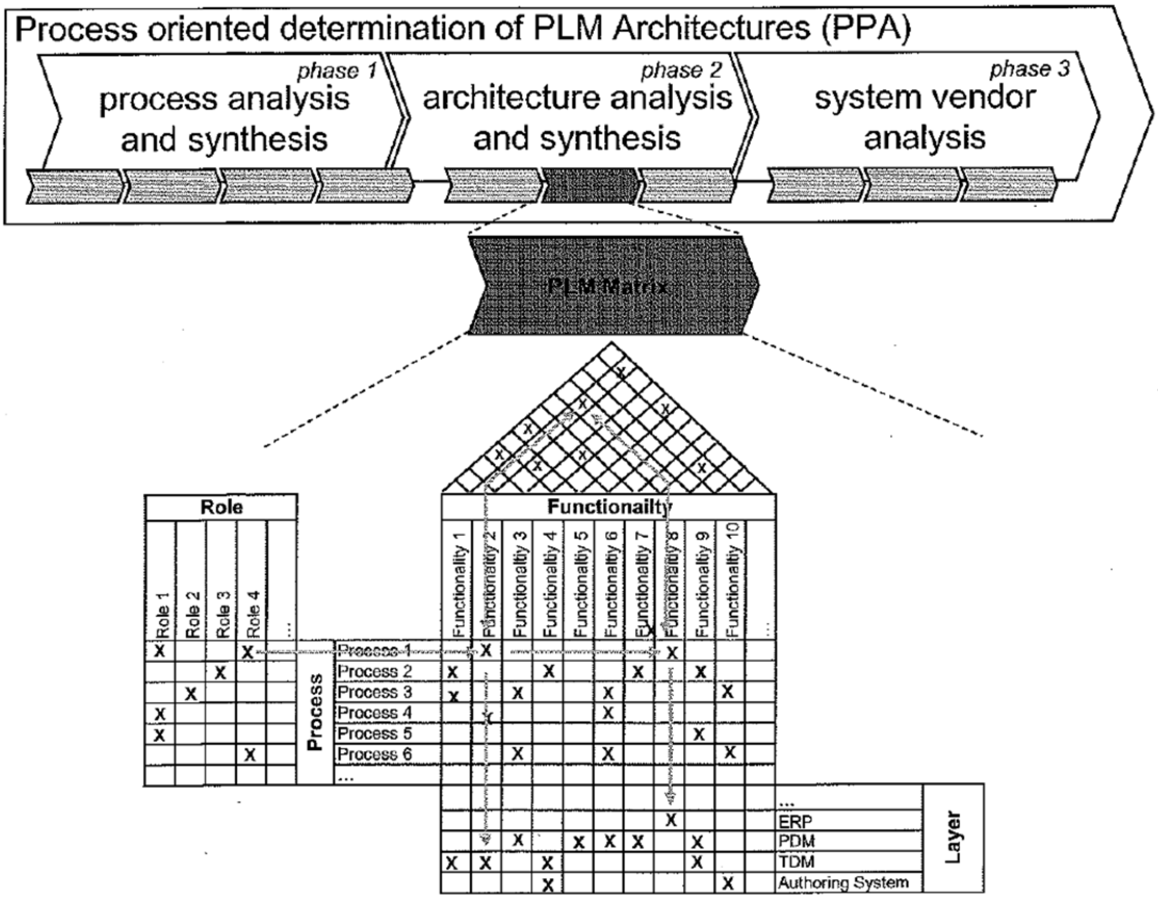

Figure 2-10 Example of a method to derive PLM architecture elements from business needs using QFD (Source: Bitzer et al., 2009).

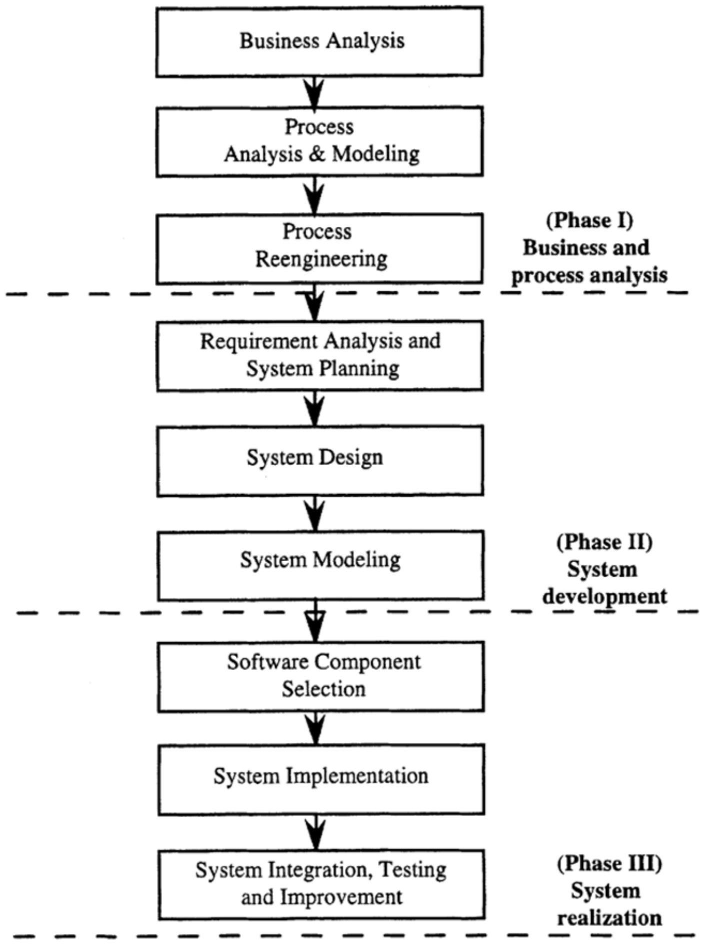

Figure 2-11: An PDM implementation methodology (Source: Chen and Tsao, 1998).

Chen and Tsao (1998) propose a methodology for PDM implementation (Figure 2.11), focusing on modelling support. They argue that their methodology can be applied both for developing PLM solutions from scratch and for developing PLM solutions based on COTS software. However, their support does not make visible the influence the use of COTS software may have on the requirements management activities.

Last, Eynard et al. (2004; also, see Eynard et al., 2006; and, Merlo et al, 2005) demonstrate that UML use-case, class and activity diagrams (cf. Booch et al., 1999) provide an effective support for requirements management activities in PDM implementations. They focus on the development phase, acknowledging that different COTS software have different possibilities and constraints. However, similar to Chen and Tsao (1998), they, too, focus on modelling and not as much on other requirements management activities, such as elicitation and the prioritization of requirements.

To conclude, PLM implementations are commonly based on COTS software and, hence, requirements management activities for PLM implementations need to take into consideration the possibility and constraints of that software. Furthermore, requirements management is an activity that needs to be addressed both during PLM chartering and during solution development. Methods exist to support early requirements management activities during the PLM chartering phase, prior to the selection of COTS software. Methodologies and methods for specifying requirements for PLM solutions during the implementation phase also exist. However, methods and methodologies for supporting other requirements management activities are lacking. Hence, in-depth case studies of PLM implementations focusing requirements management activities are needed.

2.7.2 Solution design and validation

Two other important activities of PLM implementation are solution design and solution validation. Sääksvuori and Immonen (2008) argue that two different approaches, with their own benefits and drawbacks, can be taken when using COTS software in PLM solution design: either to adapt the software to the business processes; or to adapt the business processes to the existing capabilities (and constraints) in the COTS software. In reality, a mixture of the two approaches may be selected. Adapting the software to the business processes may, according to them, result in increased costs for solution design and deployment and, later on, for maintenance as well (during the stabilization and improvement phases). In addition, adaptations may make it more difficult to upgrade to new software solutions in the future. On the other hand, the organization may be able to create a better support for their business processes, instead of waiting for vendors to develop support that will be available in future software releases.

To minimize the risk of deploying a solution that does not meet the requirements of users, a solution design also needs to be validated with the user community. Wiegers (2003) argues that despite any early efforts in requirements management prior to solution design, people still tend to have difficulty articulating their requirements without a solution to react upon. He refers to this phenomenon as IKIWISI ("*I know it when I see it*"), meaning that requirements are easier to articulate when having a solution to react to. An effect from this phenomenon is that new requirements arise and existing ones change when the users are exposed to the solution.

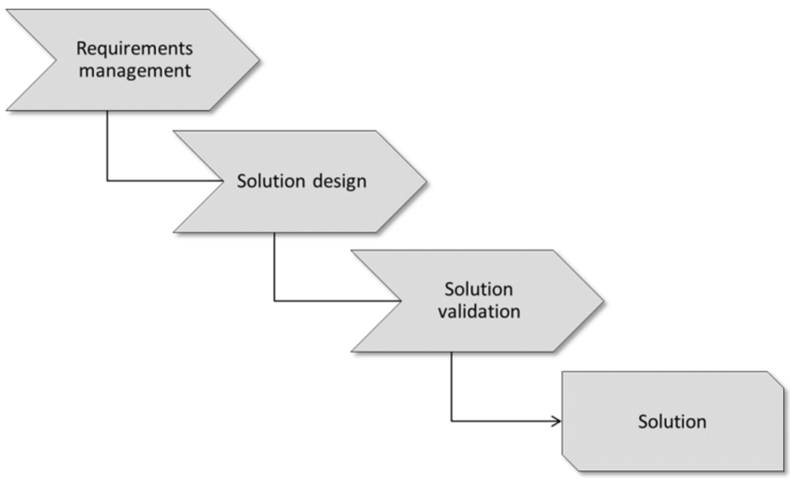

Figure 2-12: Sequential process model (Source: inspired by Sommerville, 2007).

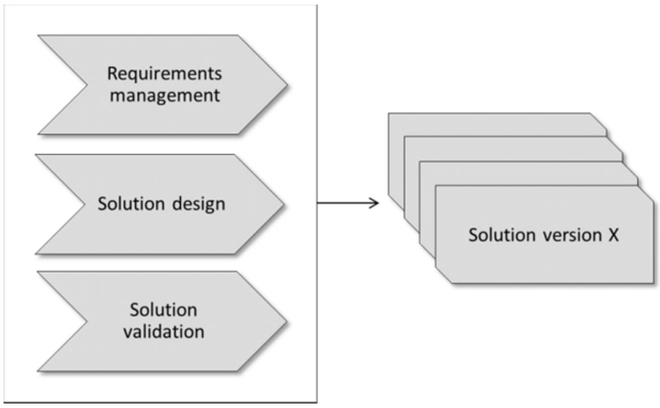

Figure 2-13: Evolutionary process model (Source: inspired by Sommerville, 2007).

