Case Study on the Relation of PLM Maturity, Architecture and Business Processes

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Abstract A study focusing on the three factors of product lifecycle management (PLM) is being presented. The selected factors are maturity of adoption, systems' architectures and product lifecycle (PLC) related businesses. The research material comes from six globally operating companies. The applied data collection method is the synthesis of interviews, benchmarking, and peer-reviewing the case companies. The material is analyzed with the application of comparative case study method. Modern PLM systems manage the data of fixed product items and the configuration knowledge of product families. Thus, companies with the most mature PLM approach are able to enhance the product configuration oriented business processes with legacy PLM architectures. Most of the studied companies are transforming their to single source architecture. This may be a challenge for some of the businesses. Another challenge is the increasing share of service related PLC businesses, which is also supported by the most mature PLM approaches.

Introduction

Product lifecycle management (PLM) was being studied through the analysis of six industrial cases. The focused factors of PLM were the maturity of PLM, business types and PLM systems' architectures.

Motivation was to find out the potential combinations of factors in the above. The research questions of the paper are: what kind of business processes are the main customers of PLM, how mature is the PLM approach and what kind of changes are taking place in PLM architectures of case companies?

The paper continues with literature review, which substantiates the research approach and outlines the details of the factors, which serve as a means of analysis. The research method is outlined and results presented. The conclusions summarize the findings, estimate the effects of the changes in the architectures of PLM systems and compare the aspired situation with the overall diversity of business processes taking place in the case companies.

Three PLM factors: maturity, business and systems architecture

PLM is the activity of managing products effectively across their lifecycle [Stark 2004] or a strategic business approach, which applies business solutions, collaborative creation, management, dissemination of product definition information throughout the PLC [CIMdata 2011].

Essentially, Product Data Management (PDM) is the core activity of PLM [Stark 2004] and PDM system an essential IT platform for PLM. A PDM project is composed of two main stages [Crnkovic et al. 2003]: evaluation and deployment. As the implementing and utilizing PLM is not only a software project, we consider PLM as a continuous process that comprises of several IT-projects, as well as strategic and organizational initiatives. Generally, the productivity of PLM is a sum of the efficiency of implementation projects and effects attained by the utilization of PLM in business. Hence, we chose to assess the maturity of PLM in different cases, the type of business and the architecture and integration of PLM subsystems (CAE, PDM, etc.).

PLM maturity

For this research, a four level PLM maturity model was put together by Vainio [2012]. It is based on the two models presented by Stark [2004] and Batenburg et al. [2006]. The five dimensions of the model characterize the state of PLM systems and organisations in a company. The synthesized model is presented in the Table 1.

Table 1 The PLM maturity definition model

	Level 0	Level 1	Level 2	Level 3
Application of PLM	Non-existent	Local initiatives exist, but there is no overall vision	Company-wide understanding of the importance of product data is taking shape	PLM is seen as a business problem spanning the whole product lifecycle
Involvement and understanding	From few to none people involved	Few people understand PLM	It is clear for everyone where the company is and where it wants to be	Widespread understanding of PLM in the company and in its extended enterprise
Organisational integration	No integration	Simple departmental integrations between some PDM tools	Integration between PDM tools and simple integrations with for example ERP	PDM tools are fully integrated and there is widespread integration with related systems such as ERP
Level of interoperability	Between individual tools only	On a departmental level	On a cross-departmental level	Across the extended enterprise
General description	There is no PLM investment and individual legacy systems are used.	PLM is realized as individual applications integrated on a departmental level. There is no overall PLM vision.	PLM is understood relatively well and integrated on a cross-departmental level	PLM is integrated across the supply chain. PLM is utilized in state-of-the-art ways, for example in a closed-loop fashion.

In the analysis, the position in the table above presents the maturity of the PLM in a company regarding the dimension of maturity.

Type of businesses

It is important to understand the business processes, because the industrial characteristics define the context of PLM in a company. This is why we characterize the main business processes into two main areas. The case companies create and deliver value by selling and delivering:

- Tangible products in the beginning of PLC.
- Service products (operations and spare parts) in the middle of PLC.

