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Transforming ETO Businesses with Enhanced PLM Capabilities

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Abstract

This paper studies the specific Product Lifecycle Management (PLM) capabilities needed for the transformation of Engineered to Order (ETO) manufacturing towards Configure to Order business strategy. The material for the research comes from a project conducted with public private partnership. The four industrial companies that we studied engineer and/or manufacture highly customized products in low volumes with globally distributed networks. This is an industrial context, which requires specific PLM capabilities. The capabilities are essential for business transformation, broadening the utilization of PLM, and enhancing and maintaining the competitive edge of ETO manufacturing organizations.

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Keywords: ETO, CTO, PLM, Business transformation, Case study

1. Introduction

Improvements in productivity have been the result of industrialization, based on product and process development and standardization. The standardization enables the repetition of activities and re-use of engineering

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information in serial production. The productivity itself is the combination of efficiency of operations in the value-chain and the effectivity of the results of the operations as a whole. Especially the effectivity calls for high quality, up-to-date product knowledge, based on structured and contextually meaningful information and eventually on correct data [1].

In recent decades, the varying degrees of customization [2] and globalization have challenged the product and production development, resulting increased complexity [3]. There is an increase in the transfer of data and information both regionally and globally [3]. The high volume of data comes along with the variety of content and the modern information and communication systems make it possible to store and transfer large amounts of data. However, IT does not solve the problem of complexity and variety, but improved productivity in global manufacturing networks require enhanced generation and use of product and product lifecycle knowledge, information and data.

A key question in this situation is how to enable the transformation of business towards enhanced productivity in a business context? This research focuses on the capabilities of Product Lifecycle Management (PLM) in specific industrial context and therefore we formulate the research question as follows:

How PLM capabilities can support the transformation of Engineer to Order (ETO) business strategy by enabling enhanced productivity?

This question leads to sub-questions such as what is the ETO strategy, what are the PLM capabilities how they are related. In the remaining section of introduction, we address the conceptual definitions on these questions and present the results of case study research in chapter 2. Finally, concluding remarks (chapter 3) end the article.

1.1. The role of PLM briefly

The stream of the interrelated specifications and configurations of product information and data are the means of communication in the value chain [1, 5]. The configurations constitute the digital twin [6] of product throughout its lifecycle. All the lifecycle processes demand product and produce lifecycle data and information that can serve as the basis for lifecycle knowledge for product engineering. Kiritsis et al. call the management of this bi-directional process the closed loop PLM [7]. PLM integrates people, processes, business systems and information through a common body of knowledge [8]. In order to better utilize and reuse information for the extended product throughout the lifecycle, well-defined information packages/modules and mechanisms are needed to support product development and to coordinate business processes along product lifecycle.

The utilization of PLM has been slow and scattered in manufacturing industry, while automotive industry has been the forerunner of PLM. Consecutive studies in automotive industry show that the level of PLM use goes hand in hand with the level of PLM integration. The PLM champions have advanced in both the level of PLM use and in the level of PLM integration. The KPIs of PLM champions indicate higher productivity than the KPIs of PLM stragglers. [9]

We regard the PLM capabilities a combination of knowledge, process, software and skills to utilize the set of PLM functionalities, e.g. ECM functionalities, for specific purposes. They strategic assets that company or an organization can attain. An important factor here is the maturity of the PLM in an organization, but the maturity alone does not suffice. Moreover, a strategic aim gives the purpose for the PLM capability.

1.2. The industrial context of our research

The strategic choices of production approaches are highly determined by the level of customization in the manufacturing company. The degree of customer alignment is determined by the customer coupling point and the amount of customer-oriented information [2]. The more and the earlier the customer is involved in the business process (design–manufacturing–assembly–distribution), the more customer contact and information is needed. In addition, the types and forms of communication on product information is highly affected by these strategic choices.

An important customer-centric strategy in manufacturing is the Assemble-to-Order (ATO) or Configure-to-Order (CTO) strategy. In this case, the customer requirements influence the assembly/configure the activities directly, not the design and manufacturing process. CTO companies make products that satisfy the specific customer needs with a set of ready-designed components and modules [2]. Routine CTO processes and standardized and well-documented product definition knowledge ensure the communication and documentation of product instance [10].