Two main approaches exist for designing the solution (Sommerville, 2007): sequential (Figure 2-12) and evolutionary development (Figure 2-13). According to the sequential approach, the full project scope goes through all activities associated with software development in sequential steps. It can be argued, however, that although requirements management is done first, followed by solution design and solution validation, some degree of iteration is likely to occur between the activities. The Waterfall model by Royce (1970) is an example of utilizing a sequential process model. Chen and Tsao (1998) in Figure 2.11 is another example, taken from the PLM area.

According to the evolutionary approach, the activities occur simultaneously in iterations instead, where each of the iterations results in a new and improved version of the solution. The idea is that stakeholders are allowed and expected to react upon each solution version and provide feedback for further development. In this sense, the requirements specification evolves together with the solution and the project can be said to be test-driven (cf. Morandotti, 2007). Extreme programming (Beck, 1999) is an example of utilizing an evolutionary process model.

Sommerville (2007) discusses benefits and drawbacks with the above two approaches. He argues that the sequential model is similar to process models of other engineering disciplines, which facilitates better integration with those process models. Also, having a sequential model facilitates the documentation of the outcome from each activity before moving on to the next activity. It would not be cost effective to generate documents of every version of evolutionary designed software. Therefore, he argues that the sequential approach is more visible for management. He also argues that the software produced in an evolutionary approach is more likely to meet various customers' requirements. That is because customers are able to evaluate and suggest changes based upon each new and improved version of the solution. In contrast, the sequential approach requires that stakeholders commit to the full scope as early on as in the earlier activities, and changes during later activities are more difficult to pursue. The frequent changes associated with the evolutionary approach make it more difficult to maintain stable software architecture. He concludes that a sequential approach should not be used when requirements are not well understood and change often, and that an evolutionary approach should not be used for large and complex systems.

As identified in Section 2.5, PLM solutions are large systems and have high complexity. It is therefore likely that a sequential solution design approach is suitable for PLM implementations. However, no dominant process model has emerged yet.

2.7.3 Organizational change management

Grönvall (2006; also see Grönvall, 2009) argues that for PLM deployments to be successful, sufficient focus needs to be put on organizational change management. He discusses organizational change in deploying PLM in relation to the eight success factors identified by Kotter (1996):

1. Establishing a sense of urgency
2. Creating the guiding coalition
3. Developing a vision and strategy
4. Communicating the change vision
5. Empowering broad-based action
6. Generating short-term wins
7. Consolidating gains and producing more change
8. Anchoring new approaches in the cultures

Stark (2005) argues that three main activities are required for achieving organizational change. First, the scope of change and why change is necessary need to be communicated to all stakeholders. More specifically, the following needs to be communicated: what the current situation is, what the future situation will be, and what the path of moving from the current to the future situation will look like. Second, employees need learn to work according to the new PLM solution. The activity can be facilitated with both theory and practical exercises. However, regardless of how well the employees have understood what and why change should happen, and regardless of how skilful they are in working with the new PLM solution, change may still default. Although the PLM solution may facilitate high level business benefits, it may also result in drawbacks for some or several of the individual employees, drawbacks which may result in a resistance to change. Hence, for an organization to change and to stay changed, a reward structure also needs to be put in place. At the least, drawbacks need to be mitigated.

It can be observed that the first four success factors from Kotter (1996) focus on developing and communicating the change message and map very well to the communication activity proposed by Stark (2005). While Kotter's (1996) success factors 5-7 focus on generating business benefits from the change and success factor 8 focuses on hindering the organization to change back to the state it was in before it changed, Stark's (2005) activities of learning and establishing a reward structure can be seen as support for those success factors.

Siddiqui et al (2004) identified through a survey that most issues in PLM implementation are organizational. In particular, lack of top management support was found to be the largest issue. As a response, they propose a framework with key processes aimed at increasing support from top management.

To conclude, general as well as PLM specific support for organizational change management exists. Having discussed the need for descriptions of PLM implementations, the next area of relevance to this thesis is the evaluation of PLM.

2.8 Evaluation of PLM

Evaluation is about determining *"the value, usefulness or strength of a solution with respect to a given objective"* (Pahl and Beitz, 1996). PLM can be evaluated by different means. One approach is to evaluate the effects resulting from using a PLM solution. Another approach is to evaluate the PLM implementation or the PLM solution as such. All three of these approaches are discussed in the following sections.

2.8.1 Evaluation of effects from using PLM solutions

Success from PLM investments can be derived from the successful utilization of a PLM solution. As such, this utilization depends on both the functionality and quality of the PLM solution and the behaviour of the users working with the PLM solution.

In order to be able to evaluate the effect from using a PLM solution, changes to the income or cost parameters need to be possible to measure. Alemanni et al. (2008) propose such a method based on key performance indicators for time, cost, quality, infrastructure and communication, and demonstrate its use for the data and configuration management processes in a case from the space industry. Examples of their key performance indicators are: "*average number of engineering change proposals"* and *"average time for documents distribution."*

However, several difficulties accompany the approach. In order to utilize the method, what to measure needs to be agreed upon. This task is not entirely straightforward since different stakeholders may have different viewpoints. However, de Wit (1988) argues that the work of trying to specify the measures and their fulfilments is still worthwhile in order to pass on lessons learned from one project to another.

Assuming that what to measure is agreed upon, to what degree changes in income or cost parameters can be derived from the use of the PLM solution, rather than from other events or artefacts, still needs to be clarified. Also, the results vary depending on in what time the performance indicators are measured. How far the change process has proceeded and how much stabilization and improvements have been made to the PLM solution play a part, and it may take a long time before changes in behaviour are visible through changes in income parameters.

Since the effects from using a PLM solution are only visible subsequent to solution deployment, methods to measure the effects from using a PLM solution have only potential for contributing to improvements during the stabilization and improvement phases. Potentially, it is possible to simulate the use of a PLM solution and compare the effects from using different PLM solutions. Engineering processes can, for example, be simulated with the use of design structure matrix methods (cf. Eppinger and Browning, 2012). However, methods to simulate the use of complete PLM solutions, including all layers of the PLM architecture, are lacking.

To conclude, evaluating the effects of using a PLM solution presents several difficulties. It would be beneficial to be able to evaluate tentative PLM solutions during development and to evaluate PLM implementations leading to the development and deployment of PLM solutions.

2.8.2 Evaluation of PLM implementations

One common way to evaluate PLM implementations is to measure to what extent the project meets pre-specified performance indicators, such as time, cost, and quality, often referred to as the iron triangle (Figure 2-14). Performance indicators are defined during project definition and can subsequently be used to support the monitoring of project progress and to support follow-up after project completion.

Standish Group (2004) utilizes this approach in their report on outcomes from large IT projects. They measure per cent over budget, per cent over time and to what degree the initially stated features and functions are fulfilled. They have found that although large IT projects still commonly finish over budget, over time, and fail to fulfil all features and functions, the outcomes have improved since earlier measurements (cf. Standish Group, 1994). According to them, the three topmost factors for a successful project are involved users, support from executive management, and clearly stated requirements (Standish Group, 1994).

Those reports, however, have been challenged, and questions have been raised as to whether the figures are correct and if the definitions and measures are clear enough (e.g., by Jørgensen and Moløkken-Øsvold, 2006). Also, the approach provides no recommendations for how to improve the results. Furthermore, the method is dependent upon the actors' ability and will to establish trustworthy performance indicators to be compared with during project definition. To conclude, it is of interest to search for alternative methods to evaluate PLM implementations.

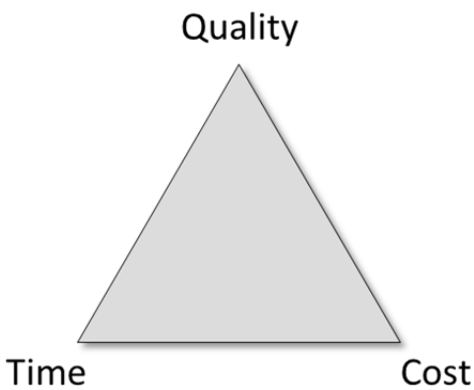

Figure 2-14: The iron triangle

2.8.3 Evaluation of PLM solutions

Evaluating tentative PLM solutions allows for improvements during solution development. Methods to evaluate tentative PLM solutions, however, are difficult to find in literature. It may be possible to compare different tentative PLM solutions against each other in order to select the most appropriate one, similar to concept scoring techniques for product evaluations (e.g., Ulrich and Eppinger, 2012). However, multiple PLM solution concepts with variants of all layers of the PLM architecture would be cumbersome to establish. Instead, identifying risks, or weak spots, in a PLM solution concept in order to improve it could be an alternative approach. A risk can in this sense be defined as:

Risk: *The effect of uncertainty on objectives (ISO Guide 73, 2009).*

As the above definition infers, risk is about the probability of an event, and the negative effects to which such an event could lead. The opposite of risk can be said to be chance, referring to positive effects. Two activities are imperative for risk management: risk assessment, meaning the identification and prioritization of risks, and risk control, meaning the planning and follow up of countermeasures (Boehm, 1991).

Although not written from a software perspective, the work of Johannesson et al. (2004) argues that evaluations of solution concepts can be more or less systematic and structured. On one extreme, evaluations can be made solely based on intuition and feelings. On the other extreme, evaluations can also be based on highly systematic and structured methods. It is unlikely that any company would like to evaluate their PLM solution based solely on intuition. The stakes and risks of such an approach are simply too high. On the other hand, too rigid and formalized evaluations may be too difficult to apply to generate a trustworthy result, at least for the complexity of PLM solutions.

Regardless of the evaluation method, a prerequisite for evaluating a tentative PLM solution is a model of its elements. Several frameworks for modelling PLM solutions exist, as discussed in Section 2.2. The different elements of these frameworks may be described using informal techniques, such as natural language descriptions. Formalized techniques also exist. One example is IDEF0 (Ross, 1977) for process modelling.

To conclude, being able to evaluate PLM solutions may enable the implementation of possible improvements as early on as during PLM solution development. However, although methods to model PLM solutions exist, no method yet exists to evaluate such models. The identification of risks associated with a PLM solution concept can be a promising approach.

