Supporting Product Lifecycle Management with Requirements Information

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Abstract Consistent definition, categorization and operation of products delivered to global markets and customized for different buyer segments is one of the major challenges for Product Lifecycle Management (PLM). Customer requirements with all related product requirements need not only be integrated with each other, but with all processes and stakeholders involved through the related business functions of product lifecycle. In this chapter we examine the various challenges of requirements management, especially related to Product Lifecycle Management. We introduce an integration framework, according to which challenges at different levels are categorized. In order to illustrate the specific integration challenges of requirements information with PLM, a case study of automotive industry is introduced. As a conclusion, the study shows the core points where and how the concepts of PLM and requirements management should be developed to create requirements-integrated solutions for extended products and systems through the product lifecycle.

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1 Introduction

Manufacturing companies are facing more and more comprehensive challenges when coping with customer requirements related to product requirements. In order to produce new competitive products and innovations, companies should pay more attention to managing requirements information throughout the whole product lifecycle.

Product Lifecycle Management (PLM) is an integrative information-driven approach comprised of people, processes/practices, and technology to all aspects of a product's life and its environment, from its design to manufacture, deployment and maintenance. Product Data Management (PDM) is a systematic, directed set of tools by which to manage and develop an industrially manufactured product. Information systems of PDM and with wider frame -oriented PLM systems are based on a data model enabling accessing, updating, manipulating and reasoning about product information in a fragmented and distributed environment (Grieves 2006; Saaksvuori and Immonen 2008).

Customer requirements management is generally not a part of current PLM systems. Because today's product development process is very fast-moving and products have become more customer-oriented, it is very important not only to collect but also track customers' voices and feedback to satisfy the demands of the markets. According to Schulte (2008), the classical customer-oriented approaches can be classified as solutions for the identification and evaluation of customer requirements, measurement of customer satisfaction, and customer integration into value-added processes.

Requirements management is a critical activity, which ensures that the voice of the customer is heard throughout the product development process, and it is not restricted to a single phase only, but takes place in all phases of the product lifecycle. Requirements are not only significant at the front-end phase of the innovation process, but are essential through the whole lifecycle, covering all life cycle activities associated with understanding a product's necessary capabilities and attributes (Maletz 2008a). According to Jiao and Chen (2006), it appears to be difficult for engineers to translate customer requirements, i.e. the voice of customers, into concrete product and engineering specifications. In addition, the requirements for products typically change during new product development, products are becoming increasingly complicated and the customer segments more fragmented (Möttönen 2009). Thus, requirements management has become a critical activity throughout the PLM.

In this chapter we examine what kinds of challenges are met when linking requirements management with Product Lifecycle Management, with emphasis on the early phases of the product lifecycle. In addition, the aim of this chapter is to find out how product-related information on customer requirements could be utilized better and integrated with PLM. We focus on some of the most important challenges and capabilities of requirements management (RQM) and on the integration of RQM and PLM. The theoretical part consists of a literature review to outline firstly the definitions and features of PLM, and secondly to introduce the processes, methods/tools and challenges of RQM. As a result we categorize the challenges of integrating RQM with PLM, by combining literature results and earlier research in the manufacturing industry. The integration framework introduced in this study is utilized in the categorization of the challenges. In the case study, company-specific challenges are identified when integrating requirements management with PLM in the case company operating in the automotive industry.

2 Features of PLM Concepts and Systems

The term Product Lifecycle Management emerged in the late 1990s after nearly twenty years of market and technological evolution. With the advent of Computer Aided Design (CAD) solutions as the means of creating a geometric model of products, engineering design entered a new era. Product Data Management systems appeared during the1980s, focusing originally on solving the problems of CAD file management by providing a data vaulting facility, and being typically limited to the engineering aspects of products.

2.1 Definitions and Processes

According to Grieves (2006), PLM is an integrative concept for managing products and product-related information throughout the whole product lifecycle, from design to manufacture, deployment and maintenance - culminating in the product's final disposal. PLM systems, as an extension of PDM systems, are based on a data model. They enable accessing, updating, manipulating and reasoning about product information produced in different phases of the product lifecycle and is usually scattered in a fragmented business network.

CIMdata defines PLM as a strategic business approach that applies a consistent set of business solutions in support of collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, from concept to end-of-life, integrating people, processes, business systems, and information (Maletz et al. 2008b).