In the Manufacture-to-Order (MTO) strategy, the customer requirements influence directly the manufacturing activities, not the design process. In the sales-delivery process, a MTO company usually offers potential customers a base product that it modifies according to the customer's preferences without actually changing the basic design. So, the degrees of flexibility and the modifications that may change the base product are defined in advance and the communication may be partially based on standard design documentation and identifiers.

In pure customization, the Engineer-to-Order (ETO) strategy achieve the most intensive customer orientation. ETO or project-based manufacturing is suitable for unique products that have similar features, and where the production relies on receiving a customer order and developing a technical specification accordingly [11].

The ETO projects consume lots engineering resources and lack repeatability, which the increased productivity requires. Product requirements and available information are key factors for business success and competitive advantage. However, requirements are always on the move. Customers often change their mind; market drivers change; authorities keep adding new constraints relating to environmental or safety concerns; and sometimes the project encounters difficulties that require a revision of the initial targets. There are several challenges in reusing (requirements) information, e.g. tracking and tracing of requirements in product-related structures, processes and applications [12]. Thus, the ETO project companies need a transformation towards systemic customization and CTO approach in order to be globally competitive.

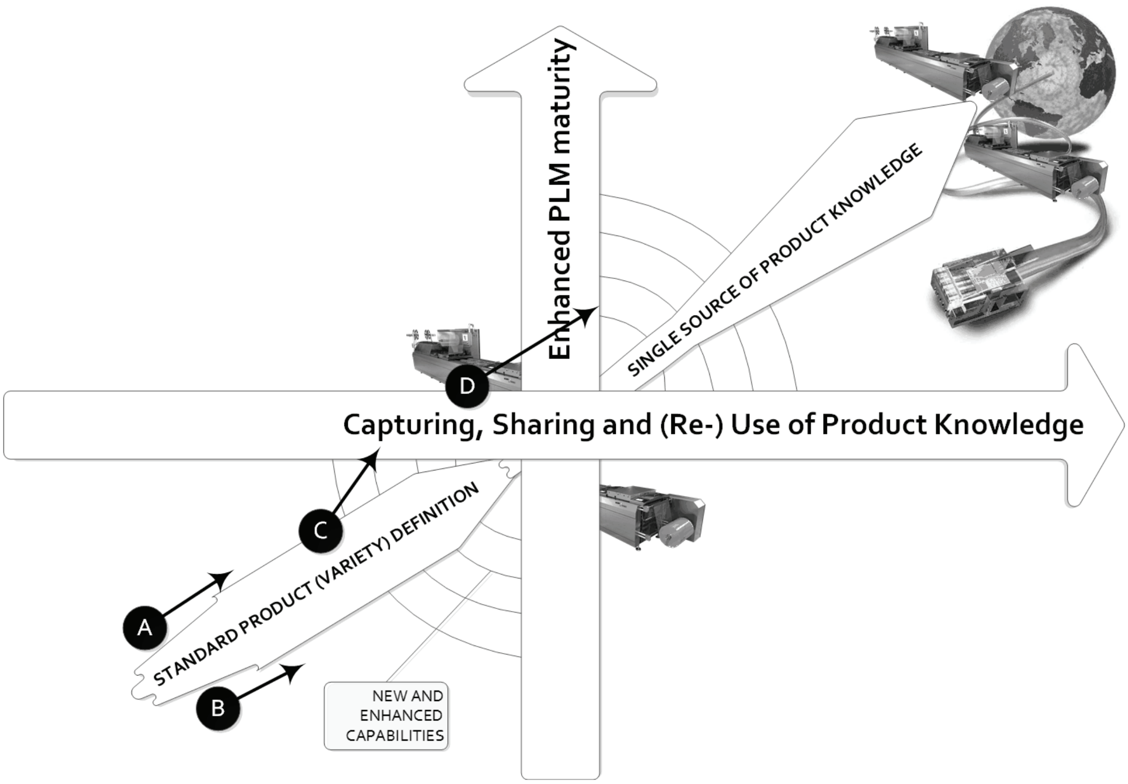

Figure 1. PLM capabilities for business needs: the transformation of manufacturing and new businesses

The case companies (A, B, C, and D) of this research can be characterized according to the business strategies above and the Figure 1. Two companies (A, B) were either beginning to utilize PLM and systematizing their ad hoc offering as standard product variety definition. The other companies (C, D) were enhancing the already existing PLM solutions towards a single source of product knowledge for the stakeholders of product lifecycle. The market shares of the case companies are quite high in niche markets and the products are investment goods, such as mobile machinery, equipment and cabin modules for production plants and ships. The volume of annual sales and production is quite low and fluctuating according to global markets. This is an industrial context, which requires specific PLM capabilities. The capabilities belong to two areas and the new generation of software products supporting the capabilities.

