

Process oriented framework to support PLM implementation

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Abstract

Product lifecycle management (PLM) innovates as it defines both the product as a central element to aggregate enterprise information and the lifecycle as a new time dimension for information integration and analysis. Because of its potential benefits to shorten innovation lead-times and to reduce costs, PLM has attracted a lot of attention at industry and at research. However, the current PLM implementation stage at most organisations still does not apply the lifecycle management concepts thoroughly. In order to close the existing realisation gap, this article presents a process oriented framework to support effective PLM implementation. The framework central point consists of a set of lifecycle oriented business process reference models which links the necessary fundamental concepts, enterprise knowledge and software solutions to effectively deploy PLM. © 2007 Elsevier B.V. All rights reserved.

Keywords: PLM; Business process; Reference model

1. Introduction

Product lifecycle management (PLM) is defined as a concept for the integrated management of product related information through the entire product lifecycle [1]. This vision is enabled by recent advances on information and communication technologies and is needed to support current industry needs for faster innovation cycles combined with lower costs.

Although PLM has recently attracted a lot of attention both at industry and research because of its potential benefits to cope with current manufacturing challenges, the promise of PLM has yet to be realised in most organisations [2]. The limited results of current PLM implementations lie fundamentally in three main causes. First, PLM is a complex concept and there is still a lack of deep understanding of what it really means in practice. Second, many current PLM initiatives focus primarily on isolated aspects, such as document management or parts classification, without the necessary holistic approach to the whole product lifecycle and its underlying processes. Finally, there is a research and literature gap regarding PLM implementation issues.

In order to fill this gap for implementation support, the purpose of this article is to present a process oriented framework to support PLM implementation. This conceptual

framework links the existing initiatives and recent research results into a comprehensive and logical structure, which is based on business process reference models.

1.1. PLM state of the art and lack of implementation support

Although PLM is a new theme, it stems from computer integrated manufacturing (CIM) and engineering data management [3]. The original CIM definition from the beginning of the 80s introduced the idea of integrating the engineering and production systems and data [4]. The initial attempts to implement comprehensive CIM solutions failed, but the integration as the core fundament of CIM has since then been considered in the evolving IT solutions and related management concepts, including the recent emergence of PLM [5].

PLM is defined as a systematic concept for the integrated management of all product related information and processes through the entire lifecycle, from the initial idea to end-of-life [1,6]. The aim of this integration is to overcome the existing organisational barriers and to streamline the value creation chain [7].

Most authors currently agree that PLM does not only refer to an individual computer software, but, moreover, it is related to a broad management concept which depends on the integration of multiple software components [1,5,6]. The IT solution to

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support PLM results from the integration between enterprise resource planning (ERP), product data management (PDM) and other related systems, such as computer aided design (CAD) and customer relationship management (CRM) [8].

Nevertheless, a recent survey with 54 system vendors demonstrates that one third of the vendors currently position themselves as providers of PLM solutions [9]. The confusion between PLM as a broad concept and PLM as mere software application, and the lack of transparency in the software market are some of the factors that hinders PLM comprehension and, therefore, its implementation in practice.

PLM has been approached from multiple perspectives, ranging from methods and process specification for partial PLM aspects to detailed technical issues at software integration level.

At the methods and process level, Schuh et al. [10] position the product structure as a core discipline of PLM, as it structurally connects the modules, items and information of a product. Eigner and Stelzer [11] consider the management of the product configuration over the entire lifecycle as an integral part of PLM. Xu et al. [12] emphasize the cost tracking and analysis associated with each phase of the product lifecycle. Other authors also apply the lifecycle perspective in order to analyse the environmental impact of products [13].

At the technical software integration level, McKay et al. [14] present a product specification data model to support the transition between product requirements to design at early development stages. Eynard et al. [15] explore the advantages of using an object-oriented approach and UML diagrams to specify the product structure and workflows for a PDM implementation. Aziz et al. [16] analyse the application of open standard, open source, and peer-to-peer solutions to support collaboration in product development considering a PLM context. Kiritsis et al. [17] describe the potential of smart embedded systems to collect product data during its use in order to close the lifecycle information loop.

