NordDesign 2016
August 10 – 12, 2016
Trondheim, Norway

Product Lifecycle Management – How to adapt PLM to support changing product development processes in industry?

Dr.-Ing. Michael Bitzer[1], Prof. Michael Vielhaber[2], Jerome Kaspar[2]

[1]Accenture GmbH, Germany
[2]Universität des Saarlandes, Lehrstuhl für Konstruktionstechnik,Germany

Abstract

Product development as a collaborative process which requires the contribution of multiple engineering disciplines within a design department and cross the enterprise network. In industrial practice, more and more companies are facing the need of a transformation from a pure part or component manufacturer to a system provider. At the same time products – parts, components and systems – are shifting from pure mechanical design to a systems design, including electric/electronic and software. Together with trends mainly known as Internet of Things, Industrial Internet or Industry 4.0 the industrial market requires a higher level of interoperability of designed products to be addressed by the product development process.
Product Lifecycle Management (PLM), a concept to manage product-related engineering data cross all phases of the product lifecycle, needs to adapt to be able to support these various emerging facets of the product development process. This paper will discuss from an industry perspective what can be leveraged from two other well-known concepts and approaches to support the evolution of PLM: Firstly, Systems Engineering as a concept to support complex product design cross engineering disciplines; and secondly Technology Management as a concept to support product innovation. Both concepts are well-established from a research point of view, but often implemented isolated within industrial companies. Implementing both concepts in companies not only as methods, but also in terms of processes and respective organization, can provide a big potential to cross-benefit PLM.
PLM as a combination of processes, methods, tools and respective organizations is focusing on the ability to manage product information and provides a defined set of capabilities to a company. At the same time these capabilities can be the prerequisites for a company to establish concepts in product design or innovation management.
The paper, as part of a series of research work, will elaborate on the challenges product development is currently facing, formulate requirements to PLM emerging therefrom, and propose an approach for evolving PLM developed based on an industrial client example.

Keywords: Product Design Process, PLM, Systems Engineering, Cross Engineering Discipline, Technology Management

1 Introduction

The manufacturing industry is still facing well-known and further evolving trends, such as globalization, increasing product complexity and shorter life and innovation cycles. New trends as Internet of Things, Industrial Internet or Industry 4.0 appear on the scene – cross industry sectors. Those new trends have a strong focus on the product itself and the manufacturing capabilities which are required to produce existing and new products [The MPI Group, 2016]. At the same time the product development stays a key success factor for manufacturing industries. But product development and their supporting functions and capabilities need to adapt to the new trends which are forming the environment a company is interacting within in future.

One of those supporting functions and capabilities is the Product Lifecycle Management (PLM) which enables companies to manage their product-related data throughout the entire product lifecycle.

This paper is part of a series of research work [Bitzer & Vielhaber 2013] [Bitzer & Vielhaber 2014] and wants to utilize existing and well-established approaches and methods of Technology Management and Systems Engineering in the area of PLM, Figure 1.