1.3. The enhanced capabilities for the business context

The utilization of PLM is hardly complete in any companies, because not all the present PLM functionalities available are taken into use and new potential is continuously under development [13]. First of studied PLM capabilities is business oriented PLM implementation models, which enable companies to plan, deploy and benefit from a PLM roadmap for managing a business producing low volume and high variety products more systematically.

Previously many companies have been involved with development projects that aim for demonstrations and prototypes of a modular product family definition. However, without strategic investment in the organization capabilities as well as systematic processes and tools, the demonstrations do not ensure the transformation. The second studied capability is broad re-use of product knowledge and design automation.

Third PLM capability, enhanced enterprise change management (ECM+), is a set of novel means that cover the life-cycle, networks and product types of a company. We focused the first two in the project, which meant proactive change management in product development and change management as defined in CMII standard with released products. The expanded 3D (3D+) models and intermediary virtual prototyping (IVP) that in itself is the fourth PLM capability, which can be utilized in many different positions over the product lifecycle [14] support this.

Location independent manufacturing and supply (LIMS) is a PLM capability that will enable new ways of managing factory plant and technology projects supported by new PLM platform based solutions. The new generation of software is aimed for the enhancing of collaboration within networks, design automation, and PLM system integration

1.4. Research approach and method

The material for the research comes from the project ProMaGNet conducted with public private partnership. The four industrial companies that we studied engineer and/or manufacture highly customized products in low volumes with globally distributed networks. The research approach was participatory as the researchers from four institutes took part in the sub-projects of the companies. However, this article is based on the final report written jointly by the researchers who collected the feedback from the practitioners of the projects and formulated the capability framework [15]. The approach has advantages as the knowledge on capabilities is not only academic but also practical, which is the nature of the research. Also, quick feedback on the capabilities could be attained. On the other hand, the objectivity of researchers can be called into question. However, the mentioned approach ensured quick peer review, because the researchers from different institutes took part in different sub-projects and capabilities. Also, the final report was reviewed by practitioners and thus the results were being double checked.

The effect of the capabilities is not yet based on strict follow-up figures, because all of the results of sub-projects had not been fully implemented by the end of the project. Also, the implementation of capabilities can be affected by many different aspects of companies, such as mergers and changes in the global economy, especially the global markets and supply networks of niche business areas the companies operate. However, in most cases the implementation of capabilities has been ongoing throughout the project and the developed capabilities appear to produce such kind of business impact that was anticipated in the business case studies of the participants.

2. The results: capabilities and the effect on business

The remaining paper deals with the specific PLM capabilities we defined with the industrial companies and how they affect the companies. We review each PLM capability briefly and present the findings. Finally, we combine the findings and present them in relation to case context.

2.1. Preparing for business transformation: capturing standard product variety definition

Repeatability and re-use by product configuration require the definition of re-used standardized design structures, the intention of re-use and setting up the means of re-use by supporting documentation and knowledge capture [16]. In the ETO context (companies A & C), this means definitions on processes and corresponding standardized and modular structures as well as the implementation of PLM to support the business transformation.

Low-volume & high-variety products are not easy to configure, because delivered systems are seldom or only partly modular, as they lack common modular structures. Supply/delivery projects could be modularized utilizing product platforms and process modularity. The question is: what are the factors differentiating 'project-based products' such that the earlier made designs cannot be reused? A typical answer is that the designs are not standardized or they are not easily available modules. In project-based (ETO) manufacturing repeatability at project level can be achieved through guidelines for process modularity, defined general interrelationships between common technical parameters, workflow commonality and shared data & information objects (Case company A).

Company C predicted that project business concepts based on modularity could allow a time decrease of even 20 percent for every repeated process. The modular manufacturing/construction concept could thus bring significant value-added to the normal stick built project concept. The company B achieved substantial benefits in process efficiency as well as in the savings of material and product stock levels. The company B also improved design process efficiency and design quality with own CAD environment development as well as by increasing integration between ERP - PDM - CAD systems. [15] These results indicate that it is a viable option to modularize not only products but also processes and to enable repeatability that improves the productivity of a project-based ETO company.