The analysis of the existing PLM literature indicates that the implementation issues, placed between the process and software integration levels, have attracted little attention up to now. Therefore, there is need for deeper research and support regarding PLM deployment, change management and education [2].

1.2. PLM implementation status at industry level

Data collected from multiple primary and secondary case studies indicates that PLM implementation is still on its initial stage, mostly focusing on partial aspects and still based merely on PDM software.

The results of a wide survey in the automotive industry have shown that there is a wide gap between the current implementation status and the state of the art. The gap is greater in other segments like the machinery industry, especially at small and medium enterprises (SMEs) [5]. Scheer et al. [3] present a series of eleven cases studies, where most of the examples focus on partial PLM aspects, like reduction of product variants, parts classification and product change management.

The data collected at primary case studies conducted at small and medium European manufacturing companies in the scope of this research (a niche player at the rolling bearing market and a pump manufacturer) also shows similar results. Although the observed initiatives are aligned with a broad vision of PLM, there is still need for a full and coherent PLM implementation.

2. Application of the business process paradigm to PLM

A process is defined as a group of structured activities that result in a determined product for a specific client. It generally involves activities from various functional departments across the organisation and has a clear customer orientation [18]. Throughout business processes, product data is generated. Therefore, the description of the enterprise processes builds the ideal foundation for PLM strategies [3] and is considered the suitable underlying paradigm for the proposed PLM framework.

The identification and modelling of enterprise processes can be used as an efficient tool to capture and share process knowledge within the organisation [19]. A business process model is a representation expressed through the formalism specified by a modelling method. A special class of enterprise models is formed by more comprehensive and generic models called reference models, which may be used as the basis for the development or evaluation of specific models [20]. Adaptable and reusable reference models for PLM processes set the basis for the proposed framework presented in the next section.

3. Process oriented PLM framework

The proposed conceptual framework to support PLM dissemination and implementation links the existing initiatives and recent research results about PLM on a comprehensive and logically structured whole. It comprehends the necessary elements to enable PLM realisation and can, therefore, be used as a guideline for implementation initiatives at the industry.

The framework results from a series of research initiatives and industry projects conducted during the last 5 years at WZL (Laboratory for Machine Tools and Production Engineering) in Germany and at Advanced Manufacturing Nucleus (NUMA) in Brazil. The results are drawn mainly from the following four projects: the definition of PLM reference models in an applied research project, whose main objective is to transfer research results to SMEs (financed by the German Research Foundation); the specification of vendor neutral IT requirements for PLM and the analysis of existing PLM solutions (in cooperation with Trovarit AG); the systematization of PLM knowledge and the specification of a teaching curriculum for PLM education (supported by the State of Sao Paulo Research Foundation); the development of a PLM implementation methodology for SMEs (supported by the German Academic Exchange Service and the Brazilian National Council for Scientific and Technological Development). Some of these projects are still being carried out and the proposed framework takes advantage of partial available results.

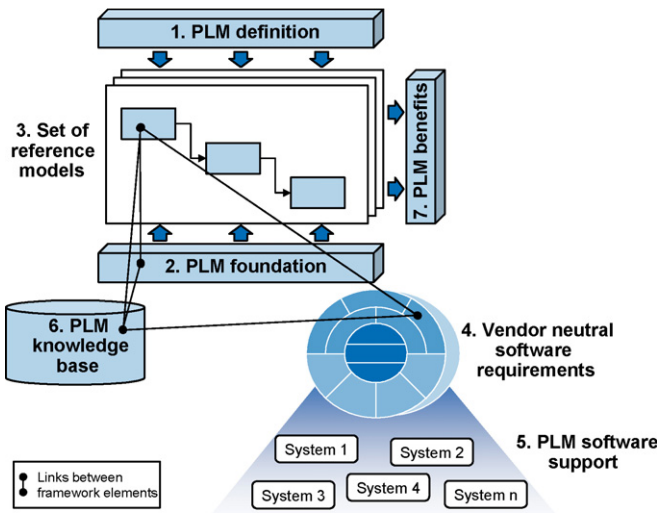


Fig. 1. Elements of the PLM process oriented framework.

The proposed framework comprehends seven elements: a tangible definition; the specification of the fundamental concepts (PLM foundation); a set of process reference models; a list of vendor neutral software requirements; the profiles of specific software solutions (PLM software support); a knowledge base; and the specification of the potential benefits. Fig. 1 presents the elements of the framework and their interrelations.