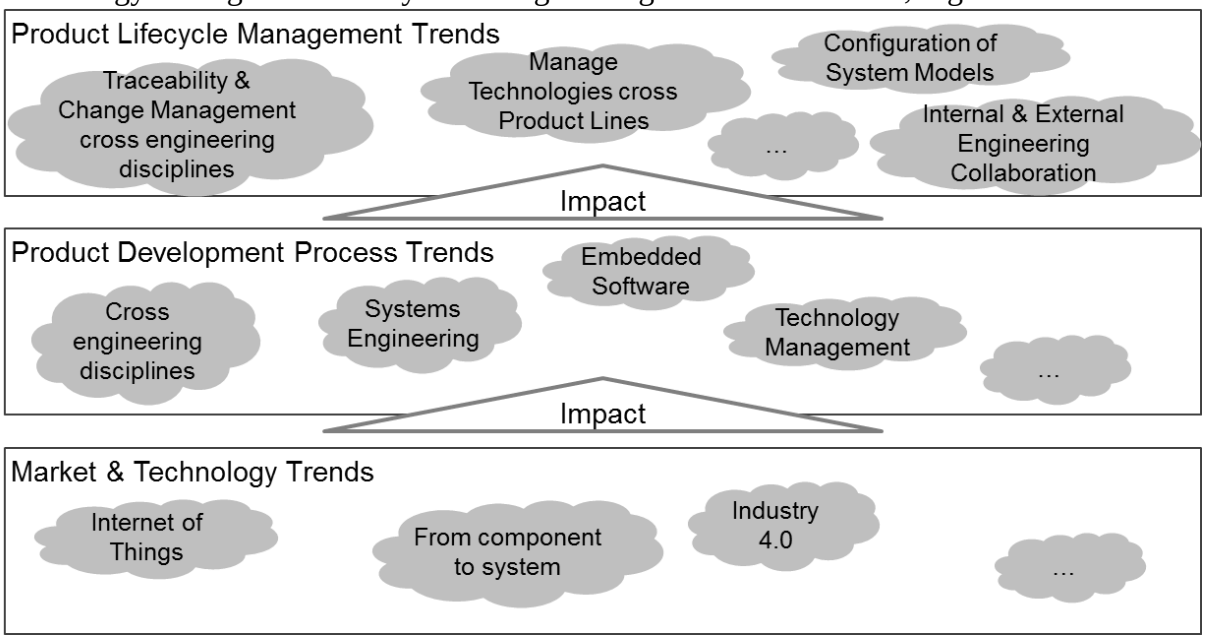

Figure 1. Market & Technology Trends impact Product Development Process and lead to trends which drive an evolution of PLM.

In a first step the scene is set by positioning this paper with regards to the "State of the Art". In the following chapter a new approach is presented which combines existing approaches to address the industrial requirements. Moreover, an industrial use case is discussed to illustrate the approach.

The paper concludes with a recapture on the research questions and an outlook on further research work in this area, including a link to the "Nordic Approach".

In order to address and structure the scope of this paper the following research questions are defined:

1. What are the operational challenges product development is facing from an industrial point of view?
2. How does PLM need to be adapted to bridge these operational challenges?
3. How can research help to address these points?

2 State of the Art – Research & Industry

Product Design Processes

Multiple methods for product design exist in research and literature and typically are tailored to single engineering domain, such as mechanics (Pahl / Beitz 1993) or electric/electronics (Gajski 2009). With respect to the German industry many globally successful manufacturing companies have a strong history in pure mechanical product design. For this reason, their entire organizational structure is tailored to their traditional core competencies. With focus on the Research and Development departments their core capabilities also are traditionally based on product development of pure mechanical design. In industrial practice the approach for product development according to VDI 2221is still a core methodology for product design (VDI-Richtlinie 2221, 1993) (Pahl / Beitz 1993).

With the introduction of the V-Model (VDI2206) to also reflect mechatronic systems as first step was done to take growing product complexity cross engineering discipline into account (VDI-Richtline 2206, 2004). According to Gausemeier mechatronic can cover mechanic, electronic, control engineering, software and material (Gausemeier 2001). A combined structure of V-Model and design methodology by Pahl/Beitz as described in (Rahman 2007) can provide a structure cross engineering disciplines and cross phase of product development process. While the V-Model today plays a major role in many engineering departments only part of the guideline often is implemented. The dimensions "model building/ tool" and "organization" often are not implemented in industry.

Product Lifecycle Management (PLM) in this paper is understood as strategic management concept for managing products along their lifecycle (Eigner, 2009) (Stark 2007) (Bitzer & Vielhaber 2011).

Integrated Product Structure

Depending on the product complexity of the traditional product portfolio manufacturing companies often faced different level of need to support their product structure management by stringent methods, processes and IT tools. With a traditional basis in pure mechanical products and a low product structure complexity (e.g. bearings) companies often are used to handle their structure management per design project with less or no predefined set of methods, processes or IT tools. According to many project situations this is very often the case – even today.

But business situations, such as product re-calls or material compliance cases, force companies to invest in their capabilities of traceability. One major building block of traceability according to (Eigner, 2009) is the capability to manage product-related structures along the entire product lifecycle.

Figure 2 illustrates the end-to-end traceability: starting from requirements, breakdown in functional bill of materials (BOM), Engineering BOM, Simulation & Testing BOM, Manufacturing BOM and Service BOM.