PLM systems and processes are vital in enabling the documentation and the means of reuse. For the case company A, which is taking steps towards systemic customization and CTO, the definition of the PLM strategy, processes and structures are necessities. During the project, a case company A defined a PLM strategy based on the business-oriented PLM concept for a project-oriented, low-volume and high variety manufacturing company. The impact of this is a higher awareness of PLM issues. The awareness did introduce the transition to systemic customization and prevented the many errors related to the learning-by-doing approach. During the project the company B recognized processes and structures in the organization that are not supporting life cycle business optimally, and on the other hand we developed new processes that cannot work without complete and accurate product data. The company B recognized PLM as a critical strategic factor in sustaining competitive advantage. On top of this, the company aimed to take the next steps and transform its organization toward creating value from product life cycle data, working on topics such as defining tangible and intangible products, applying new PLM functionality and moving gradually from the ETO to CTO business model. In addition, the company and researchers defined new approaches for service offerings, product lifecycle practices and digital services resulting a major impact on future development of new products and offering portfolio. [15]

2.2. Harvesting by broadening the utilization of single source of product knowledge and enhancing the competitive edge

When a company has initiated the transition from ETO to CTO, it is essential to leverage the potential of competitive edge broadly and to harvest the benefits in operations. The objective of an initiating project may have been the proof of CTO concept or the implementation of PLM system. However, a company has to fulfill the promises quickly and maintain the competitive edge. The benefits of repeatability have to be provided throughout the value chain and product portfolio. Furthermore, it is crucial to enhance the competitive edge by innovation and change management as well as by opening new possibilities for business generated by digitalization and improved product management.

In an earlier project an ETO-company (C) had developed a prototype system based on the parametric CAD skeleton model, which was further enriched by configuration software and optimization algorithms. The company C reported substantial savings in engineering hours, as the engineering took only a fraction of time that it used to take in previous sales-delivery processes [17]. The next steps in the transformation towards CTO the company C was aiming at broadening the use of the concept to other offerings and solutions. Essential part of this was taking into use the PLM systems, integrating the systems according to the value chain and design automation in the generation of manufacturing documentation to enable further steps in business transformation from ETO to CTO. In addition, the company was aiming at to support service business with the implementation of PLM. The company C reported that with the systematic development and implementation of PLM capabilities it had significantly improved the management of parametric and configurable product architectures. The company C recognized consequent improvements in the efficiency and quality of product development, because concurrent engineering practices, change management and knowledge sharing became possible [15].

Updating and maintaining product knowledge throughout product lifecycle are vital assets for a company. It is essential to provide means and methods for providing feedback from the product lifecycle to product development, e.g. closed-loop PLM. A company has to be integrate traditional methods for providing the feedback, such as engineering change management and integrated product development, to PLM. For this, we suggested ECM+ and 3D+ as the new concepts for PLM [15]. Fourth case company (D) that had both CTO and ETO businesses begun adopting the ECM+ and 3D+ concepts during the project. The company D reported that new product development indicators had made it possible to predict the potential of the benefits of production development at an early stage of product development. The company D estimated benefits be up to 10-times bigger than the invested cost in the first 2 years of a new product life cycle. This is due to cost reduction incurred due to lesser engineering changes in production ramp-up. The use of advanced 3D methods led to better quality in the manufacturing planning in the company and therefore short time to profit. The research on parallel structures (i.e. eBOM & mBOM) and factory simulation gave the company wider understanding on what implementing fully 3D-based production planning would mean for the company D. Especially, the characteristics of work load, system infrastructure and visual communications were addressed in the company D. Thus, the means of modern PLM appear to be viable capabilities in low volume and high variety production – not only in mass production.