2.9 Guidelines for PLM

Ika (2009) makes a useful distinction between success criteria and success factors. Referring to the Oxford Dictionary (1998), he claims that while success criteria are those indicators against which that we measure success, success factors are the proven means for achieving fulfilment of those criteria. Hence, an alternative approach to evaluating the success of PLM would be to evaluate the fulfilment of factors leading to success. Success factors for PLM are thus needed. Pahl and Beitz (1996) identify the following three categories of success factors for engineering design:

- Rules
- Principles
- Guidelines

The difference between the types of success factors is that while rules are more generalized and apply to a wider field, the principles and guidelines are more specific and depend on the objectives to be met. Hence, their relevance needs to be assessed from case to case. Guidelines are even more specific than principles and apply to an even narrower context. A guideline in this sense can be defined as:

> ***Guideline:*** A directional recommendation for what to do (or what not to do) in a specific context.

Pahl and Beitz (1996) argue that three general rules apply to all engineering design: clarity, simplicity, and safety. Furthermore, they argue that these three rules are useful when evaluating solution concepts. Clarity and simplicity intuitively seem to be valid for PLM solutions as well, but it is not evident how the rules should be applied in practice. Pugh (1990) applies a formula to calculate the complexity number to assess the simplicity of products. A similar approach could also be possible for evaluating PLM. Regarding the safety rule, it is questionable whether there is any PLM solution that does not apply to human or environmental safety. This makes the rule superfluous. Pahl and Beitz (1996) also propose several principles and guidelines for various fields of (mainly) mechanical engineering. However, those principles and guidelines seem to be of little direct use in evaluating PLM due to their specific fields of application.

As discussed in Section 2.7.3, success factors for organizational change management have also been published (e.g., Kotter, 1996). Furthermore, success factors for projects have been published in literature (for example, Slevin and Pinto, 1986; Cooke-Davies, 2002). Cooke-Davies (2002) proposes the following success factors for individual projects:

1. Adequacy of company-wide education on the concepts of risk management
2. Maturity of an organization's processes for assigning ownership of risks
3. Adequacy with which a visible risk register is maintained
4. Adequacy of an up-to-date risk management plan
5. Adequacy of documentation of organizational responsibilities on the project
6. Keep project as far below three years as possible
7. Only allow changes to scope through a mature scope change control process
8. Maintain the integrity of the performance measurement baseline
9. The existence of an effective benefits delivery and management process that involves the mutual co-operation of project management and line management functions

The first eight success factors, he claims, are necessary to secure project management success, meaning to meet pre-specified indicators for time (factors 1-6) and cost (factors 7-8). The last factor, he claims, is necessary for securing project success. The success factors from Kotter (1996) and Cooke-Davies (2002) complement each other. Put in the terminology by Pahl and Beitz (1996), they can all be said to be principles.

Instead of general principles to evaluate PLM solutions and implementations, guidelines from the more specific area of PLM can prove useful. Although it is unlikely PLM implementations will not generate learning (Hartman and Miller, 2006), the published knowledge of such learning is only partial and scattered into different sources (Wognum and Kerssen-van Drongelen, 2005). However, sources of guidelines drawn from past experience exist (e.g., Zimmerman, 2008; Pikosz et al., 1997; Berle, 2006) and should be possible to utilize.

It is likely that applying existing guidelines can contribute to improved outcomes from PLM implementations. Prior to utilizing them in practice, however, they need to be summarized. Furthermore, their degree of relevance needs to be assessed, since success factors for projects need to be based on the project characteristics (Wateridge, 1998). Depending on their characteristics, they might be possible to use for evaluating PLM solutions or even whole PLM implementations.

2.10 Research Needs

The identified research needs in this thesis, and hence the areas of contribution, are related to the areas of characteristics and challenging issues in PLM implementations (Section 2.2) through case studies of PLM implementations (Section 2.6) focusing on requirements management (Section 2.7.1) and the evaluation of PLM implementations (Section 2.8.2) and PLM solutions (Section 2.8.3) through the use of guidelines for PLM (Section 2.9). There is a need for in-depth case studies of PLM implementations and for methods and tools to evaluate and guide PLM implementations. These research needs are described in the following subsections.

2.10.1 In-depth case studies of PLM implementations

In-depth understanding of the operational aspects of PLM implementations, elaborating on various modes of action and their effects, is needed in order to propose and develop methods and tools that can support practitioners. However, most of the existing discussions of characteristics and challenges are provided without thorough case studies of the implementation projects from which they are drawn. This makes it difficult to understand the characteristics and challenges in practice.

2.10.2 Methods and tools to evaluate PLM implementations

Different means for evaluating PLM exist. Real (deployed) PLM solutions can be evaluated by measuring the effects resulting from using the solution. However, such approaches only allow for improvements subsequent to solution deployment. PLM implementations can be evaluated measuring the fulfilment of pre-specified key performance indicators such as project time, cost and quality of delivery. The approach, however, has several difficulties. Tentative PLM solutions can potentially be evaluated as well. However, no such method or tool yet exists. Hence, new methods and tools to evaluate PLM implementations in general and PLM solutions in particular are needed. One idea would be to identify risks, or weak spots, associated with PLM implementations.

Experiences drawn from past PLM implementations are published in literature and should be possible to utilize in terms of guidelines. However, existing guidelines are scattered across different sources, and their validity for new cases is unknown. A summary and validation of existing guidelines, creating a comprehensive tool of best practices, could possibly support practitioners to evaluate and guide PLM implementations.

3 Scientific approach

This chapter starts by stating and characterizing the research problem posed in this thesis. A framework for the research process and the components of research are then discussed, especially the components of methods and validity. Last, the applied process, methods and validation strategies in the appended papers are described.

3.1 Research questions

Based on the research goals in Section 1.6 and the research needs identified in Section 2.10, the following research questions are posed for this thesis.

The first research question relates to the first research goal, as well as to the first identified research need. In-depth case studies of PLM implementations are sparse in literature. They are, however, imperative for being able to construct methods and tools useful for practitioners. In particular, no works focus on the role and impact of requirements management-related activities. Hence, the first research question is:

> ***Research question 1:*** *What is the role and impact of requirements management in PLM implementations?*

The next research question relates to the first research goal, but is oriented towards the second identified research need. Guidelines exist in literature, but are spread across multiple sources. No works focus on what guidelines for PLM implementations exist or whether increased application of PLM implementation guidelines leads to improved outcomes. Hence, the next research question, with sub-questions, is:

> ***Research question 2:*** *Does, and if so how does, an increased application of PLM implementation guidelines lead to improved outcomes in PLM implementations?*
>
> ***Research question 2a:*** *What PLM implementation guidelines are available from literature?*
>
> ***Research question 2b:*** *To what extent are those guidelines relevant to PLM implementations?*

> ***Research question 2c:*** *To what extent are those guidelines applied in PLM implementations? What are potential reasons for, and consequences of, low application of relevant guidelines?*

The last research questions relate to the second research goal and are oriented towards the second identified research need. Methods to evaluate PLM solutions and PLM implementations are needed. One possible approach could be to evaluate PLM solutions and implementations in terms of risks, or weak spots, using success factors as guidelines for PLM implementations. However, no such approaches exist. Hence, the next research questions are:

> ***Research question 3:*** *How may PLM implementation guidelines support identifying risks associated with PLM implementations?*

> ***Research question 4:*** *How may PLM solution guidelines support identifying risks associated with PLM solutions?*

3.2 Characterization of research problem

The research problem is concerned with the investigation of real people in real life situations, social science, or, more specifically, a project organization conducting multiple activities in order to implement a PLM solution. Robson (2002) distinguishes between fixed and flexible research designs regarding real world research. In fixed research designs, most research steps occur sequentially. In flexible design, instead of having sequential process links between the research components, multiple bi-directional arrows indicate that each component affects the other components. He claims that research of quantitative nature is more likely to have a fixed research design. In research of qualitative nature, a flexible research design is more likely, although that does not rule out the use of some quantitative elements.

The research presented in this thesis fits the characteristics of a flexible, emergent, research design, where each of the research components has evolved over time. The current states of the research components are thus different from their initial state. It has been claimed that it does not matter what research component matured first. "*Once a study is published, it is in many ways irrelevant whether the research problem prompted the study or instead emerged from it*" (Brewer and Hunter, 1989; cross-referenced from Robson, 2002).

3.3 Research process

The Design Research Methodology (DRM) has been developed as a response to what the authors refer to as a lack of a common research methodology for design research (Blessing and Chakrabarti, 2009). The model (Figure 3-1) is improvement oriented, recognizing the need to improve design and not just to understand current practice. Blessing and Chakrabarti (2009) acknowledge that although the overall purpose of all design research is to improve design (the artefact, the process, or both), the purpose of all individual research efforts does not have to be to improve design.

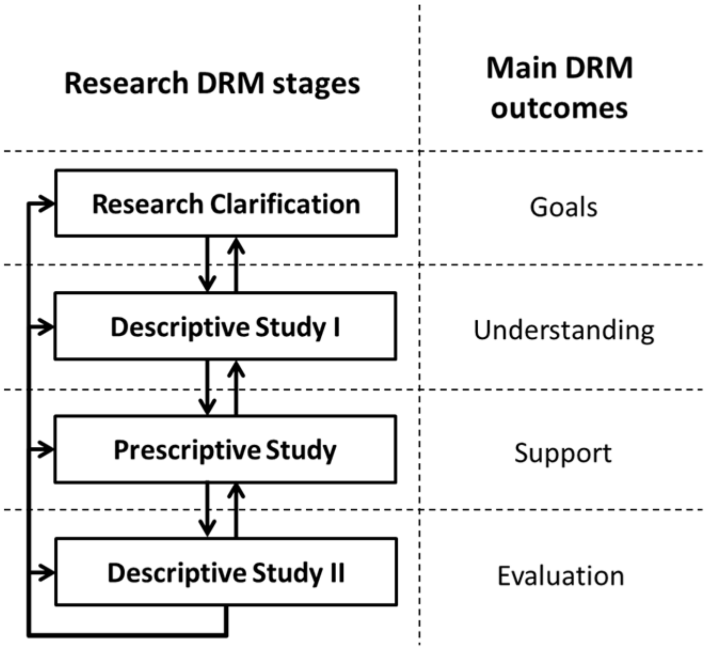

Figure 3-1: A design research methodology (Source: Blessing and Chakrabarti, 2009).

The above model contains four sequential process steps, although the arrows in between the steps indicate a need for or possibility of jumping back and forth. The aim of the first step, research clarification, is to delineate the goal and corresponding scope of the research. The goal of the second step, descriptive study I, is to further increase the understanding and line of argumentation between various influencing factors. The goal of the third step, prescriptive study, is to propose a support for improvement. Finally, the aim of the last step, descriptive study II, is to evaluate the support against the goals.