In order to fulfil business standards in configuration management by establishing full capabilities of traceability companies need to build-up also structure management cross engineering disciplines (mechanic, electric/electronic and software).

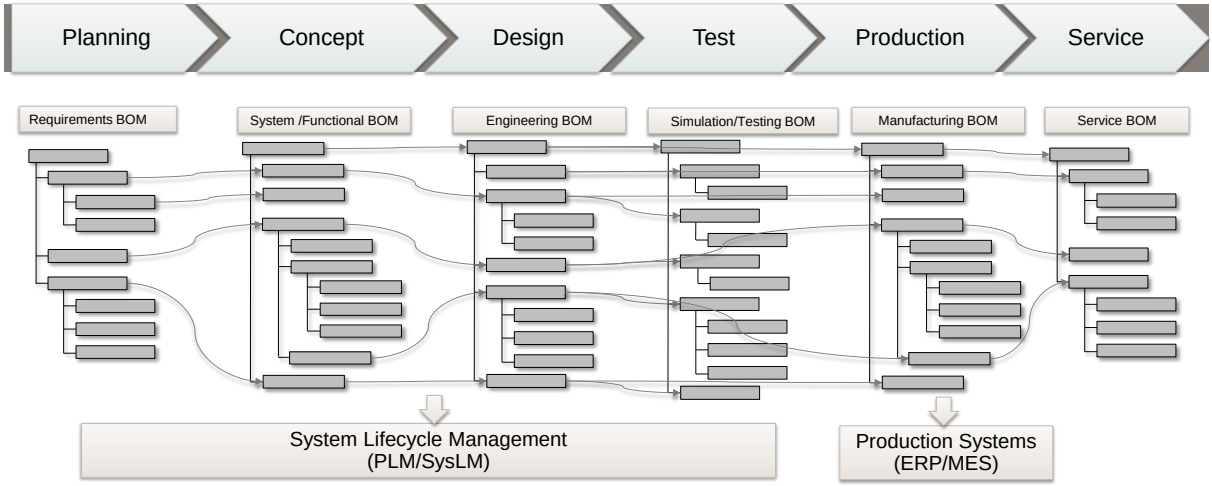

Figure 2. Traceability along the Product Lifecycle enabled by linked Structures (Eigner, 2016).

Integrated Product Ecosystem

Product Design currently is facing another tremendous challenge when it comes to the integration of so-called product ecosystems. In this paper the term "ecosystem" is used to describe the scope of product itself and the environment the product is interacting with, also see (Gausemeier 2008). As depictured below, the business models in industry have the ability to change in the upcoming years: today product design is facing at smart but standalone products. For many companies this is state of the art – but for many others, their core competence is still in the pure mechanical design. With the journey toward the so called "outcome based services" – which might only apply for a sub-set of the entire manufacturing industry – the scope that needs to be addressed by product design increases: from product, to services and to information & eco systems.