PLM can be considered as a holistic business concept for managing and controlling the product and product-related information. PLM does not refer to any particular software or method. PLM is a large functional system, built of the PLM concept and a group of systematic methods used to control the product information; it combines data, technologies, methods, tools, processes and people together in different phases of the product lifecycle. Product information means (1) the product definition data, (2) the product life cycle data and (3) metadata, which describes the product and lifecycle data (Saaksvuori and Immonen 2008).

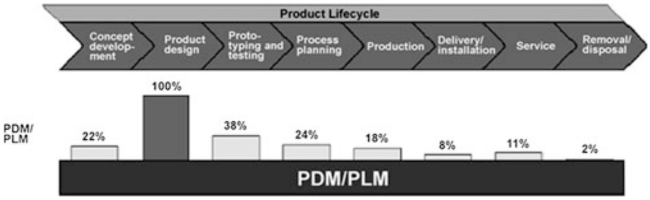

Fig. 1 Use of PDM and PLM throughout a product lifecycle; normalized to the product design phase (Lee et al. 2008a, p 298)

A typical PLM process with different stages has been introduced by Lee et al. (2008a) (see Fig. 1). The adoption of PLM systems in industry started primarily in the automotive and aerospace industry, followed by the machinery industry (Lee et al. 2008a). There are several vendors, including Windchill, IBM, Dassault Systems, SAP, UGS, etc. offering PLM solutions. Although PLM is meant to manage product information throughout the entire lifecycle of a product, an international study revealed that the adoption of PLM is still mainly limited to product design (Lee et al. 2008a), as can be seen in Fig. 1. The figure shows the relative intensities of PLM and PDM adoption in several stages of the product lifecycle. It can be seen that PLM has so far been used nearly ten times less frequently in the service phase than in product design, and that the use of PLM and PDM in the retirement phases is insignificant. Today's PLM applications are more than 5 years behind state-of-the-art solutions. The trend in the next few years is expected to focus on product lifecycle stages in general and on an improved support of engineering collaboration functionality.

2.2 *Typical PLM Objects*

The major benefit of PLM lies in seamless integration with other fields of product processes. This is done by bringing together e.g. product data, functions, processes, project tasks, costs etc. in direct correlation with related PLM objects (parts/items, documents, bill-of-material structures, change forms, requirements, resources, facility, equipment). These objects may be authored and managed in e.g. different PDM systems and other software tools used in product development (Maletz et al. 2008b).

2.3 *Use of Typical PLM System Functionalities and Capabilities*

As a software application, PLM is an extension to PDM systems. PLM systems are distributed technological information systems for archiving, administrating and providing all product information at the right time and place. Almost all modern

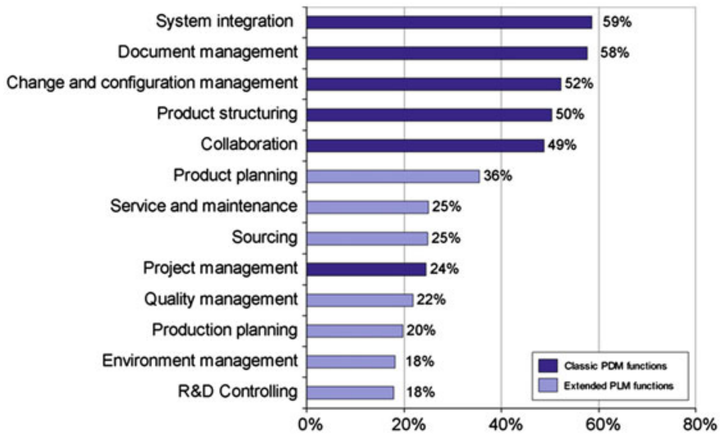

Fig. 2 Average system profile (survey with 17 PLM vendors by Schuh et al. 2007, p 215)

PLM systems provide the basic features for product information management: data (file) vault management, document and object management, release and change management, product structure management, viewing, mark-up and image service, classification and retrieval, and configuration management.

A vendor-neutral software requirements catalogue was used in a survey of Schuh et al. (2007) to assess the PLM solutions available on the market. The use of typical PLM system functionalities and capabilities was examined. The data analysis (see Fig. 2) showed that the fulfillment level was higher for the classic PDM functions, except for project management. The lower fulfillment 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 indicated a trend of enhancing product planning and service, and maintenance system capabilities in the next years. The average fulfillment levels were still low (36 and 25 %, respectively). However, there were already three lead vendors in each of these groups, covering more than 70 % of the requirements. Additional qualitative data obtained in contacts with vendors confirmed this trend.