As is the case in research on design, the overall purpose with this thesis is to improve the practice of PLM implementation. How the model relates to the research goals, research questions and the appended papers in this thesis is delineated in Section 3.7.

3.4 Components of the research

The research model (Figure 3-2) proposed by Maxwell (2005) is adopted to present the work in this thesis, and is comprised of five main components: goals; conceptual framework; research questions; methods; and validity. Robson (2002) proposes a model containing similar research components, although instead of validity he claims sampling strategy to be the fifth component of research. Maxwell's (2005) reason for separating methods from validity is two-fold: validity is such an important component of research that it deserves its own space, and validity cannot be secured by the use of a set of methods or strategies. Such can only be used to collect evidence for or against validity.

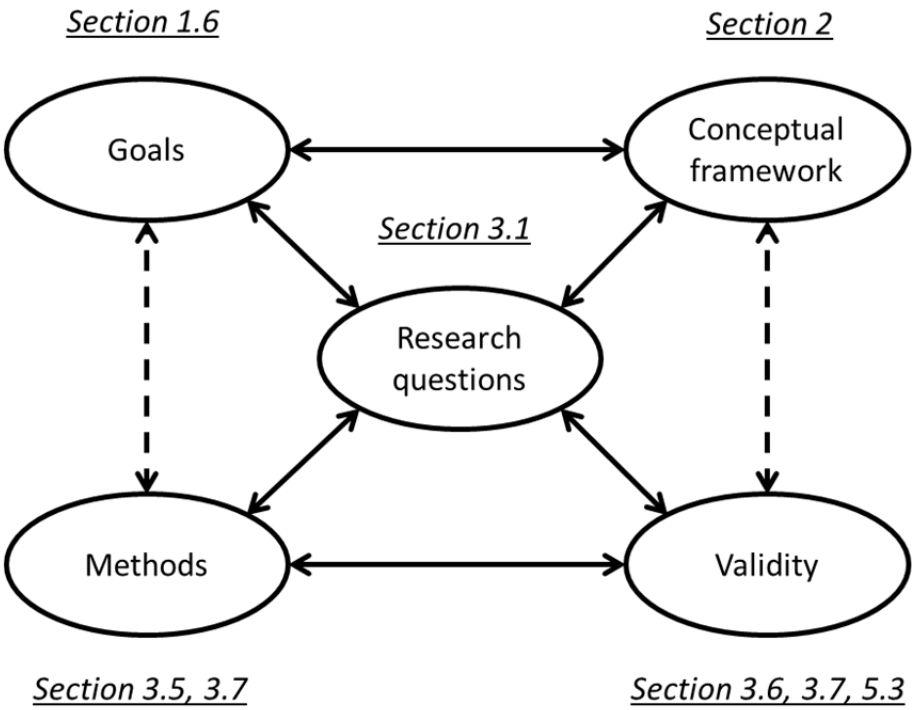

Figure 3-2: Components of research, with indications of sections where the respective components are discussed (Source: Maxwell, 2005, p. 5).

The goals of the research presented in this thesis have already been stated in Section 1.6, the conceptual framework in Section 2, and the research questions in Section 3.1. The other two components of research, methods and validity, are in focus during the rest of Section 3. First, a framework for methods and for validation is provided in Section 3.5 and Section 3.6 respectively, before their application in the appended papers is described in Section 3.7. Validity of the thesis contributions are discussed separately in section 5.3.

3.5 Methods

Using an explicitly stated broad definition of the term methods, Maxwell (2005) argues that four components need to be addressed when conducting qualitative methods: research relationships; site and participation selection; data collection; and data analysis. As previously stated, synthesis is also a major part of this thesis. These five components are briefly described in the following section.

3.5.1 Research relationships

For research initiation, a researcher needs to establish relationships with the people involved in the phenomena of interest to be studied. Such relationships have a large impact, and both facilitate and constrain other decisions regarding the research design, such as site and participant selection. Furthermore, the relationships affect both the researcher and the researched people, and often require some kind of bilateral benefits from the study.

3.5.2 Site and participation selection

Regarding the issue of selecting site and participants, Maxwell (2005) states that a purposeful, rather than probabilistic or convenient, sampling is appropriate for qualitative methods. This means that the site and participants are selected for purposes of the information they can provide. Sites and participants can be selected based on, for example, their typicality, their unique characteristics, their criticality for theory, or for making comparisons with other sites and participants.

3.5.3 Data collection

While the research questions frame what needs to be understood, the data collection methods aim to gather evidence for that understanding. Developing data collection methods, such as interview questions, is concerned not only with the research questions, but also with the empirical context within which the data is to be collected. Maxwell (2005) therefore suggests that researchers should try to anticipate how their interview questions will work in reality and preferably also test them in a pilot study.

3.5.4 Data analysis

Data analysis is an on-going activity that starts from the first data inquiry and continues until the end of the study. Listening through interviews, reading through transcripts, and even transcribing interviews are facilitators for analysing data.

3.5.5 Synthesis

The ultimate aim of this thesis is to develop new support in terms of methods and tools for PLM implementations. Developed methods and tools need to be based on an understanding of the existing situation in order to address appropriate factors (Blessing and Chakrabarti, 2009).

3.6 Validity

Validity of research is defined by Maxwell (2005) as "*the correctness or credibility of a description, conclusion, explanation, interpretation, or other sort of account*" (Maxwell, 2005). Four tests are commonly referred to when assessing research validity (Yin, 1994): construct validity; internal validity; reliability; and external validity (or generalisability). The four tests have emerged from research on natural science in the positivistic paradigm, and their applicability to assessing the validity of qualitative research has been discussed. From an explicitly stated realism (or constructivist) paradigm, Guba and Lincoln (1989) prefer to test trustworthiness, instead of validity as a whole. They also prefer alternative but similar tests to assess trustworthiness in qualitative research: they prefer to test confirmability rather than construct validity, credibility rather than internal validity, dependability instead of reliability; and transferability instead of external validity. Transferability puts a great deal of responsibility on the receiver, while the researcher would be responsible for claiming external validity.

A wide set of strategies, or methods, exist that can be used to assess research validity. Maxwell (2005) argues that although applying the strategies does not in itself rule out threats, they can be used to collect argumentation, or evidence, for ruling out threats. He suggests the following strategies:

1. ***Intensive, long-term involvement:*** *Can lead to higher construct validity, which in turn may lead to less need for the researcher to make his or her own inferences.*
2. ***"Rich" data:*** *Can lead to a nuanced understanding of the studied phenomena and its context, which can lead to improved inferences.*
3. ***Respondent validation:*** *Can lead to reduced amounts of errors and misinterpretations, as well as feedback concerning the researcher's own beliefs and values.*
4. ***Intervention:*** *Can be used to support internal validity by intentionally manipulating one or a few of the factors believed to have (or not have) an effect of the results.*
5. ***Searching for discrepant evidence and negative cases:*** *Can be utilized to question the researcher's hypothesis and conclusions, thereby improving internal and external validity.*
6. ***Triangulation:*** *Can lead to less bias and, thereby, improved construct validity.*
7. ***Quasi-statistics:*** *Can be used to provide a frame of reference. "More expensive than originally expected" can be backed up with data to "50 % more expensive than expected 3 years earlier."*
8. ***Comparison:*** *Can allow for studying causality and for making generalizations.*

The strategies from Guba and Lincoln (1989) overlap with the ones from Maxwell (2005), but they also identify:

9. ***Progressive subjectivity:*** *Developing the construct throughout a study is seen as evidence of credibility.*
10. ***Inquire audit:*** *A visible process can lead to higher dependability (or reliability). Traceable data and constructs can lead to higher confirmability (construct validity).*
11. ***"Thick" descriptions:*** *Can lead to higher transparency in the presentation of the findings, which in turn can lead to higher transferability.*

The above mentioned validity tests and corresponding strategies to assess validity will be used when assessing the validity of the appended papers in Section 3.7.

3.7 Applied process, methods and validation strategies

In Figure 3-3, the appended papers are mapped to the different stages of the DRM in connection with the research goals and questions. The first research goal focuses on understanding the current situation, while the second research goal aims to improve it.

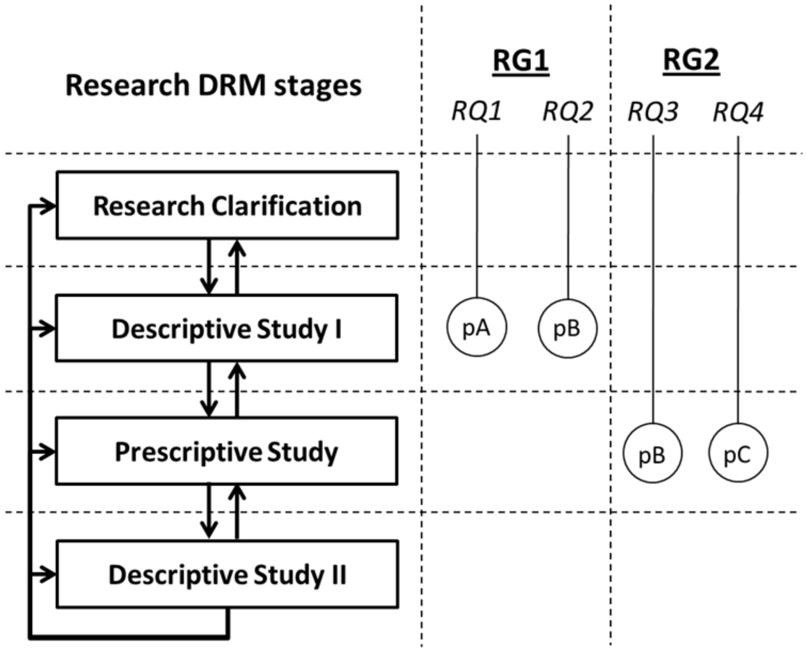

Figure 3-3: Research goals (RG1 and RG2), research questions (RQ1-RQ4) and contributions from the appended papers (pA, pB and pC), in relation to the design research methodology prescribed by Blessing and Chakrabarti (2009).

For all three papers combined, a total of about 450 documents (in addition to project and company documents) have been generated and stored. They include documents such as oral and written presentation material, initial study focus, versions of interview guides, interview recordings and transcripts, memos of the analysis, and versions of all papers. Due to non-disclosure agreements and ethical considerations, most of the documentation is inaccessible for external researchers. However, the documents make visible the changes in constructs of the researchers throughout the study, indicating progressive subjectivity. Furthermore, the documents implicitly make visible the process of the studies. The interview recordings, interview transcripts and project and company documents also make visible that the empirical constructs exist.