The PLM definition provides the boundaries within which the reference models are detailed. The PLM foundation is based on a robust specification of the product structuring that provides the necessary fundament for the implementation. The set of process reference models is located in the middle of the framework and integrates its other elements. It provides different reference models varying according to a group of characteristics of a company (sector, size, order type, etc.) which coherently define typical industrial enterprises. The vendor neutral software description consists of a structured catalogue that lists the software requirements needed to support process activities. Detailed software profiles and capabilities to support PLM have been identified in relation to the neutral functional representation. The knowledge base supplies the necessary material to support training. Finally, the PLM benefits show the potential competitive advantages related to each reference process. A detailed description of the framework elements is provided in the following sections.

3.1. PLM definition

Although a generally accepted PLM definition already exists (see Section 1.1), it must be further detailed to a level in which the concrete meaning for the industry is made clear.

Fig. 2 describes the seven key elements of the detailed PLM definition considered in this research. It is built on previous PLM definitions as a concept to the integrated management of product data over the complete lifecycle (see [1,6]), but goes a step further, as it details the necessary elements to close the lifecycle information loop.

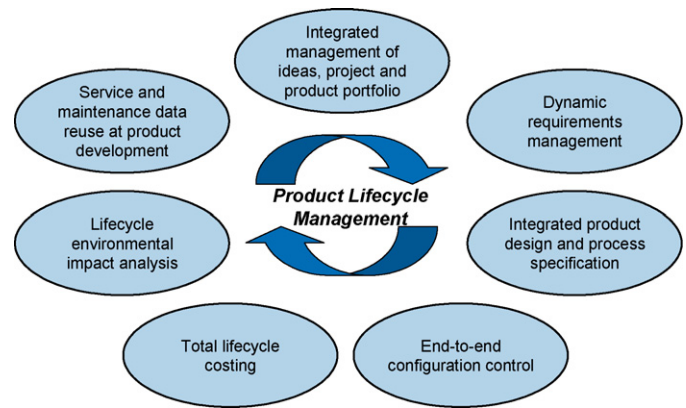


Fig. 2. Elements of the PLM definition.

The first element on the top of Fig. 2, *integrated management of ideas, projects and product portfolio*, enables the upfront planning of the product portfolio in accordance with the project capacity and the stream of new ideas. The feasibility analysis of new ideas must also consider the resources availability to conduct its development project and the idea fit into the product portfolio [21]. The other way around, gaps in the future product offering indicate the need to streamline idea generation and project execution. The integration of the ideas evaluation with the capacity planning and the portfolio management allows the identification of existing interdependencies and, therefore, enables fast company reaction to market shifts.

Requirements management supports the clear definition of product specifications. This discipline has gained importance as product development activities are increasingly spread over the extended supply chain [14,22]. An efficient requirements management demands the consideration of the stakeholders needs since the beginning of a new development. Moreover, the requirements evolution must be controlled [23]. In this sense, *dynamic requirements management* comprehends the tracking of evolving requirements over the entire product lifecycle and the identification of impacts from changes.

The integration of product and production process development, also known as concurrent engineering, has been an issue that companies have been trying to solve for a long time [24]. In order to anticipate consensual decisions and reduce development lead-times, many companies structure multi-functional development teams [21] and increase supplier participation already in the beginning of the development projects [25]. Considering the lifecycle perspective, *integrated product design and process specification* means expanding these initiatives to effectively encompass the later maintenance, service and disposal activities and functions.

On the bottom right hand side of Fig. 2, *end-to-end configuration control*, supports the identification, control, accounting and audit of functional and physical characteristics of specified product parts, called configuration items [26]. On the bottom left hand side of Fig. 2, the *total lifecycle costing* considers all the costs that incur over the product lifecycle and therefore enables tracking and analysing the individual costs related to each of the lifecycle phases [12,27]. This approach

supports also the estimation of the total cost of ownership for the end-user, which is increasingly considered to guide sourcing decisions, instead of basic price comparisons.