3 Requirements Engineering & Management

3.1 Requirements Engineering & Management Process

The concept of product lifecycle management can be seen to be connected integrally to requirements engineering (RE) (Möttönen 2009). RE as a field originates from software engineering, and it is a sub-discipline of systems engineering. Traditionally, RE has been seen as a front-end activity that forms a solid basis for the other activities

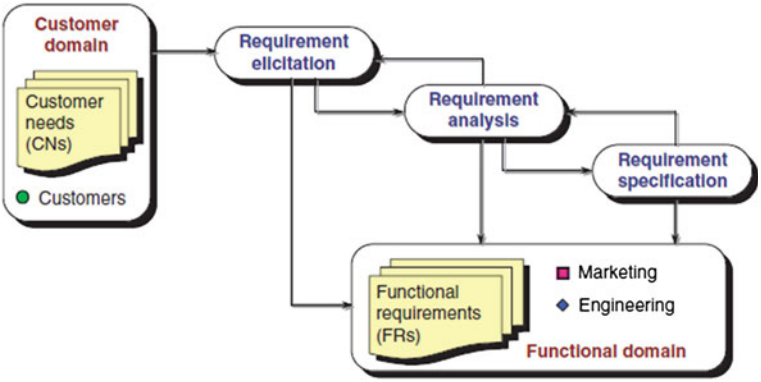

Fig. 3 Customer requirements management process (Jiao and Chen 2006, p 174)

of product development (Kauppinen et al. 2007). Wiegers (2003) defines RE as the domain that includes all project life cycle activities associated with understanding a product's necessary capabilities and attributes. According to Wiegers, RE can be divided into requirements development and requirements management (RQM). The requirements development phase focuses on developing baseline requirements before the actual product development, and it can be further subdivided into requirements elicitation, analysis, specification, and validation, and once the development is started, the requirements are managed through a requirements change process (Wiegers 2003). RQM is concerned with all of the processes involved in changing system requirements (Sommerville and Sawyer 1997), and it is a process that supports other RE activities and is carried out in parallel with them.

There exist several definitions of requirements management in the literature, however, and for example Tseng and Jiao (1998), and Jiao and Chen (2006) define requirements management as the whole process of requirements elicitation, analysis, and specification, as depicted in Fig. 3. The evolution process of design requirements ends up with a complete specification of functional requirements, from which a successful design can follow (Jiao and Chen 2006).

Requirements elicitation is the first step in the requirements management process dealing with customer needs in the customer domain. According to Jiao and Chen (2006), the requirements elicitation phase has several activities, which include e.g. systematical extracting and making inventory of the requirements of customers and stakeholders, including the environment, feasibility studies, market analyses, business plans, and benchmarks of competing products. The second step is requirements analysis, where the customer requirements are analyzed and interpreted to derive explicit requirements that can be understood by marketing and engineering. This phase includes classification, prioritization, and negotiation of customer needs. The third phase, i.e. requirements specification, is about the definition of concrete product specifications in the functional domain, which includes continuous interchange and negotiation within a team regarding conflicting and changing objectives.

Table 1 Properties for requirements classification

Categorization			Attributes			
Dimension	Level	Type	Target	Source	Priority	Status
Features	Project	Product	Engine	End-user	Must have	Created
Costs	Product	-Functional	Transmission	Strategic	Important	Active
Scheduling	System	-Non-functional	Cab	Marketing	Not critical	Change
Reliability	Component	Process	Hydraulics	Customer supp		Obsolete
		Organizational	Axles/differential	Sales channel		
			Electronices	Legal		
			Stying	Standard		
			Other	Engineering		
				Production		
				Competitor		
				Envirolmental		
				Social		

3.2 Requirements Classification

The requirements for products can be set by the end-users, customers, other stakeholders, standards and technical and/or environmental constraints. The diverse definitions of the term requirement suggest that there is no universally accepted definition of what a requirement is (Kauppinen 2005). On the other hand, Kauppinen discloses that researchers seem to agree relatively widely on the division of requirements into functional and non-functional ones, and many researchers also classify constraints as one of the requirement types. In addition to the different requirement types, Kauppinen points out that there are different levels of requirements as well, and requirements can be defined from the business, user and development perspectives. Wiegers (2003) defines

1. *business requirements* as a high-level business objective of the organization that develops a product, or of a customer who produces it,
2. *user requirements* as user goals or tasks that users must be able to perform with a system, or statements of the user's expectations of system quality, and
3. *functional requirements* as a statement of a piece of required functionality, or a behavior that a system will exhibit under specific conditions.