The following is a delineation of the methods and validation strategies applied in each of the appended papers.

3.7.1 Paper A

3.7.1.1 Initiation and research relationship

GlobalGroup (fictitious name used in Papers A and B) is a multinational company in the manufacturing industry. The paper stems from a perceived issue by GlobalGroup's IT division to elicit requirements from its business divisions in PLM implementation projects. Also, a literature review revealed that there is a lack of thorough case descriptions that focus on the operational level of PLM implementation, specifically regarding requirements management. As a response, a research relationship was established with GlobalGroup to clarify the requirements management characteristics and challenges in PLM implementation. The objective called for an in-depth PLM implementation case study.

3.7.1.2 Site and participation selection

At the time of that call, GlobalGroup had just recently finished a PLM implementation project in which they developed and implemented a new PLM solution. Multiple divisions and sites around the world had been involved. Also, the old PLM solution and the new one were fundamentally different from each other, which indicated a certain degree of technical challenge in the project. Therefore, the case allowed for insight into a long range of characteristics and issues regarding changes to the organization, the processes and the PDM systems and engineering applications.

A study reference group was set up with managers from the divisions involved in the project. They functioned as leverage into the organization, making interviews possible and providing access to interesting documentation. Also, on three occasions during the study, preliminary findings were presented to the study reference group in search for discrepancies in the researchers' constructs. Careful considerations were made during those presentations to not favour the constructs of the study reference group members over other information sources.

The interviewees were sampled according to a purposive heterogeneous strategy in order to represent as many viewpoints as possible. Examples of interviewees' roles include business and IT project managers, project steering committee members, business and IT reference group members, and IT project members. One interview was done with two interviewees from the company's requirement engineering methods department, in order to analyse similarities and differences – making an internal comparison – between the studied case and the company's abilities in general.

3.7.1.3 Data collection

Three semi-structured interviews (with five interviewees) were conducted as a pilot for the study. Findings from those were presented to the reference group. The findings served to identify a tentative timeline of the project, tentative outcomes, a tentative description of the project organization, and tentative challenges in the project. As such, they served to better focus the rest of the study. Based on the findings, additional informants, as well as interesting documentation, were identified. Subsequently, another fourteen semi-structured interviews (with sixteen interviewees) were conducted. In addition, more than 200 project and company documents were collected. Examples of documents include white books, meeting minutes, communication letters, and technical documentation.

All interviews were recorded, transcribed, and sent to the interviewees for respondent validation. The transcribed interviews, together with the collected documents, contribute to a "rich" data set and triangulation of sources.

All the interviews were based on an interview guide, with roughly 40 questions covering the interviewee's background, the implementation process and requirement engineering methods, the project organization, and project outcomes. The researchers' construct of the implementation project grew with the carrying-out of each interview. This, in turn, allowed for deeper questions and answers. The researchers' individual interpretations were slightly different from each other's and were mitigated by means of discussion throughout the study.

3.7.1.4 Data analysis and presentation

Interview statements were categorized into different analysis areas according to the questions in the interview guide. Communication letters and meeting protocols were summarized in a few sentences and added to the analysis material, and the technical project documentation was analysed in depth. Statements regarding events and their causes and effects were structured in a graphical timeline and explicitly described in natural language text. Statements regarding challenging requirements management issues were grouped into five main areas: project scope and goals; implementation process; requirements elicitation and validation; system testing; and user involvement. During the analysis, evidence for and against different constructs were looked for.

A presentation of the final findings was held for the study reference group and most of the participating interviewees, for respondent validation and for further search for evidence of discrepancies. In addition, two presentations were held at another company, with characteristics similar to GlobalGroup, which also served to search for evidence of discrepancies.

The paper was constructed, including “thick” descriptions of the empirical setting, the implementation process (with causes and effects of important events), and challenging requirements management issues. Prior to publication, the paper was reviewed by the study reference group.

3.7.2 Paper B

3.7.2.1 Initiation

While constructing Paper A, a literature review revealed several sets of PLM implementation guidelines. However, where cases are referred to, the implementations are only briefly described. This makes it difficult for readers of those articles to understand the rationale behind various guidelines to be applied in practice and what the consequences can be if the guidelines are not applied. This finding led to the initiation of a paper to clarify the relevance and application of existing guidelines in a contemporary PLM implementation project. The detailed understanding of GlobalGroup’s conducted PLM implementation project served as a suitable case, and, hence, no new research relationship needed to be established.

3.7.2.2 Data analysis, synthesis and presentation

The relevance and application of each of the guidelines to the case were assessed on a three-levelled scale (low, medium, high). The effects of the application (or the lack of application) of each guideline were also assessed, and potential reasons for the low application of relevant guidelines were discussed. The analysis led to the recommendation that projects should review their project plans with PLM implementation guidelines in mind.

To facilitate transferability, Paper B builds on the same “thick” description of the empirical setting and the implementation process (with causes and effects of important events) that Paper A had. It also includes the above mentioned assessments, discussions and recommendation. Prior to publication, the paper was presented to and reviewed by the study reference group in search for evidence of discrepancies and for respondent validation.

3.7.3 Paper C

3.7.3.1 Initiation and research relationship

As background to Paper C, GlobalCorp (fictitious name used in Paper C and not to be confused with GlobalGroup) is also a multinational company in the manufacturing industry, consisting of a large number of acquired subsidiaries. GlobalCorp wants to leverage on their size, and have developed a global PLM solution, based on commercial engineering applications and PDM systems. A research relationship was set up with representatives from the PLM department in one of the subsidiaries. The objective was to analyse the benefits and drawbacks of this global PLM solution. Part of the results from that study was a description of GlobalCorp's PLM solution.

Simultaneously, as a spin-off from Paper B, a goal was set up to develop a method to evaluate a PLM solution based on PLM implementation guidelines. The empirical description of GlobalCorp's PLM solution was deemed suitable for demonstrating and evaluating the method.

3.7.3.2 Site and participant selection

Multiple semi-structured interviews and examples of e-mail correspondence with six employees from GlobalCorp's PLM Centre of Excellence (COE) form the empirical base for the description of GlobalCorp's PLM solution. Four of the interviewees work at GlobalCorp's centralized PLM department. Meanwhile, two of the interviewees work at local PLM departments in two different subsidiaries that are currently implementing the PLM solution. They were all selected due to their knowledge of GlobalCorp's PLM solution and the process of developing it. Also, in addition to the six employees who made the main data contribution to this study, eleven other employees were interviewed, providing contextual knowledge.

3.7.3.3 Data collection

The interviews lasted between one and two hours and were done by two interviewers. The interview guide covered, among other areas, the interviewee's background, GlobalCorp's PLM COE, their PLM solution, and the process of developing it. Archival records, such as GlobalCorp's defined information model and organizational charts, were reviewed during some of the interviews. The study thereby utilized a triangulation of sources and researchers. The researchers' individual interpretations were slightly different from each other's, and were mitigated by means of discussion and additional questions to the interviewees (through e-mail correspondence) throughout the study.

The interviews were recorded, transcribed and sent to the interviewees for respondent validation. The transcribed interviews contribute to a "rich" enough data set regarding GlobalCorp's PLM solution.

3.7.3.4 Synthesis, analysis, and presentation

A method for identifying risks associated with a PLM solution, based on a layered PLM architecture model and a sub-set of the PLM implementation guidelines, emerged through several iterations of refinements and re-evaluations, eventually leading up to its current form.

Last, Paper C was constructed. Prior to publication, the paper was presented to and reviewed by the interviewees at GlobalCorp in further search for evidence of discrepancies and respondent validation.

4 Results

In the following chapter, the background, aims, main results and conclusions of the appended papers are summarized. In short, Paper A provides an in-depth description of a PLM implementation case and discusses challenging requirements management issues in the case. Paper B builds on the case description provided in Paper A by discussing the relevance and application of PLM implementation guidelines, available from literature, to the case. Finally, Paper C utilizes a subset of the summarized PLM implementation guidelines - those regarding the PLM solution - in a proposed method to identify risks associated with a PLM solution.

4.1 Paper A: Challenging requirements management issues in PLM implementation – findings from a retrospective case study

Existing models for PLM implementations (e.g., Schuh et al., 2007; Bitzer et al., 2008; Batenburg et al., 2006; Kumar and Midha, 2006) focus primarily on requirements management for the chartering phase, resulting in PLM systems being selected. However, in-depth case studies of how the subsequent operative phase of PLM implementations has been conducted, what the rationale has been for different courses of actions, and what effects that action has had, are lacking. In particular, requirements management activities are not sufficiently described.

The aim of Paper A was to clarify the role and impact of requirements management activities in PLM implementations, and to discuss challenging requirements management issues in PLM implementations. This was done through an in-depth case study of a recent PLM implementation case at GlobalGroup (fictitious name, as stated above).

4.1.1 Result: case study of a PLM implementation

The implementation process model, with requirements management activities highlighted, is depicted in Figure 4-1. Major events in the project, described in the paper, include the following:

- The project was initiated by GlobalGroup’s vendor, who announced that their support for GlobalGroup’s PDM system would end in the near future.
- It was decided that business processes were to remain the same and that the PDM system was to be used out-of-the-box with minimized customization.

- Based upon the prototypes, it became evident that the out-of-the-box release of the PDM system initially intended would require major customizations to fit with GlobalGroup's processes.
- The project therefore sent a system change request with additional functionality to their vendor, who agreed to include new functionality in their next release.
- The next PDM system release was delayed.
- Several tests were performed that revealed important issues with regard to the solutions, concerning both functionality and performance.
- The date for system deployment was postponed several times before the system deployment date was set.

In total, the initial budget was overrun by a factor of three. This was due to overly optimistic initial assessments and a string of events causing delays. Benefits from the project include: less complex system architecture with a decreased number of systems; a globally standardized way of working (for example, with release management); and more efficient information sharing. However, some interviewees indicated decreased user efficiency.