However, with one-of-a-kind projects it is can be difficult to find such a common and repeatable set of requirements, designs, and eventually standardized objects that form the set of re-usable business items, which enable the enhanced efficiency of operations. In these kinds of cases (e.g. company A), all the knowledge about the manufacturing, maintenance, use, services and recycling should be standardized and modularized, if possible, and linked to the PDM or PLM system. Even organizations and business units can be the objects of configuration. Location independent manufacturing and supply (LIMS) is a concept that adopts the idea of intangible configuration objects that can be combined as plans, processes, specifications and documents concerning project deliveries. [18, 19]

2.3. Summary of results in industrial cases

It was estimated that the business impacts of PLM roadmap decrease lead-time even by 20% for every repeated process that is enabled by shared data modules, in a case company A. The repeatability of projects and earlier product-related data makes this possible. Thus, the business oriented PLM implementation models are a fundamental PLM capability for enhanced productivity. From the experiences of case company C, it can be estimated that systematic design re-use and automation save thousands of engineering hours over a relatively short period (0-3 years) if the capability is broadly utilized as a company-wide means of engineering industrialization. The capability of the broad re-use of product knowledge and design automation is another cornerstone of enhanced productivity.

Based on the data provided by the company D, we analyzed that systematic ECM processes, review practices and digital product models enable substantial savings in time and costs by preventing material shortages and errors (15-25%) from progressing to production and procurement. ECM+ is a capability needed for the maintaining the business transformation. The capabilities related to concepts such as 3D+ and IVP enable capturing and transforming product knowledge from all stakeholders, thus design and validation of product's downstream properties and processes already in virtual stage. 3D+ and IVP models structure and conceptualize value creation mechanisms and preconditions for PLM and digitalization of manufacture. Because the company can review designs at an early stage, the reduction of time to profit and costs is possible.

The company A predicted that competitive advantage for project and lifecycle business can generate substantial growth and profit in the future, when concepts like LIMS are implemented. However, the proof of this remains to be verified. In the software development, the requirements of the specific industrial context were being collected, analyzed and taken into account. All of the three software vendors that participated the project delivered new versions of their software.

Table 1. The case studies in relation with PLM capabilitiews.

Capability	Case A	Case B	Case C	Case D
PLM road mapping	**Active in roadmap**	**Active in defining PLM use scenario**	-	-
Re-use and automation of design	Studied and planned, re-engineering portfolio	Partially pre-existing, Tested new features	**Active in broadening**	Partially pre-existing
Enhanced Engineering Change Management	-	Studied	Studied and Planned	**Active in re-engineering ECM**
Intermediary Virtual Prototyping and $3D^+$	Studied	-	Studied & tested	**Active in testing and using IVP and 3D**
Location independent manufacturing (LIMS)	Studied & Planned	Studied	-	-
Integrated Set of Novel PLM Software	Implementation of basic PLM elements	Implementation of basic PLM elements	Novel software, integration	Pre-existing PLM Tested new features

Table 1 above highlights in which PLM capabilities the case companies were most active at the project. In relation to Figure 1 the PLM capabilities are in line to the assumption that the initial steps for transformation are investments (e.g. preparations, plans, studies, and implementations) and the further a company (C and D) have advanced the more specific capabilities are needed (re-use, change management, use of virtual reality, etc.). Companies A and B were active in introducing the basic features and functionalities of PLM systems and integrations, such as product data management, new CAD systems and integration to ERP. The companies C and D were implementing and testing new features, and broadening the use of already proven concepts (e.g. configuration tools, training CMII methodology

3. Conclusions

A company can use the PLM capabilities not only to prepare for business transformation but also to enable the transformation from ETO to CTO or partial CTO business strategy and maintain the chosen strategy. The indicators of the productivity increase of the case studies suggest that the PLM capabilities, which an organization has obtained, are vital in the stages of transformation. They may not be the trigger or the initiator of the transformation. Instead, a high-level purpose to all the case companies was the enhanced productivity of the lifecycle activities, such as engineering, sales and manufacturing, of high variety products with low volumes. The enhanced productivity is expected to result in the future, in all cases. When compared to the PLM benefits in automotive industry [9], the attainable benefits are similar. However, in automotive industry the utilization of PLM is not as transformative but more incremental than in ETO manufacturing business.

The industrial experts provided the estimations of the business benefits of the PLM capabilities. We base our analysis of the situation in the companies on the estimations. The presented research can be criticized on the lack of objectivity. However, the research process explained in the section 1.4 contained iterations and checks that enable the required objectivity of academic research. For example, we carried out several peer reviews in three research organizations in the analysis. There is substantial a reason to believe that development and utilization of PLM capabilities support the transformation of other companies with similar industrial context. Despite this, follow up studies on the progress of case companies is very welcome.

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