The minimization of total product environmental impact, including aspects like energy efficiency and materials recycling, involves a global approach similar to *total lifecycle costing*, involving all lifecycle phases. Another point that must be considered in a PLM implementation is the *service and maintenance data reuse at the product development*. Companies usually do not take advantage of field data from the product usage phase, mainly because this kind of data may be difficult to gather. However, this topic gains momentum with recent advances in electronics and software, including RFID (radio frequency identification) transponders, wireless communication technologies and software for remote diagnosis [17].

3.2. PLM foundation

The necessary foundation for a PLM implementation is provided by a robust product structure. The product structure plays a fundamental role for the PLM implementation as it defines the physically structured relationship among the modules and components which constitute a product. Besides that, it also integrates all the product related information and documents (e.g. CAD models, NC programs, cost analysis, maintenance procedures, disassembly plans).

The product structure links therefore all objects which represent the lifecycle information of a product. An object is in this sense a generic concept for multiple elements within the product structure, including product requirements, functions, single components, assemblies or the product itself [10]. The role of the product structure within the PLM is then to manage all product related objects and their structural connections [11], providing the necessary implementation foundation.

3.3. Set of reference models

Industry reference models generally encompass proven business practices and can be used as a starting point for process innovation initiatives. However, recent research results as well as evidence from the practice indicate that the unique reference models cannot be defined as a best practice for all companies. Moreover, even in a single industry sector, the process that best

fits a specific company may vary according to multiple characteristics of the development projects, like the innovation level and the number of product derivatives [10].

Based on this fact, the framework presented on this paper considers a set of reference models customized according to typical companies' characteristics. The reference models developed on this research focus specially the machinery industry.

In order to construct the set of reference models, eight key PLM processes have been defined (see Table 1). For each process, a standard reference model has been initially built. In a next step, companies' characteristics that influence process configuration have been identified (sector, size, order type, etc.). The most significant characteristics have been selected to define the different existing process types. Afterwards, for each process, two or three process types have been defined (Table 1). Finally, a reference model for each process type has been deployed from the standard reference models developed initially. Table 1 shows an overview of the eight PLM processes and their related process types.

Although the set of reference models focus a specific industry, the applied specification methodology can be reused in other industry sectors.

3.4. Vendor neutral software requirements

The existing PLM software solutions vary in functionality depth and breadth, depending on vendor market focus, software origin and its evolution in the last years. The differences between each available system hinder software comparison and market understanding.

In order to enable PLM software assessment in a common basis and enhance market transparency, a vendor neutral PLM software requirements catalogue has been developed. This catalogue encompasses all functions that are necessary to implement the PLM definition and processes considered on the proposed framework.

The catalogue consists of four functional areas, namely core data management, product data generation, process management, and system integration. These four areas are sub-divided in 13 functional groups (Fig. 3).

The core data management area concerns the central data that define a product. Consequently, this area is located in the

Table 1
Set of PLM reference models for the machinery industry

| Process | Process types | | |
|--------------------------|--|---|--|
| Idea management | Local components and systems producer | Medium-sized manufacturer of high-tech products | Global manufacturer and service provider |
| Requirements management | Engineering-to-order (ETO) manufacturer | Modular product developer | Series-manufacturer |
| Product structuring | Incremental product program developer | Modular product developer | Product program developer |
| Product program planning | Order specific engineering (ETO) | High-variant manufacturer | High-variant manufacturer in dynamic markets |
| Change management | Components and systems producer | Medium-sized manufacturer | Global manufacturer |
| Project controlling | Incremental innovations of existing products | New product development | Architectural/radical innovations |
| Risk management | Medium-sized manufacturer in stable markets | Medium-sized manufacturer in dynamic markets | Coordinator from project network |
| Quality controlling | Order manufacturer | | Series-manufacturer |