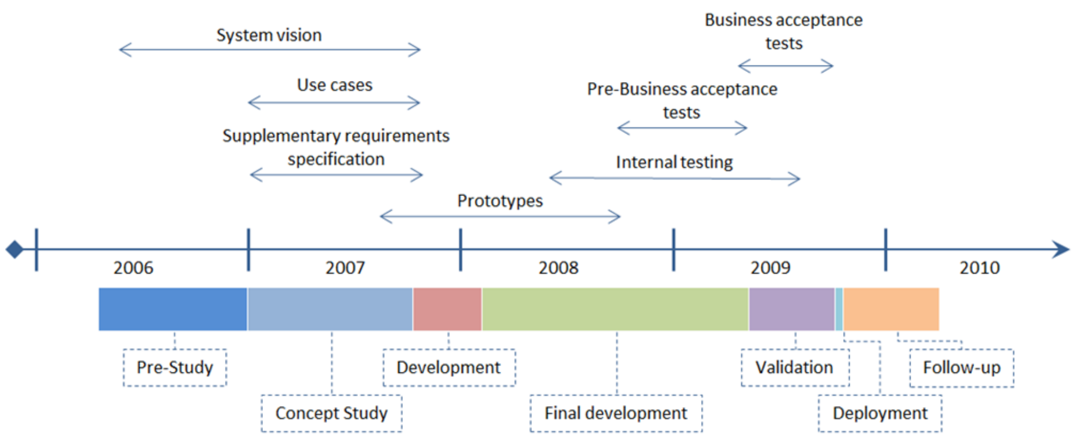

Figure 4-1: PLM implementation process model, with requirements management activities highlighted. (Source: Bokinge and Malmqvist, 2011).

4.1.2 Result: discussion of challenging requirements management issues

Challenging requirements management issues were identified and discussed as they regarded the following matters:

- **Project scope and goals:** The project applied a strategy containing inherent contradictions. Furthermore, the project had difficulties in the beginning to gain commitment from all necessary divisions. Once involved, the divisions were either unwilling to adapt to, or unaware of how their needs contradicted with, the other divisions' needs.
- **Implementation processes:** Integration between their lower-level and higher-level project models was lacking.
- **Requirements elicitation and validation:** The requirements specification template was not adapted to COTS development, and the requirements specification did not

align with the possibilities and constraints of the new system. Also, some of the requirements were contradictory and requirements for specific technical areas were missing.

- **System testing:** The solution developers found it difficult to get relevant feedback on prototypes in early phases of the project.
- **User involvement:** Most members of the business reference group represented their own views, rather than those of the global organization. Furthermore, the business reference group members had too little knowledge of the possibilities and constraints of the new system.

4.1.3 Conclusions

A through description of a PLM implementation case is put forward in Paper A, focusing on requirements management activities and issues. Rationale for different courses of actions, and what effects they have had, is also described.

The case demonstrates that a more skilled application of the requirements management toolbox could have resulted in a more successful project outcome. However, the case also demonstrates the importance of events beyond the project's control. Well-performed requirements management activities are essential for a successful project outcome, but they do not alone insure that success.

4.2 Paper B: PLM implementation guidelines – relevance and application in practice: a discussion of findings from a retrospective case study

Works on PLM implementation based on empirical case studies typically provide guidelines on what to do, and what not to do, when implementing PLM. However, where cases are referred to, the implementations as such are (commonly) only briefly described. As a result, readers of those articles may find it difficult to understand the rationale behind various guidelines to be applied in practice and what the consequences can be if they are not applied.

To address this issue, the aim of Paper B was to compare current practice in a conducted PLM implementation project with available PLM implementation guidelines from literature. Based on a refinement of the case description of GlobalGroup in Paper A, the goals of Paper B were to assess the degree of relevance and application of each guideline and discuss potential reasons for why relevant guidelines are not used in industry.

4.2.1 Result: summary of available PLM implementation guidelines

PLM implementation guidelines were summarized from literature. In addition, new guidelines were constructed and added to the list, based on experiences from GlobalGroup. All of the guidelines are summarized in Table 4-1.

4.2.2 Result: assessment of relevance and application of guidelines

As seen in Table 4-1, the project in full applied rather few of the relevant PLM implementation guidelines. Of the 24 guidelines, 20 were assessed as having high relevance for the case. Of these 20, only one was assessed as being followed to a high extent, five to a medium extent, and 14 to a low extent.

Guideline category	*Guideline*	*Relevance*	*Application*
Project process	Divide project into sub-projects	Low	Low
	Perform a pilot project	Low	Low
	Conduct pre-study prior to system selection	High	Low
	Plan carefully	High	Medium
	Follow-up and control project process	High	Medium
	Be prepared to adjust the plan when business changes	High	Low
	Establish a PLM roadmap	High	Low
	Apply project models for COTS implementation	High	Low
Goals	Define benefits for all stakeholders	High	Low
	Aim to satisfy rather than optimise	Medium	High
	Do not force the same solution on the whole organisation	Medium	Low
	Carefully estimate the magnitude of change	high	low
	Align project with PLM strategy	High	Low
System and process design	Establish a coherent PLM architecture	High	Low
	Improve processes prior to or simultaneously with PLM projects	High	Low
	Align processes with system capabilities	High	Medium
	Only roll out tried software releases	High	Low
	Minimise customisation	High	Medium
Organisation	Ensure management support	High	Medium
	Involve users from all departments and disciplines	High	Low
	Authorise the project participants	High	Low
	Use expertise from third parties	High	Medium
	Educate system users	High	Low
	Define clear responsibilities for all project groups	High	Low

Table 4-1: Summary of available PLM implementation guidelines and additional guidelines drawn from this case, with indications of relevance and application in the researched case (Source: Bokinge and Malmqvist, 2012).

4.2.3 Result: discussion of why relevant guidelines are not applied

Potential reasons why relevant PLM implementation guidelines are not applied fall into one of the following three categories:

- **Lack of awareness of the guidelines:** Knowledge about PLM implementation guidelines is not known to, or at least not understood by, project participants.
- **Awareness, but active decision to not apply the guidelines:** Project participants are aware of and have understood guidelines, but make an active decision to not apply them.
- **Awareness but failure, despite the intent to apply the guidelines:** Guidelines that a project fails to follow despite the intention to do so.

It is suggested that guidelines assessed as having a combination of high relevance and low application are the most problematic ones and need to be analysed in order to achieve better project outcomes. It is also suggested that projects review their project plans with PLM implementation guidelines in mind.

4.2.4 Conclusions

An analysis of relevance and the application of PLM implementation guidelines in a PLM implementation case is put forward, based on a refinement of the GlobalGroup case presented in Paper A and guidelines available from empirical based literature. New guidelines are also constructed based on the case description.

Out of the 24 guidelines, 20 were assessed as having high relevance for the case, but only a handful of them were applied in full in the case. Potential explanations were: lack of awareness of the guidelines; awareness but active decision to not apply the guidelines; and, awareness but failure, despite the intention to apply the guidelines.

It is argued that guidelines with a combination of high relevance and low application are the most problematic ones and need to be analysed in order to achieve better project outcomes. It is suggested that projects review their plans with the guidelines in mind, assessing the degree of relevance and including a plan for how to apply the guidelines.

It is demonstrated that with the PLM implementation guidelines, it is possible to conduct systematic studies of the execution of PLM implementation projects.

4.3 Paper C: A method to identify risks associated with a PLM solution

Measuring the business effects from using a PLM solution is essential. However, that step can only be taken subsequent to solution deployment. It could be beneficial to make an early evaluation of the PLM solution, resulting in the business benefits, making corrections possible prior to deployment. However, while methods for modelling PLM solutions exist, methods to assess PLM solutions are sparse.

The aim of Paper C was to propose, demonstrate and evaluate a method to identify the risks associated with a PLM solution, based on a subset of the PLM implementation guidelines summarized in Paper B, and the PLM architecture model from Zimmerman (2008).

4.3.1 Result: method proposal

The method (Figure 4-2) comprises five steps: (1) develop and document the PLM solution, leading to an architecture model of the PLM solution; (2) analyse the architecture model to identify risks; (3) map correlations between elements of the architecture model and existing PLM solution guidelines, leading to a correlation matrix; (4) analyse the correlation matrix to identify risks; and, (5) generate change proposals based on the identified risks.

4.3.2 Result: method demonstration

The proposed method was tested in a multinational manufacturing company called GlobalCorp. Elements of GlobalCorp's PLM solution were identified and categorized in accordance with different layers of the PLM architecture model presented by Zimmerman (2008). Agreements and conflicts between elements of the architecture model and the PLM solution guidelines from Paper B were mapped in a correlation matrix.

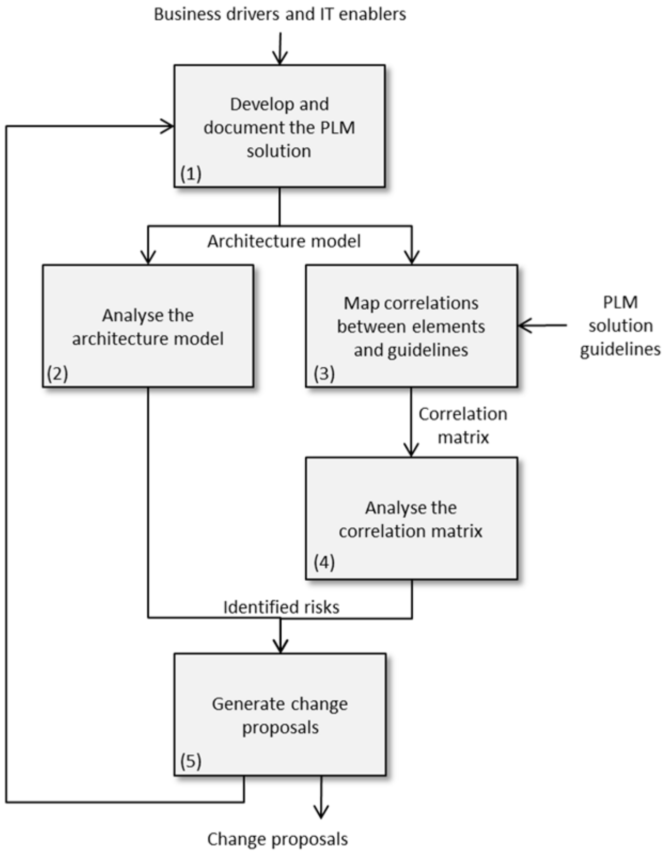

Figure 4-2: A method to identify risks associated with a PLM solution (Source: Bokinge et al, 2012).