According to Hansen et al. (2008), different levels of requirements may be discovered, specified and managed across stakeholders or organizations, and ensuring consistency across different levels creates a complex set of challenges.

For example, Table 1 presents some categorization and attribute examples for creating requirements classification in the commercial vehicle industry. By using dimension information as categorization, impacts can be analyzed from the perspectives of features, costs, scheduling, and reliability. Also hierarchy levels (project, product, system and component) can be used for requirements categorization. In addition, a requirement type can be added, such as functional, non-functional or organizational requirements. However, if more information is needed for specifying the requirements, this can be done by adding attributes related to the target, source, priority and status of a certain requirement. Documenting and linking the attributes related to a certain requirement ensures that e.g. a certain component level requirement can be traced back to the initial customer need. When utilizing the classification of Table 1 in other industries, the target elements and possibly some other elements must be adapted to the technology base of the company.

3.3 Challenges Related to Requirements Management

Understanding and fulfilling customer requirements has been recognized as an urgent challenge for companies across industries (Jiao and Chen 2006). According to Möttönen et al. (2009), the more complex and abstract a product is, the more vital RQM becomes for a successful new product development process, and especially for embedded systems containing both hardware and software. The requirements for products typically change during new product development, products are becoming increasingly complicated and the customer segments more fragmented, and thus requirements management has become a significant challenge for especially high tech companies (Möttönen 2009).

According to Tseng and Jiao (1998), requirements have the tendency to be vague, fuzzy and difficult to manage. Furthermore, requirements are derived from different perspectives of the product lifecycle, including such issues as manufacturing, reliability, maintainability, and environmental safety. Jiao and Chen (2006) point out that different stakeholders use different semantics and terminology, requirements are often poorly understood, and they are expressed in abstract, fuzzy, and conceptual terms. Valenti et al. (1998) discovered that several users may evaluate the same information need differently, or may present requirements raising either conflicting or competing use of limited resources, according to their role in the organization, background or mindset. In addition, there may be problems when mapping the customer requirements and relationships in the customer domain into functional requirements in the functional domain (Jiao and Chen 2006).

In general, requirements change, new requirements will appear or requirements can be removed at any phase of a product's lifecycle. One primary cause for requirement volatility is the fact that the user or customer needs evolve over time. Another cause for changing requirements is that requirements are a product of the contribution of many individuals, and these individuals often have conflicting needs and goals. Requirements may also emerge from new stakeholders who were not originally consulted at the early phases of the product lifecycle (Sommerville and Sawyer 1997). Furthermore, according to Ovaska (2009), the understanding of the requirements changes during product development. Preconditions, attitudes and expectations among stakeholders change the participants' interpretation and understanding of the requirements. In addition, the priorities of requirements may change. The importance of a particular requirement may change during the development, as people often find it difficult to assign priorities during the requirements elicitation phase, because they do not have a complete picture of their needs and product requirements at that time.

Requirements management is a multi-disciplinary effort, where requirements come from several domains, such as mechanics, software, and/or electronics. Although several tools exist to support requirements management in each of these domains, the integration of domain-specific requirements is still a huge challenge. Changing requirements in a certain domain may affect also other domains, and the dependencies between domain-specific requirements have to be ensured. Among others, systems engineering addresses this challenge.

3.4 Methods and Tools

Several methods and tools have been developed to help organizations to obtain a better understanding of customer requirements (Wang and Ji 2010). In the following paragraphs, some methods and tools are presented, especially related to the classification of customer requirements.

3.4.1 QFD

Quality function deployment (QFD) is a widely used customer-driven design and manufacturing approach developed in Japan during the 1960s, and it has been used in the manufacturing industry for several years. Generally, it utilizes four sets of matrices called the house of quality (HOQ) to translate customer requirements into engineering characteristics (Li et al. 2009). An HOQ is a conceptual map used by a cross-functional team to identify the customer and user requirements, and how best to develop systems (Karlsson 1997). According to Wiegers (2003), QFD provides an analytical way to identify those needs and requirements that will provide the greatest customer satisfaction. The QFD technique classifies requirements as

1. *expected requirements*, where the requirement might not be even stated by the customers, but who will be disappointed if they are missing,
2. *normal requirements*, and
3. *exciting requirements*, which provide high benefit to customers if they are included in a product but little penalty if not (Wiegers 2003).