Service business has steadily gained importance instead of the plain manufacturing of investment goods. In practice, it is important to know the share of service business in a company's turnover.

In the sales-delivery processes the products can be engineered, configured and/or assembled to order or made to stock (ETO, CTO & ATO, MTS). However, the pre-recognized sub-domain of above characterization, which is typical for Finnish industry, is partial configuration, i.e. the use of configured products as sub-elements of projects. Therefore, the kinds of product definition processes for the analysis were

1. ETO in project deliveries
2. Partial CTO in project deliveries
3. CTO in ATO
4. Fixed / Standard products / MTS

The abovementioned typology of product definition does apply to both tangible products and services. Also services can be engineered or configured to order (e.g. in the upgrading of a plant or maintenance of an investment product) or standardized (e.g. standard service programs in automotive industry).

The architecture of PLM system

Vainio [2012] characterized the relations of PLM applications with the synthesis of two architecture integration models [Crnkovic et al. 2003, Bergsjö et al. 2006] as three major trends of integration: legacy, single source and service-oriented architecture.

Table 2 Synthesis of the architecture definitions and analysis of case PLM architectures [adapted from Vainio 2012]

	No integration	Loose integration	Full integration
Best in class	Has typically resulted in **Legacy Architecture** Case: *F→F'*	One to one *ad-hoc* integrations. Cases: *A→A', B & C→C', D*	One system as an integrator (standard integration interface). Cases: *C'', E''*
Peer to Peer		**Service Oriented Architecture** (SOA). Case: *B''*	
All in one			Typically **Single Source architecture**. Case: *A'', B', D', E→E'*

Table 2 illustrates which of the definitions are essentially describing the same architecture types. The synthesis is used in the analysis, which is presented also in the table (case state and transition in italics). For example, case company A will either remain to have loose integrations between best in class systems (*A→A'*) or transform to single source architecture (*A''*).

Research method and material

We applied different methods for collecting the raw data and for the analyzing of it. The data was collected with eight of structured interviews (3-4 hours) and six benchmarking sessions (six of each). The benchmarking sessions involved the participants of all the case companies. In a session the hosts presented the PLM approach of a company and answered consequent questions. The active audience (typically 15-25 PLM experts) consisted of practitioners, managers,

consultants, and researchers. The benchmarking sessions gave more accurate information on the PLM in a company than the interviews.

All the sessions were recorded, notes were taken and presentation material (e.g. presentation slides) collected. The collected data was processed and reported (6 reports of 20-30 pages). Four people were involved in the processing of the material. Their expertise varied from novice in transcribing audio recordings to senior researcher correcting the reports. Finally, the reports were sent for validation and verification to the interviewees. The reports were the basis of the analysis and therefore are the essential material for this research.

The application of benchmarking was considered positive by all participants. The practitioners got the direct feedback and insight on level of PLM in all the companies. So, they could attain other experts' ideas for the benefit of their own PLM processes. For the researchers there was a large set of experience taking place in the sessions. The quality of questions was high and new issues arose in the discussion resulting with a large set of material. However, the common themes are recognizable in the material.

The cases were analyzed with the application of comparative case study method. A more detailed description on the utilization of Qualitative Comparative Analysis (QCA) by Ragin [1987] for our purposes is presented in [Rissanen et al. 2012]. In short, the essence of the method is the set of truth tables documenting the properties of the cases with Boolean logic (best illustrated with the Table 4 of the results). The tables of the cases are summed up as matrices, which are comparable to tabular formats of other fields. The combinations of tables present the properties of cases with a matrix that is conceptually close to the utilization of morphological matrices in product development [Pahl & Beitz 1996]. The combinations of case properties are similar to possible configurations in matrix based product configuration methods [e.g. Bongulielmi 2003].

Results and analysis: maturity, processes and architecture

We present the studied cases with figures and tables, which are based on the frame of analysis, which consists of the factors of research. Each factor is dealt separately and conclusion combines them.

The maturity of the companies is analyzed in five dimensions represented with the five directions of the Table 3. The range of maturity is according to Table 1 from level 0 to level 3. The most mature PLM approaches were recognized in cases D, A and E.