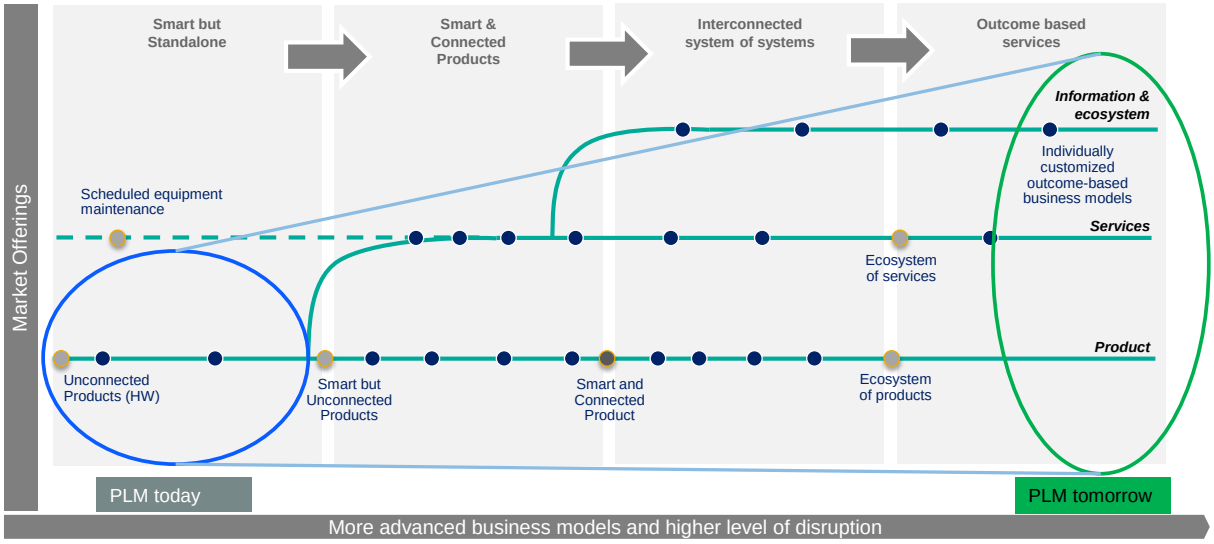

Figure 3. Evolution from Smart but Standalone product to Outcome based Services in Product Ecosystems (Bitzer & Maitin, 2015).

Operational Challenges

The above elaborated impulses describe the main operational challenges from an industry point of view in the context of PLM and can be summarized as follows:

- Today classical methodologies for mechanic product design is often well-established from a research and literature point of view. Form a theoretical point of view the V-Model also provides guidelines for mechatronic product design. In industrial practice often the implementation or adaption of these guidelines is not well-established. The challenge is how to bridge the gap "between research and industry".
- Moreover, the integrated view on the product data is often not ensured in many companies. Fragmented creation and management of product design relevant information is often state of the art in industrial environment. Product compliance certificates often are only feasible by enormous manual effort in tracking product design data and reflecting traceability.
- With regards to trends that change the scope of products towards interconnected systems of systems and outcome based services, product design is also impacted by this change. Companies need to adapt also their capabilities in managing PLM within this context.

3 How to adapt PLM

Systems Engineering

The concept of Systems Engineering is often interpreted in various ways in industrial practice. Following the definition of the German Association for Systems Engineering (GfSE) as German Chapter of INCOSE, in this paper Systems Engineering is an interdisciplinary approach and means to enable the realisation of successful systems (GfSE 2016).

Systems Engineering is a concept to bridge the traditional engineering disciplines (e.g. mechanic, electric, software) and allow the product development to design and manage products and its related data as "one system".

As elaborated above from research point of view many aspects of Systems Engineering are defined and documented as of today. Especially with the focus on Germany, many companies are in a very early phase of adaption of these concepts and guidelines and partially struggling in the operationalization of those. Those companies need to establish the System Engineering concepts not only on in their engineering methods (how to design "systems") but also in their entire so called "Operating Model". With the Operating Model companies define how to set-up the organizational structure and operations. The following figure shows typical elements of an Operating Model from an industry perspective.

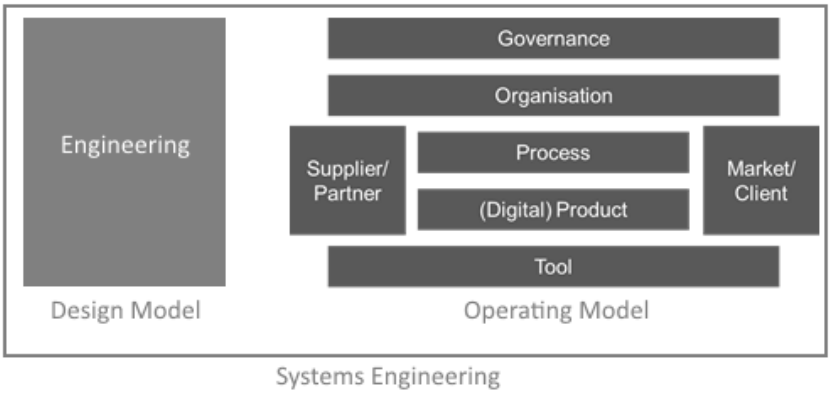

Figure 4. Typical elements of an Operating Model in Industry which need to be addressed beside the pure focus on the Design Model within the context of Systems Engineering.

When Systems Engineering concepts are applied in an Operating Model, this needs to be adapted to the PLM concepts in the company to be able to support the product development process accordingly.