3.4.2 Kano's Model

Kano's model is a widely used tool for understanding the voice of customers, and the model categorizes different customer requirements based on how well they are able to achieve customer satisfaction (Wang and Ji 2010). Thus, the model suggests that there are three main types of customer requirements, must-be, one-dimensional and attractive attributes (Wang and Ji 2010):

1. customers take must-be attributes for granted if they are fulfilled, but are dissatisfied if the product does not meet these requirements sufficiently,
2. the fulfillment of one-dimensional attributes is positively and linearly related to the level of customer satisfaction, and
3. the fulfillment of attractive attributes will lead to greater than proportional customer satisfaction, but the absence of these attributes does not mean dissatisfaction because they are not expected.

In addition, Kano's model also proposes another set of three categories of customer requirements, which are indifferent, reverse and questionable. A Kano questionnaire has been designed to help in categorizing customer requirements into the six Kano's categories (Wang and Ji 2010).

3.4.3 Extensions of the Original Kano's Model

The analytical Kano model (A-Kano) extends the traditional Kano model by introducing

1. Kano indices, which are quantitative measurements of customer satisfaction,
2. Kano classifiers, which consist of a set of criteria to classify customer requirements,
3. Configuration index, which provides a decision factor for selecting the functional requirements, and
4. Kano evaluator, which is a performance indicator leveraging upon both the customer's satisfaction and producer's capacity (Xu et al. 2009).

Xu et al. (2009) propose a comprehensive process model to integrate these techniques for customer need analysis. Further, Lai et al. (2004) have combined the Kano model and QFD to meet customer requirements in product design, and to provide a product design optimization method. This method uses the Kano model to analyze the customer requirements and QFD to translate customer requirements into product design. Lee et al. (2008b) have presented an integrative approach by incorporating the Kano model with a fuzzy mode into the matrix of QFD and adjusting customer requirements weights. In addition, Li et al. (2009) have introduced an integrated method, which combines the rough set -theory, Kano's model, the analytical hierarchy process (AHP), and the scale method in order to obtain the final importance of customer requirements in the product planning house of quality.

3.4.4 Tools for RQM

The challenges related to requirements classification and management have raised an absolute need for requirements management tools. According to Maletz (2008a), a great number of requirements management tools are available in today's market, and most of them are developed and used in the field of software development. The International Council on Systems Engineering (INCOSE) and the Tools Database Working Group (TDWG) have gathered information on requirements management tools since the 1990s, and publish a comparison of the features of many RM tools, updated periodically (INCOSE 2011). INCOSE divides the tools into *requirements management* and *requirements generation tools,* and further the requirements management tools into three different categories (INCOSE 2005):

1. *Requirement Classification Tools.* These tools help the engineer classify the requirements based on work to be done, so that the requirement analysis activity can be scheduled and tracked. They help an engineer to classify requirements based on how the requirements will be used in modeling so that completeness of traceability can be monitored.
2. *Requirements Capture & Identification Tools.* Requirements capture tools accept text information from heritage sources, users, customer requirements and customer operations concepts. They assist an engineer in finding relationships among entities in the information and in moving among the entities, whereas requirement identification tools aid the engineer in separating requirements in the information before him from extraneous information. Modern versions of these tools use natural language processing to identify statements containing imperatives of any kind in the information.
3. *Requirement Traceability Tools.* enable the engineer to link requirements to their source, to changes in requirements, and to modeling elements that satisfy the requirements. They provide traceability among the successive documents that are used to review the system development.

Commercial tools especially for requirements management are e.g. IBM Rational DOORS, MKS, or Teamcenter Requirements.

4 Challenges and Capabilities in integrating RQM with PLM

One of the most holistic approaches to integrate requirements management with product lifecycle management found in the literature is the concept for integrated requirements modeling (Maletz et al. 2007). Integrated requirements modeling is a consistent concept allowing continuous integration of requirements into every phase of the product lifecycle. The concept combines the different aspects to be taken into consideration. Starting with the requirements specification document, ontology with requirements is the basis for classification and traceability. Mapping and verifying requirements structures with other product structures through