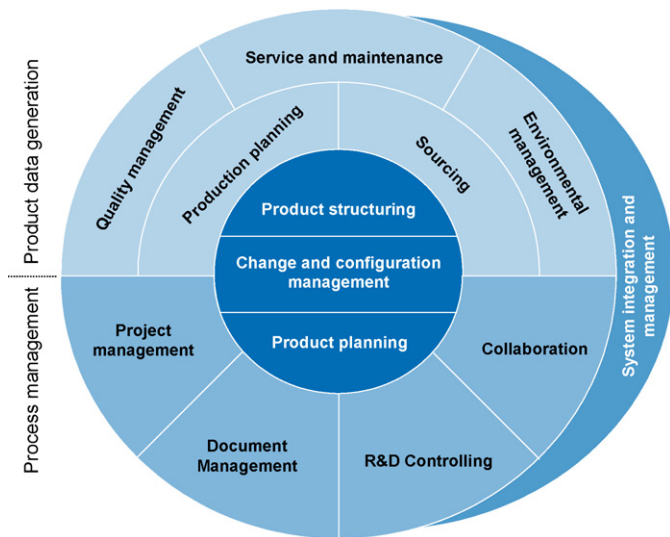


Fig. 3. PLM software requirements catalogue.

central point of the catalogue, as a main information supplier for the other functional areas. The functions of the core data management are organised in three groups:

- *Product planning*: comprises the functions for an integrated portfolio management, as well as for the gathering, evaluation and selection of new ideas, and the management from product requirements.
- *Product structuring*: within this functional group, the material master records are managed. Materials and other objects in the system are classified according to predefined classification schemas, in order to reduce the efforts to find and reuse information. The bill of materials can be managed according to different views (development, assembly, etc.).
- *Change and configuration management*: encompasses the management of changes and the configuration control over the complete lifecycle.

Functions related to generating and updating product information are allocated in the product data generation area of the catalogue (Fig. 3). This area is organised in five functional groups:

- *Production planning*: provides access to resource (e.g. machine and tools) data, and supports the generation from process plans and plant layout.
- *Sourcing*: comprehends a supplier's data bank and a catalogue of standard items. Requests for quotations are supported through eSourcing functionalities.
- *Quality management*: comprises the application of quality methods (e.g. FMEA – failure mode and effect analysis), the generations of control plans and the management of quality inspection results.
- *Service and maintenance*: service scripts and maintenance plans are generated and managed and the results of services executed are recorded in the system.

- *Environment management*: comprehends the management of hazardous items and the handling from scrap and recyclables.

The process management area focuses the PLM business processes from the proposed framework. The functions from this area are organised in four groups:

- *Project management*: besides the plan and execution from individual projects, the integrated plan from multi-projects is also supported by this functional group.
- *Document management*: documents are described with metadata and are saved in a data vault. Each document can be linked to one or more objects from the system and can be visualised. Moreover, the publishing from technical documents and the data archiving are supported.
- *R&D Controlling*: comprehends the project controlling, the product cost calculation over the complete lifecycle and the generation of key performance indicators.
- *Collaboration*: solutions like workflow management, video-conferencing, application sharing, and a knowledge data bank enable cooperation among project team members.

Finally, the system integration area comprises the standards and interfaces needed to enable data exchange among the solution used to compose the complete PLM software solution.

The software catalogue described above has been detailed in a requirements questionnaire with 298 questions and 1244 possible answers. Examples of questions are: Which different BOM views are available? How are product variants managed in the system? For this last question, possible answers include: the system enables the definition of order independent product structures with their respective variants and a material master record does not have to be created for all possible variants. This catalogue links the activities from the set of business process (Section 3.3) to the specific software solution described in the following section.

3.5. PLM software support

The vendor neutral software requirements catalogue (Section 3.4) was used in a survey to assess the PLM solutions available on the market. The survey started with the identification of 54 PLM vendors in Europe. Two complementary instruments were used to collect data from available systems. The vendors which agreed to take part on the survey received an electronic spreadsheet with the questions and their multiple choice answers from the software catalogue described in Section 3.4. They also had the option to access a vendor specific online version of the questions catalogue. Among the 54 vendors that were initially contacted to take part on the survey, 17 responded the questionnaire. The data gathering phase took 6 months, from mid October 2005 until mid April 2006. The questionnaire was filled out mainly by technical sales personnel.