- Elements "Governance & Organisation": Systems Engineering often leads to new organizational structures and roles within a company. Typically the System Engineer is one of the first new **roles** which is implemented. PLM needs to reflect these new roles and organizational structures to support core engineering capabilities like Release and Change Management also on "System Level".
- Elements "Supplier/Partner & Market/Client": **Engineering Collaboration** in both directions is a key success factor for many companies – already today. With Systems Engineering these capabilities are facing a next level of complexity and relevance, when it comes to collaboration and exchange of entire system models. PLM needs to be able to also support these process capabilities, by providing Engineering Collaboration capabilities, such as data exchange, simultaneous engineering, and baselining.
- Elements "Process & (Digital) Product": Focussing on the VDI 2206 V-Model new process steps need to be performed to cover the system design. For example the development of the **system architecture** is a process step that is new for Systems Engineering and was not required in that depth for pure mechanical products. From process and product data point of view PLM needs to be able to reflect the entire digital product with all kinds of systems and sub-systems along the product development process.
- Element "Tool": Form an industry point of view Systems Engineering is supported by authoring tools for **Model based Systems Engineering** (MBSE) – for example: PTC Integrity Modeler (PTC 2016). The concepts of PLM traditionally have a strong background in IT tools and a very strong aspect on the "integration" of surrounding tools, such as different kind of authoring tools.

Technology Management

"Technology Management" covers aspects to handle technology oriented development and innovation. With a strong background in economic research this approach is on the one hand well-defined in research but rarely established in engineering departments within industry sectors. Technology management describes all activities and methods which are required to make a certain technology usable for industries. A technology describes the fulfilment of a requirement by a technique. Both terms are used in literature and business context not distinctly. In this context the term technology will be used also as a representation of a technique.

The Technology Management Process describes the activities within technology management, see figure 4. In research and industry literature several variants of the process are presented. Currently the focus in management of design information is the single product or product families and their related information. There is no doubt that this information is a key element for companies in the discrete manufacturing. But looking into innovative and successful companies the potential of capturing information on a more abstract level – cross products and product families – and thereby transfer and further develop it from one product release to the next promises a huge impact.

The Technology Framework is an approach to support product design information, introduced in [Bitzer & Vielhaber 2011] [Bitzer & Vielhaber 2013].

To apply Technology Management concepts in the context of PLM not only the well-established Technology Management Process needs to be established. As proposed in [Bitzer 2011] [Bitzer 2013] additional building blocks need to be investigated and defined – which are bundled and introduced as the Technology Framework. The following building block have impact on PLM and describe how to adapt PLM concepts.

- The Technology Object as a core building block of the framework reflects key product design information on the technology layer. PLM needs to be able to reflect not only product-related information (product geometry + properties) but also technology-related information. This information needs to be managed cross product lines and in many cases cross business unit within one company or even cross companies.
- The building block Methods & Processes utilizes the defined elements of the technology object and defines the way of using the objects by engineers and end-users. Moreover, behavior and rules per object and in structures of objects will be described. PLM concepts need to be able also to integrate these kind of information and approaches.
- The Organization building block addresses topics and requirements that are related to the business organization where the technology framework will be used. The focus here will be on a single entity (e.g. a company or institution) – in contrast to the next building block. Governance and ownership of technologies that can be leveraged in multiple product lines or cross company boundaries might be typical challenges in this building block. For a set-up of PLM these organizational and governmental aspects need to be included in the PLM scope as well.
- The building block Environment covers the interacting area within a network of entities (e.g. companies, supply chains and interaction with customer and market). This building block is in the focus of PLM and its Engineering Collaboration capabilities and need to cover this.

4 Revolution or Evolution of PLM?

As elaborated above, product design is facing tremendous impulse and PLM needs to adapt to continue in supporting product design successfully. With respect to many different client situations cross Europe, greenfield approaches to PLM may have no chance for realization. Thus, for the upcoming years, PLM is facing more an evolution than revolution.
Many companies start to understand PLM beyond just IT as an organizational change and the need to change the organization. With a strong focus on business value and the changing business models as depicted above, companies are implementing not only tools, but also respective processes and organizations – to establish a holistic PLM operating model. (Stern, 2014)
As described in (Bitzer & Maitin 2015) also from functional point of view the PLM Evolution needs to happen according to the needs and changes of the product design – here: from customizable product to connected product eco-systems.