Table 3 The PLM maturity of studied companies

Maturity vs. Cases	*A*	*B*	*C*	*D*	*E*	*F*
Application of PLM	3	2	2	3	2	1
Involvement and understanding	2	1	1	3	2	1
Organisational integration	2	2	2	3	3	2
Level of interoperability	2	1	1	3	2	1
General description	**2**	**1**	**1**	**3**	**2**	**1**

In the Table 3, the sales-delivery type is according to previous combination. Many of the companies utilized configuration in ETO projects, which is visible in the table (cases A, C & D). In these cases there is an indicator (1) in the both of the rows designated for ETO and CTO.

Table 4 The type of business vs. case companies

Business vs. Cases	*A*	*B*	*C*	*D*	*E*	*F*
Sales-Delivery type	2	1	2	2	3	1
- **MTS**	0	0	1	0	0	0
- **ETO**	1	1	1	1	0	1
- **CTO**	1	0	1	1	1	0
Service business > 50%	1	0	0	1	0	0

The share of service business is higher than the 50% of turnover in two companies (A & D). The share of turnover is characterized with options ranging from less than (0) to more than (1) half of the turnover. We had more accurate data on the share of service business that could be used in fuzzy-set QCA more precisely. Actually, the row presenting sales delivery type as a whole combines the approach with a more precise manner (1 for MTS, 1 for pure ETO, 2 for CTO in ETO, 3 for pure CTO). Concerning PLM architecture the present and future dimensions were presented already in the Table 2.

Conclusions

According to the sample of study the sales-delivery (ETO) projects applying partial configuration are the main customers of PLM. The most mature company (at least PLM wise) is making its turnover mostly by service business. Pure project based business seem to be less mature. However, the sample is small and statistic verification is impossible with it.

It seems to be a sound strategy to approach PLM is to first systematize products and processes along with the increase of PLM awareness and the readiness of adoption in an organization. Focusing only on changing PLM architecture may lead to mismatch that lies within the compatibility of IT architecture and the diversity of product lifecycle (PLC) related business needs the companies are running.

Obviously, maturity is a matter of aligned initiatives (see Table 3). A company cannot focus the one dimension of maturity and omit the development in another. In all dimensions the most mature company appeared to be the case D, which had started its PDM/PLM process already in early 1990's. However, the PDM/PLM process of another company (case F) had begun already in the same years, but the maturity of case F was much lower. Apparently, long history of

PLM does not ensure the maturity in a company. The companies that utilized configuration (in sales-delivery projects) had the higher degrees of PLM maturity.

There are some research findings that are not reported in the results of this paper. One of them is that the deployment processes are actually long chains of consecutive development projects. The consecutive projects can be considered as the reason of legacy architectures, which are comprised of several independent pieces of software integrated loosely by the companies, consultants and vendors.

Application integration is an important factor in PLM. The dominant trend seems to be the transition from legacy to single source architecture. This has advantages, such as data correctness and the ease administration of PLM systems. However, the disadvantages of the single source architecture, see e.g. Silcher et al. [2010] and Bergsjö et al. [2008], may lead to difficulties in the PLM processes of companies (especially with ETO products). The companies may not be aware or lack of trust in service oriented architecture.

Based on our study it appears to be so that the product configuration based businesses are supported quite well with legacy architecture. Moreover, the maturity analysis suggests that the dominant issues in companies are related to the management of PLM systems, which is one of the advantages of single source architecture. However, the notion that the emerging changes in PLM architectures may appear difficult to validate for some business functions. The role of PLM as the support of business processes should not be forsaken. Another future challenge is the configuration of services, such as maintenance and spare parts, in the middle of PLC. This requires the updating of PLM systems, e.g. data models. However, it opens new business opportunities instead of just relying on the limited markets of green field installations.

The applied research methods were very welcome way of collaborating between industry and academia. Especially the novel ap-

proach of benchmarking in data collection served all the participants. The analysis of the collected material appeared tedious. The crisp-set QCA seems to apply poorly to the material (see Table 3). Instead, for screening the material we used a frame consisting of three dimensions with values ranging from 0 to 3 (see e.g. Table 2, which is based on the PLM maturity dimensions). This approach could be transformed as a fuzzy-set QCA supported by a survey.

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