The data gathered from software vendors indicate how available systems support the PLM functions considered in the requirements catalogue. Fig. 4 shows the average requirements fulfilment level for each function group. The function groups

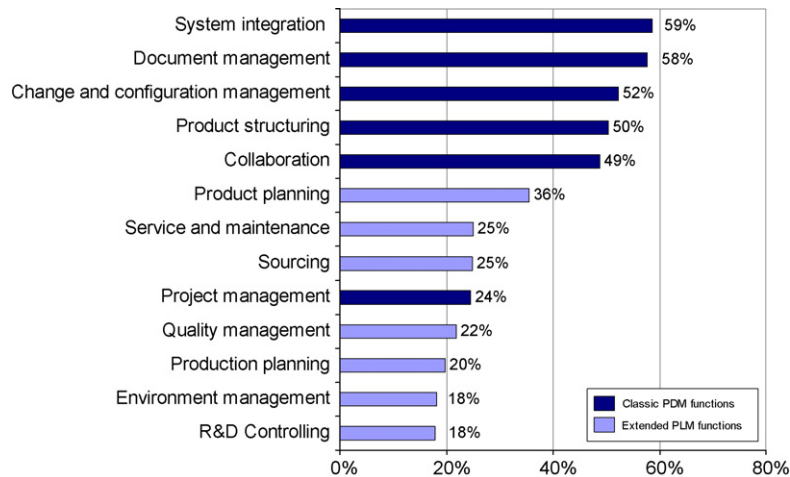


Fig. 4. Average system profile (source: survey with 17 PLM vendors).

pictured in Fig. 4 are divided into two categories: classic PDM functions and extended PLM functions. The first category encompasses functions which have been for a long time considered as typical for PDM systems [28]. The second category comprises functions which have recently been added to the PLM scope. This includes functions focusing mostly the beginning and the end of the lifecycle.

The data analysis shows that the fulfilment level is higher for the classic PDM functions, except for *project management*. The lower fulfilment degree for *project management* can be explained by the widespread use of stand-alone solutions (e.g. MS Project) integrated with project management modules from ERP.

The analysis of extended PLM functions indicates a trend to enhance *product planning* and *service and maintenance* system capabilities in the next years. Average fulfilment levels are still low (36 and 25% respectively). However, there are already three lead vendors in each of these groups which cover more than 70% of the requirements. Additional qualitative data obtained in contacts with vendors confirm this trend.

Sourcing and *production planning* are only marginally supported by PLM, as these functions are typically covered by ERP. Finally, the average fulfilment level for *quality management*, *environment management* and *R&D controlling* is low. This implies that most organisations will continue to depend on complementary IT solutions to support these functions.

3.6. PLM knowledge base

The PLM knowledge base provides the necessary material to employee education in relation to PLM topics needed to execute the activities from the reference model. The knowledge elements are organised in three groups: concepts (e.g. product modularity), methods (e.g. FMEA) and tools (e.g. CAD).

Concepts are the more extensive and widespread knowledge that serve to create a theoretical base and to supply background information to the PLM. Methods are normally structured in steps or related with something specific to reach a determined objective. Tools knowledge is related with hardware and software solutions.

The link between the knowledge base and the reference model allows the corporate education to focus on existing knowledge gaps to execute the PLM processes. At the same time, employees can learn in a contextualised environment provided by the process models [29,30].

3.7. PLM benefits

The goal of PLM activities is to realise benefits like reducing time-to-market, improving product functionality and increasing ability of customizing. The expected improvements and benefits result from changes within the company's processes.

Within the research project several studies concerning PLM implementation, successful R&D and company success have been analysed with the goal to identify correlations between design objects (activities, functions and processes) and success indicators (singular benefits, company success, innovation productivity, etc.). Table 2 shows the processes and the related benefits proven in empirical studies and in case studies.

Thus, on basis of the expected benefits the reference processes can be selected and used for developing the target PLM processes within a company.

4. PLM implementation

The proposed PLM process oriented framework can be applied to guide PLM implementation at the industry. Companies aiming to implement PLM can refer to the provided conceptual framework to establish their own framework, linking the company elements in a comprehensive PLM environment. Therefore, the following ten steps are necessary:

1. Define the goal of the PLM implementation: according to the PLM definition (Section 3.1) companies can identify the most important points to focus on.
2. Analyse the existent PLM foundation: the ability of the current product structure to support PLM (Section 3.2) must be analysed and if necessary enhanced.