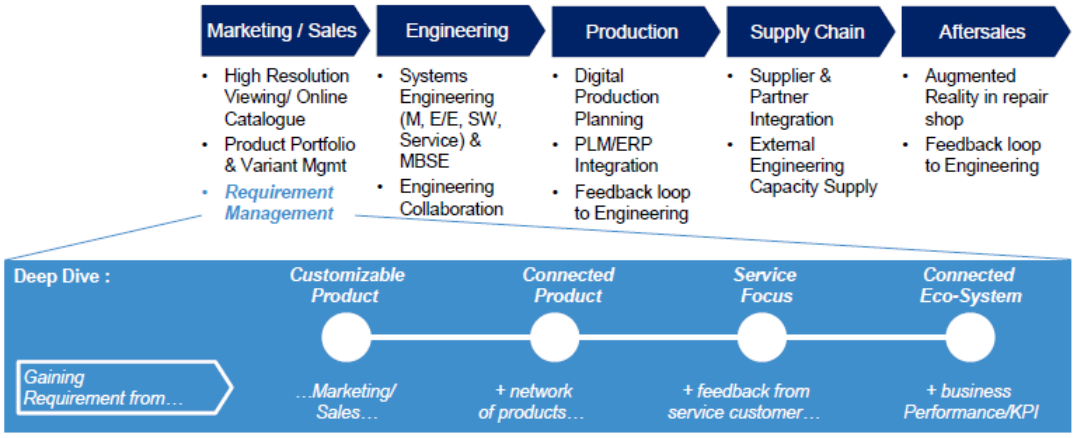

Figure 5. Evolution of PLM Capabilities needs to reflect the evolution of product design and product eco-systems (Bitzer & Maitin, 2015).

Industrial Example

The PLM Evolution that requires the integration of Systems Engineering and Technology Management concepts is shortly presented in the following paragraph based on an industrial example.

Today the company is facing the situation that the majority of the product portfolio is based on pure mechanical products. With the trends of Internet of Things or Industry 4.0 the client needs to prepare for mechatronic components within its products. For this reason the client needs to ramp-up Systems Engineering capabilities within the next couple of years. At the same time the client needs to adapt the PLM capabilities to support the product design process also in future.

Moreover, with mechatronic components new types of technologies are introduced to the company. These new technologies need to manage – cross product and product lines. To cross-leverage those technologies they need to be made transparent and traceable within the entire company. For this reason new PLM capabilities need to be build-up to be able to reflect those kind of information.

As the next step in PLM Evolution the client identified the market trend to provide and sell services instead of discrete products. With a long-term perspective client needs to build-up capabilities to close the loop of data which is created or monitored by the product infield back to product design process. The client example underpins on the one hand the need of a PLM Evolution and on the other hand provides concrete examples how PLM needs to be adapted from an industrial point of view to be able to support product design process also in future.