The PLM architecture model and the correlation matrix were analysed to identify risks associated with GlobalCorp's PLM solution, and change proposals were generated. The following risks were identified:

- GlobalCorp's process layer is only coarsely defined. The connections between high level processes and low level processes are missing and need to be elaborated in order to gain full understanding and the benefit of the PLM concept.
- Not enough PLM architecture elements exist to secure the intended increased re-use of parts and designs. In order to better gain benefits of scale, a stronger focus needs to be put on facilitating the increased re-use of parts and designs.
- The strategy of allowing for some differentiation between subsidiaries' PLM solutions could not be traced to any objective. A new objective could be formulated and communicated, legitimatizing a degree of differentiation.
- When analysing the correlation matrix, it was observed that conflicts exist between the PLM solution and three guidelines. GlobalCorp could strive to further develop their PLM solution in order to minimize conflicts with the guidelines. It is however possible that, regardless of any changes to the PLM solution, one of the guidelines in conflict ('define benefits for all stakeholders') still risks not being satisfied. In such cases, at least the potential drawbacks need to be mitigated.

4.3.3 Result: method evaluation

The following remarks could be made regarding the proposed method:

- It is demonstrated that a PLM solution could be described using natural language and the PLM architecture model presented by Zimmerman (2008). In the case of a deeper analysis, a more formalized modelling approach may prove beneficial. One may also argue the lack of an 'organizational structure' layer in the PLM architecture model, as exists for example in the model by Svensson et al. (1999).
- It was found that traceability was direct, rather than indirect, between high level strategy elements and most low level strategy and lower layer elements. This finding challenges the argument presented by Schekkerman (2003), applied in the architecture model forwarded by Zimmerman (2008), that traceability links should involve all layers of the architecture.
- Correlations between elements of the PLM architecture model and the guidelines summarized in Paper B could be assessed. The assessment scale was detailed enough given the available empirical data. Companies applying the method in assessing their own PLM solution, and thereby having a better understanding of their own context, may benefit from a multilevel assessment scale.
- The guidelines summarized in Paper B worked to some extent for evaluating a PLM solution, although it was identified that guidelines were lacking for some areas (for example, there were no guidelines regarding how to secure design re-use). More guidelines should be searched for in order to improve the assessment base. Also, conflicts between elements and between guidelines indicate that the relevance of elements and guidelines needs to be assessed on a relative basis (e.g., in order to properly prioritize standardization versus differentiation).

4.3.4 Conclusions

It has been demonstrated that a PLM solution can be identified, modelled using natural language description and a layered PLM architecture framework, and analysed to identify risks associated with the PLM solution. Furthermore, it has been shown that a matrix with correlations in terms of agreements and conflicts can be identified between elements of the model and PLM solution guidelines from literature, and that the matrix can be analysed in order to identify risks associated with the PLM solution. Last, it has been demonstrated that change proposals can be generated based on the identified risks.

The method evaluation indicates that the proposed method is useful support for identifying risks associated with a PLM solution. Thus, it serves as a base for generating suggested proposals. Rather than giving absolute directions, the method serves as discussion-facilitating support.

5 Discussion

The chapter starts by answering the research questions, followed by stating the main contributions in relation to the thesis goals. Last, a discussion of the validity of the contributions is provided.

5.1 Answering the research questions

In the following section, answers to the research questions posed in this thesis are provided.

5.1.1 Roles and impact of requirements management

> ***Research question 1:*** *What is the role and impact of requirements management in a PLM implementation?*

An answer is found by analysing the challenging issues that result from not fully appreciating the complete role and impact of requirements management in a PLM implementation, as discussed in Paper A. The aim is not to provide a comprehensive discussion of the role and impact of requirements management in PLM implementation, but to highlight such roles that were particular relevant in a case from industry.

When different business divisions enter into an effort to implement a common PLM solution, consideration needs to be given to their different existing situations. Although all business divisions in Paper A previously had PLM solutions based on the same COTS system, the PLM solutions differed, both regarding processes and system functionality through configurations and customisations. Hence, seemingly similar PLM solutions differed fundamentally on several architecture layers. The failure of not acknowledging the existence of such differences may, for instance, as in the case in Paper A, lead to a project objective with inherent contradictions. Much literature emphasises the analysis and change of existing processes prior to implementing PLM (for example, Chen and Tsao, 1998). However, they commonly fail to highlight the possible existence of an almost endless variation of existing situations that may exist within a company and the work it requires when these variations are to be harmonised and supported by one new PLM solution. Thus, one role of PLM requirements management is to identify such differences among the involved business divisions and harmonise them, since failing to do so reduces the likelihood that the future PLM solution will meet the requirements of all users.

In cases where the new PLM solution is based on COTS software, consideration also needs to be given to the characteristics and boundaries of the COTS software (Bryan and Sacket, 1997). Existing and non-existing functionality, processes imposed or made impossible by the system architecture, and the graphical user interface are examples of areas that need to be investigated and needs to be compared with the existing situation. In particular, knowing what configurations are possible and whether different business divisions are allowed to have different configurations, is important. Not knowing the capabilities and limitations of a COTS system may, as in the case in Paper A, lead to an unnecessarily long and costly process of numerous development iterations until a solution possible to develop and suitable for all business divisions to deploy is reached. Hence, another role of requirements management is to highlight the possibilities and constraints of the new COTS system, and to do so in relation to the desired PLM solution.

Further, there needs to be an agreement upon the scope of change. Process changes might need to be mitigated between the involved business divisions, and changes subsequently might also be needed between the mitigated business processes and the possibilities and constraints in the COTS software. Rather than two strategies proposed in literature (Sääksvuori and Immonen, 2008), three strategies are possible to adopt: the business processes can be altered according to the COTS software; the COTS software can be configured and customised according to the business processes; or, as in the case in Paper A, changes to the COTS software according to the business processes can also be made by the vendor, although the delivery of such changes is difficult to check. Hence, a third role of requirements management is to allocate changes to the business divisions, to the PLM solution implementers, and to the COTS system vendors. Utilising the third option as well may reduce the need for costly configurations and customisations by the implementers.

However, requirements not only relate to the PLM solution, but also cover project requirements. Which process model to follow needs to be agreed upon. In the case in Paper A, a waterfall process model was selected for project control while an iterative model was selected for supporting solution design, and it was not agreed upon how the models should interact. Hence, another role of requirements management is to agree upon project work and control models and the interactions between them. Failing to do so may, as in the case in Paper A, lead to misinterpretations and schedules that are not followed.

To conclude, the role and impact of requirements management in PLM implementation is multi-faceted. Requirements management in PLM implementation bridges the gap between different business divisions, between business divisions and solution developers, and between solution developers and COTS software vendors. It covers PLM solution requirements as well as project requirements. Better management of those roles most probably enables improvements in the project outcomes. However, other activities, such as organisational change management and events external to the project, also have major impact on the outcomes. Hence, well-performed requirements management activities are essential, but not sufficient, for a successful project outcome.

5.1.2 Benefit of PLM implementation guidelines

An answer to research question 2 is found by first answering the three sub-questions.

> ***Research question 2a:*** *What PLM implementation guidelines are available from literature?*

Guidelines for PLM implementations are available from literature. In total, 24 guidelines were summarised in Paper B (see Figure 4-1). The list is not claimed to be complete; new searches may reveal more guidelines. As discussed in Paper C, guidelines (for example, for how to expand the PLM solution over time or how to facilitate design re-use) are missing and could be looked for.

Since several of the summarised guidelines deal with similar subjects, a categorisation of them may be beneficial in order to group them together. In Paper B, the guidelines were summarised without having a pre-defined subject structure. The summarised guidelines were subsequently grouped into the categories of project process, goals, system and process design, and organisation. In Paper C, the categories of goals and system and process design were instead merged into the aspect of PLM solution design. Neither of these two categorisations is mutually exclusive. The guideline 'Involve users from all departments and disciplines' may, for instance, affect both the organisation and PLM solution design. Future research could elaborate on a more suitable guidelines structure.

> ***Research question 2b:*** *To what extent are those guidelines relevant to PLM implementations?*

Guidelines need to be assessed in terms of relevance, from case to case (Pahl and Beitz, 1996). The relevance of the summarised PLM implementation guidelines were assessed in relation to a case in Paper B. In the paper, 20 out of the 24 guidelines were assessed as having high relevance to the case. Meanwhile, only two were assessed as having medium relevance and two as having low relevance. As such, it has been demonstrated that most of the guidelines were relevant to one case. Therefore, it is also likely that several of them are relevant to other cases. However, comparisons are necessary to strengthen that hypothesis.

Although the summarised guidelines were drawn from the PLM area, all of them are not relevant for all PLM implementations. In particular, it was argued in relation to the case in Paper B that the project would not have rendered improved outcomes if it had been broken down into sub-projects, or if a pilot had been performed. The magnitude of the project was simply assessed as relatively limited.

As demonstrated in Paper C, conflicts may exist between guidelines. Hence, a guideline's relevance to PLM implementations therefore needs to be assessed in relation to other guidelines. It is, however, unsure how such assessment should be made.

Research question 2c: *To what extent are those guidelines applied in PLM implementations? What are potential reasons for, and consequences of, the low application of relevant guidelines?*

Out of the 20 guidelines assessed as having high relevance to the case in Paper B, one was assessed as being applied to a high extent, five to a medium extent and 14 to a low extent. In the following, two examples of highly relevant guidelines applied to a low extent in the case are put forward, together with reasons for, and the consequences of, the low application.

As a first example, the case in Paper B took on the mission to replace one of their PDM systems. Due to financial constraints, the project made the decision not to change the business processes, since it was argued that not changing the business processes would reduce the project scope and thereby project time and cost. They thereby decided not to apply several guidelines ('improve processes prior or simultaneously with PLM projects' and 'align processes with system capabilities', for two examples) although they were aware of them. However, as a consequence of not altering the processes, the project was forced to conduct a number of complex customisations to the PDM system in order to accurately support the processes. Although the project had a strong focus on 'minimising customisations', with the PDM system out-of-the-box, it was impossible to apply to all business requirements resulting from the existing processes. The project sent several enhancement requests to the system vendor. However, they were still forced to conduct several customisations, and this led to increased project time and cost.

As a second example, it was initially believed that the project would only have a limited impact on the business. The project failed to apply the guideline 'carefully estimate the magnitude of change', simply because they were not aware of the change the project would impose. Though it gradually became evident that the business would have to change, the initial aim resulted in a very limited budget, which made it difficult for the project to deliver while maintaining decent quality.

In total, relevant guidelines are not applied in practice for three reasons. The first is a lack of awareness of the guidelines. The second is awareness of the guidelines but an active decision not to apply them. Finally, the third is awareness of the guidelines yet failure, despite the intent to apply them.

The low application of individual, relevant, guidelines in the case in Paper B led to negative consequences either in terms of increased time, increased cost, or lowered quality. Together, the 14 relevant guidelines that were only applied to a low extent had a huge impact on all three parameters. If more of the relevant guidelines had been applied to a higher extent, the case would have gained improved outcomes.