Table 2
PLM benefits related to processes

| Process | Related benefits |
|--------------------------|---|
| Idea management | <ul style="list-style-type: none"> ▪ Higher innovation productivity through more and better products [31] ▪ Higher turnover share with new products through a broad innovation portfolio [31,32] ▪ Continuous improvement of products and processes through employee incentives [33] ▪ Higher customer focus and better coupling of product development and customers through customer integration into idea management [31,32,34] |
| Requirements management | <ul style="list-style-type: none"> ▪ Reducing the number of iterations through better input [31] ▪ Reducing number of unneeded product variants through systematic evaluation [35] ▪ Higher first-pass-through through better integration of mechatronic disciplines (mechanic, electronic, software) [31] ▪ Documentation of changes and their impacts [31] ▪ Fast product documentation through reuse of existing documents enabled by better structure [31] |
| Product structuring | <ul style="list-style-type: none"> ▪ Faster engineer-to-order process through efficient reuse of components [35] ▪ Smaller better focused product program [35] ▪ Higher margins through better pricing opportunities (basis, options, customizing) [33] ▪ Lower development efforts through avoiding re-developing existing solutions [33,35] ▪ Lower complexity costs through less parts in product program [35] |
| Product program planning | <ul style="list-style-type: none"> ▪ Better market focus through systematic planning process and alignment of products and services [34,35] ▪ Optimized product variety through planning process [35] ▪ Decrease development costs through parts reuse [31,35] ▪ Identify possible synergy potential within production and purchase [31,34] |
| Change management | <ul style="list-style-type: none"> ▪ Improve cycle time for changes through better information availability [31,33] ▪ Faster reaction to customer changes through robust processes [31,33] |
| Project controlling | <ul style="list-style-type: none"> ▪ Improve possibility to decide on projects [31,32] ▪ Improve employee productivity in development through better resource allocation [31,33] ▪ Reduce efforts for collecting project information through automatization [33] |
| Risk management | <ul style="list-style-type: none"> ▪ Early identification of project deviations through better information availability [33] ▪ Better planning results through better planning basis data [32,33] |
| Quality controlling | <ul style="list-style-type: none"> ▪ Improvement of customer satisfaction through better product and service quality [33,34] ▪ Earlier identification of quality problems [33] |

3. Rank processes: the processes to be implemented can be selected from the PLM process list (Section 3.3), considering company aims and the expected benefits (Section 3.7).
4. Identify company maturity level (as-is process): comprehends the mapping of company current processes (only for the previously selected processes).
5. Select an appropriate reference model: from the provided set of reference models (Section 3.3) it is possible to identify the process type that best suits company characteristics.
6. Customize reference model: although processes that target different kinds of company are available, processes must still be refined to reflect very specific business needs. The customized processes picture the to-be PLM scenario.
7. Specify requirements for system selection: the vendor neutral software requirement catalogue (Section 3.4) related to the already configured processes provides the system specification.
8. Select software solution: based on previously defined requirements and considering detailed software profiles (Section 3.5).
9. Define the evolution path and implement software solution: the differences between the as-is and to-be processes allow the definition of implementation roadmaps, including the necessary implementation of the selected software solution.

10. Teach employees: the knowledge base (Section 3.6) connection to the processes indicates the new necessary qualification and provide the necessary training material and context.

This implementation approach in ten steps is derived from classical approaches for process engineering [18], but it goes a step further for PLM, as it considers the needs and conditions of this area. As a result, a company specific PLM framework linking process, IT and knowledge is generated.

5. Conclusions

PLM represents a powerful approach to improve the company's strategic and operational excellence. Since strategic and operational excellence depend on many company and branch specific conditions and constraints an overall PLM solution cannot exist. PLM has to be aligned to boundary conditions and must support the company's strategy. Also from the IT point of view there cannot exist one PLM solution, since PLM represents the synergetic integration of systems to support the operational excellence.

Within this article a framework for the definition and consistent alignment of PLM activities has been presented. Beginning with the company's strategy the focus of PLM is

defined on basis of expected benefits and their related processes. The reference process models serve as an ideal state for designing company specific target processes. They have been derived by research of product development, innovation management, complexity management and PLM method literature. For the target state processes an IT-support has to be defined. Therefore, the functionality of different IT systems have been analysed on basis of a comprehensive questionnaire. In combination with the target state processes an optimal IT support can be defined. This way, the presented framework can be used to support a comprehensive PLM implementation at the industry.

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