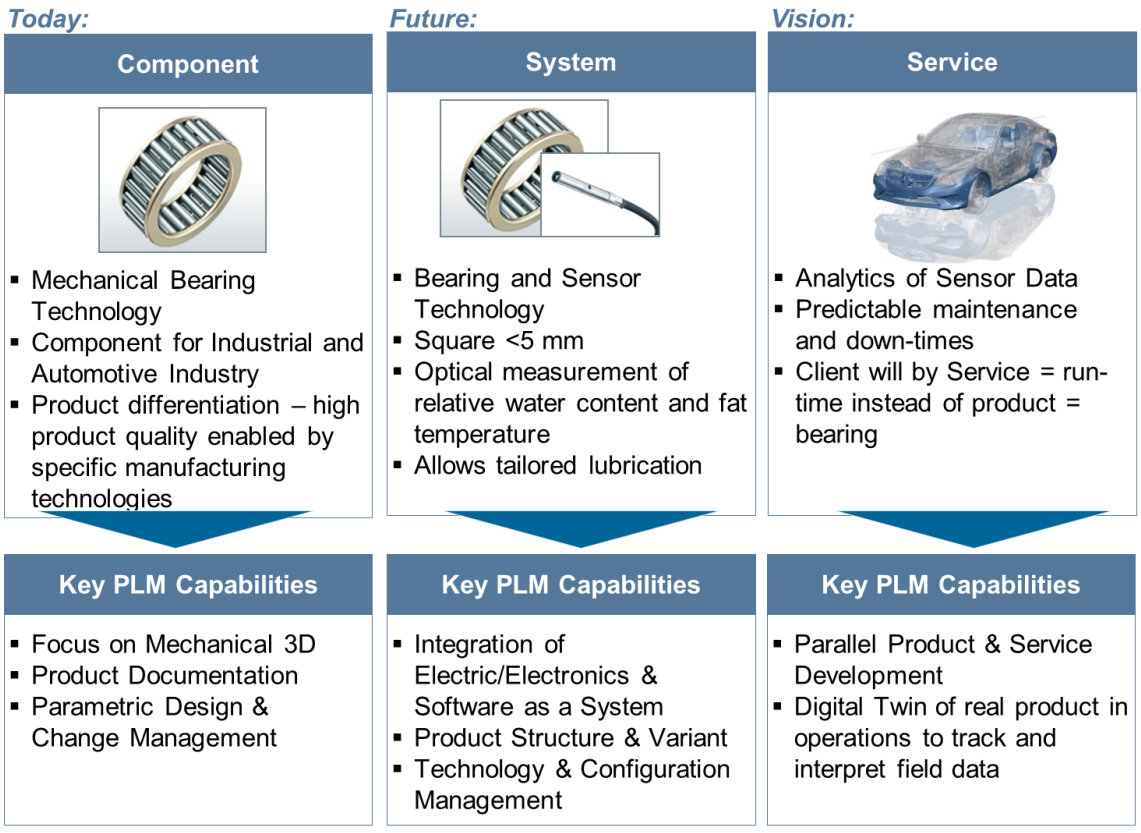

Figure 6. Example of a client case – Evolution of product, product design and related PLM capabilities.

5 Conclusion & Outlook

The paper was introduced with the objective to underline the need to action and research on the area of how to adapt PLM to support product development process in industry, leveraging both well-established approaches: Systems Engineering and Technology Management. Chapter 2 presented the current state of the art in terms of product design process, integrated product structure and product eco-systems. Moreover, operational challenges from an industry point of view were described. Elaborating potential areas of adaption of PLM in chapter 3 both concepts of Systems Engineering and Technology Management were introduced. By this the main gap of existing approaches in research and industry is described. Chapter 4 covers impulses of the PLM Evolution which helps to cross the described chasm – underpinned by a client example.

To recap and derive a conclusion on the research work presented in this paper the defined research questions are discussed in the following.

1. **What are the operational challenges the product development is facing from an industrial point of view?**
   This paper firstly discussed the shift from pure mechanical product development to mechatronic product development for many discrete manufacturing companies. Secondly, the operational challenge of an integrated view on the product – cross engineering disciplines and with respect to technology used cross product lines. Finally, the shift from product-centric towards eco-systems, which can include multiple technologies, components and systems within and outside a single product, is described.
2. **How does PLM need to be adapted to bridge these operational challenges?**
   Derived from the elaborated operational challenges in this paper and flanked by the well-established – but often stand-alone – concepts of Systems Engineering and Technology Management, concrete areas are described where PLM needs to be adapted. Finally, underpinned by a client case the direction of impact for such a PLM Evolution is shaped.
3. **How can research help to address these points?**
   This paper described in the state of the art relevant requirements for the next evolution of PLM. From a research perspective these requirements could be addressed to allow PLM to evolve according to challenges that occur due to changing product development processes.

To summarize, as stated before, this paper is part of on-going research work and provides first boundaries in terms of research scope and underlying business need. Discussions within the research and industry community show a high level of interest and relevance of this research topic.

In order to further bridge the gap between academic research and industry not only this paper is part of this exchange, but also an association was established to support this exchange: Network of Virtual Product Engineering. (Bitzer, Langlotz & Handschuh, 2014) According to our understanding, this network, similar to the **Nordic approach to design and product development**, covers one academic PLM Institutes in Germany and various PLM Experts and Managers from different companies. Looking forward, this may help to identify and leverage more and more areas of collaboration to create advantages and values for industry, academic and education.

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