Research question 2: *Does, and if so, how does, an increased application of PLM implementation guidelines lead to improved outcomes in PLM implementations?*

Guidelines for PLM implementations exist in literature, and their relevance for contemporary PLM implementations is argued there as valid. Failure to apply individual, relevant, guidelines negatively affects the project outcomes, either in terms of increased time, increased cost, or decreased quality. It is therefore likely that projects can increase their outcomes in terms of decreased cost and time and improved quality of delivery by applying all relevant guidelines in a better way.

5.1.3 Evaluating PLM implementations using a guidelines-based approach

> ***Research question 3:*** *How may PLM implementation guidelines support identifying risks associated with PLM implementations?*

It is demonstrated in paper B that the set of guidelines worked on its own as a checklist and a discussion-facilitating support in a "post-mortem" evaluation of a conducted PLM implementation, by identifying weak spots in the project. Based on the identified weak spots, plans can be constructed for how to better follow the guidelines in future projects.

It is likely that the guidelines tool also can be used as a checklist during on-going and planning PLM implementations, and that it can facilitate transferring of knowledge between projects, as well as facilitating benchmarking between projects. However, more research is necessary to strengthen those hypotheses.

> ***Research question 4:*** *How may PLM solution guidelines support identifying risks associated with PLM solutions?*

A prerequisite for evaluating a PLM solution is to have a model of a PLM solution and to have some sort of assessment base to compare the model to. In Paper C, a subset of the PLM implementation guidelines, those regarding the PLM solution, were incorporated in a structured method, as an assessment base, to evaluate a PLM solution. Primarily, the method seeks to improve one PLM solution concept based on the risks that are identified, rather than to compare completely different PLM solution concepts.

It is demonstrated in the paper that the method support identifying risks associated with PLM solutions by indicating which guidelines risk not being fulfilled, although modifying the PLM solution to better follow more of the guidelines is not a trivial task.

5.2 Contributions and goals fulfilment

The goals of this thesis have been to facilitate an increased understanding of characteristics and challenging issues in PLM implementations and to propose, develop and evaluate methods and tools which can be used to improve the outcomes from PLM implementations. It has been identified that in-depth case studies of PLM implementations focusing on requirements management activities are needed, as well as methods and tools to evaluate PLM implementations and PLM solutions and summary and analysis of PLM implementation guidelines. These are the areas of contribution in this thesis. More specifically, the following main contributions have been made:

1. An in-depth description and analysis of a PLM implementation case, focusing on requirements management activities (Paper A)
2. An identification and analysis of challenging requirements management issues in PLM implementations in relation to the in-depth case description above (Paper A)
3. A summary of available PLM implementation guidelines from literature (Paper B)
4. An evaluation of the relevance of those guidelines to a conducted PLM implementation (Paper B)
5. An analysis of why relevant guidelines are not applied in PLM implementations (Paper B)
6. A demonstration of how PLM implementation guidelines can support identifying weak spots associated with a conducted PLM implementation (Paper B)
7. A proposal, demonstration and evaluation of a method to identify risks associated with a PLM solution, based on PLM solution guidelines and a layered PLM architecture model (Paper C)

5.3 Validity of the contributions

Having enumerated the main contributions of this thesis, some remarks are in place regarding their validity.

Regarding contribution 1, the description of courses of actions taken in the case in Paper A, with the rationale for and effects of those actions, is argued to be fair but not complete. There is of course not one single reason for many of the actions taken in the case, and the effects are not restricted to the ones stated in the paper. In addition, the material has been condensed; hence, pieces of information assessed as less important have been excluded from the description. However, the description has been presented to and reviewed by interviewees from GlobalGroup in order to avoid excluding events, rationales and effects of imperial value.

The requirements management issues identified and analysed in relation to the case in Paper B (contribution 2) are argued as being valid for that case, but they are not claimed to be valid for all PLM implementation cases. The context in which a PLM implementation is performed (for example, regarding the financial constraints put on the project) affects what issues arise. However, contributions 1 and 2 have been presented for another company with characteristics similar to GlobalGroup's, and the attendees there did recognize and acknowledge most of the presented requirements management issues.

Regarding contribution 3, the search for guidelines cannot be claimed to have been made systematically. For example, search words have not been used in a systematic fashion, and records of interesting journals have not been kept. It is therefore likely that new searches may reveal additional sources of guidelines. Also, when summarising the guidelines, all were not explicitly stated as guidelines in neat bullet lists. Some authors use the term recommendation instead of guideline (e.g., Zimmerman, 2008). Others have summed up what they refer to as experiences from their case (e.g., Berle, 2006). A third category provides success factors and pitfalls in running text (Pikosz et al., 1997, for example). Also, the lack of case descriptions in relation to many of the guidelines can lead to a certain degree of interpretation by the reader, and the authors' precise intentions behind the guidelines may not have been captured.

Nonetheless, the relevance of most of the summarised guidelines, as interpreted in Paper B, has been validated against one case.

Regarding contribution 4, the relevance of each guideline to the case in Paper B has been assessed on a three-level scale (high, medium, and low). The scale was detailed enough, given the available empirical data. The relevance was qualitatively assessed based on reasoning about how likely it was that applying the guideline would facilitate better project outcomes in terms of decreased cost and time and an improved quality of delivery. There is a risk that the assessment is unfair. However, the assessment builds on a solid understanding of the case. In addition, it has been presented to and reviewed by the study reference group.

Contributions 1, 2 and 4 may be transferred to the reader of this thesis and the appended papers primarily by recognition (cf. Svensson et al., 2002). Contribution 1 facilitates transparency and thereby the transferability of contributions 2 and 4, since it provides a context for the discussions.

Regarding contribution 5, the three identified reasons for why relevant guidelines were not applied in the case in Paper B are argued to be valid for that case as well as for other cases. However, it is difficult to categorise every unfulfilled guideline as being unfulfilled for one and only one of those reasons. The reason might differ depending on who you are asking, and there might be combinations of reasons rather than one single one.

Regarding contributions 6 and 7, it is not claimed that these methods are the most effective for evaluating PLM implementations and PLM solutions. However, in the absence of other methods, they should constitute a beneficial contribution. The aim has been to be as transparent as possible about the approach taken in demonstrating and evaluating the methods. Both GlobalGroup and GlobalCorp are large, multinational companies, with multiple sites and subsidiaries around the world. Both companies are experienced in PLM. Despite that experience, the methods could be utilised to identify weak spots associated with a conducted PLM implementation and to identify risks associated with a PLM solution. As such, this may be an indication that the methods are applicable to a wide range of cases.

6 Conclusions

The aim of this thesis has been to propose tools and methods to achieve improved outcomes from PLM implementations in industry. The aim has been fulfilled by developing and evaluating methods and a tool to identify the risks associated with PLM implementations in general and PLM solutions in particular. They have been grounded in characteristics and challenging issues in real and contemporary PLM implementations. In addition, they build on the hypothesis that successful outcomes can be facilitated by applying success factors in terms of guidelines for PLM implementations. Available guidelines have been summarised in a check-list that forms the foundation of the contribution in this work.

More specifically, the following conclusions can be made:

- **Roles and impacts of requirements management:** In the thesis, different roles and impacts of requirements management in a PLM implementation case are described and analysed. One particularly important role that was lacking in the case is to identify the multitude of existing PLM solutions in a company and to harmonise those actors participating in the project. Different company divisions using the same COTS systems does not automatically mean that their PLM solutions are identical. Seemingly similar PLM solutions can still differ fundamentally on several architecture layers (for example, regarding processes and information models). Failing to acknowledge and follow this role reduces the likelihood that the future PLM solution will meet the requirements of all company divisions. It is common that companies' desired future processes cannot be fully supported by the available functionality in any COTS system out-of-the-box. Changes are likely to be necessary. Another particularly important requirements management role is therefore to allocate those changes to the business divisions, to the PLM solution implementers, and to the COTS system vendors. Utilising all three of those options, rather than the first two alone, may reduce the need for complex customisations.
- **Benefit of guidelines:** Multiple guidelines for PLM implementations are available in literature, and they cover different areas, such as project management, PLM solution design and organizational change. In the thesis, it is shown that most of them are relevant to a PLM implementation case. It is also argued that several of the guidelines are most probably also relevant for other cases. The guidelines' relevance needs to be assessed from case to case. Furthermore, since conflicts exist between guidelines, the

relevance of each needs to be assessed on a relative basis. It is argued that not applying individual relevant guidelines has negative consequences, either in terms of increased time, increased cost, or lowered quality. Consequently, it is argued that the better application of a whole set of relevant guidelines leads to better project outcomes.

- **Evaluating PLM implementations:** In the thesis, it is shown that a set of guidelines can be used to identify weak spots associated with PLM implementations in the "post-mortem" evaluation of the same. The identified weak spots provide insight into how to better proceed with future PLM implementations. It is indicated that potential exists for using the guidelines in the planning and follow-up of PLM implementations as well. A sub-set of the guidelines (those regarding the PLM solution) can, together with a layered model of a PLM solution, also be used in a method to identify risks associated with tentative PLM solutions. As such, the methods and tool serve as discussion-facilitating support and direct a focus on areas in need of improvement.

7 Future work

The research presented in this thesis has prompted a few areas in need of future work:

- **Additional guidelines:** Having an initial understanding of how the application of guidelines may support PLM implementations, it would be beneficial to further expand and improve the guidelines set. The aim could be to secure a more coherent and more complete set of guidelines to evaluate more aspects of PLM implementations. Furthermore, the aim could be to find a guidelines structure that could aid in knowing what type of guidelines to search for and in placing the guidelines in relation to each other.
- **Influence of guidelines:** Knowing that the application of guidelines may have a positive effect on the outcomes of PLM implementations, the individual guidelines' influence on time, cost and quality needs to be further illuminated. How the application of individual guidelines affects the possibility to apply other guidelines also needs to be further addressed, in order to identify conflicts in the guidelines set.
- **Relevance and use of guidelines:** Given the limited number of cases where the guidelines have been validated, more test cases are necessary. With more cases, it should also be possible to clarify which case characteristics each guideline is relevant for. Also, it would be interesting to investigate to what extent the guidelines may support the planning and follow-up of PLM implementations, in addition to the "post-mortem" evaluation of conducted implementations. Finally, it would be interesting to investigate to what extent the guidelines can facilitate the transfer of knowledge and benchmarking between projects.

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