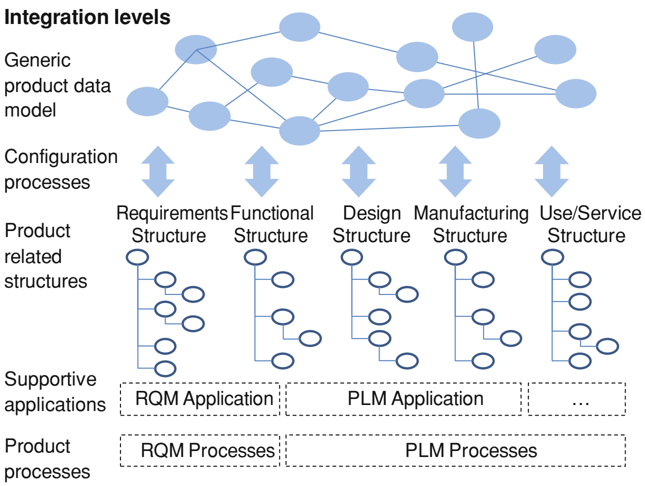

Fig. 4 Product structure integration through product lifecycle (adapted from Maletz et al. 2007)

lifecycles is one point of integration needed. Also different representation formats and tools are needed for better understanding of different stakeholders (Maletz 2008a; Nilsson and Fagerström 2006).

In order to achieve better understanding of the different integration challenges, we have developed a framework for product structure integration. In this framework, the recognized challenges are categorized on different integration levels. As a result, we have categorized the challenges of integrating RQM with PLM by combining literature results and earlier research in the manufacturing industry.

4.1 Integration Levels of RQM and PLM

It is important to have a master concept capable of collecting a variety of engineering information and providing the lifecycle processes with consistent product data information. The generic product structure, which can serve as a central information pool, is such a concept. All relevant structures, including the requirements net, functional net etc. are derived dynamically and linked bidirectionally with the generic product structure. These structures can consist of general terms (i.e. placeholders) which serve as universal carriers of information (Maletz et al. 2007). This means that specific configuration processes are needed for realizing vertical integration between the generic product structure and product-specific domains, such as functional, design, manufacturing, use and service domains, as presented in Fig. 4.

In this study we concentrate mainly on horizontal integration challenges at the three lowest levels: product-related structures, supportive applications and product processes. Moreover, capabilities required for integrating RQM with PLM are introduced.

4.2 Product-Related Structures

Product structuring describes the manner in which objects are arranged to form a product. These objects are managed in PDM systems, where they are viewed as central data-building blocks capable of describing structures from the part level upwards. Mapping requirement structures to product structures, updating the requirement structures, and linking other structures, such as functional or manufacturing structures can lead to arduous manual process (Maletz et al. 2007).

Consequently, the next type of challenges are probably met and coped with by integrating the requirements with product-related structures

- Structure management does not cover all phases of the product lifecycle: customer requirements, product features, functionalities, design, manufacturing & supply, delivery, implementation /use, service, disposal;
- Inconsistent conformance of requirements slows down rapid development and change management of interrelated structures;
- Tracking and tracing of requirements to other product-related structures may not work bidirectionally (upwards or downwards derivation);
- Configuring product instance structures according to specific requirements/ options by customer;
- One requirement can exist in several places in the product structure, and traceability must be ensured to all equal requirements.

4.3 Product-Related Processes

Typical integration challenges between the RQM and PLM processes occur due to the following reasons:

- Different terminology and concepts of the RQM and PLM process domains may cause communication problems;
- Coordination and collaboration between RQM and PLM processes is not easy to manage;
- Different lifecycle scopes: RQM is mostly seen as a project-oriented task (project lifecycle), PLM is a product process (product lifecycle), and ALM is an application process (application lifecycle);
- Change management processes of intangible requirements and physical products have completely different time frames;
- Challenges related to the processes of RQM and PLM are often tried to be solved with commercial tools, even before the process itself is managed;
- Commercial tools often guide RQM and PLM processes. When these tools are separate applications and follow different processes, the integration of product processes becomes challenging.

4.4 Supportive Applications and Tools

Typical integration challenges between RQM and PLM applications occur due to the following reasons:

- Interoperability of RQM tools and PLM systems;
- Separate applications exist for RQM and PLM;
- Only a few PLM applications include some features of requirements management;
- The functionalities of applications do not cover all the required needs of product and business processes;
- The requirements are collected and scattered to several different systems;
- The requirements specification phase for a new product can be outsourced to another company, which has its own tools for RQM.

4.5 Capabilities Required for Integrating RQM with PLM

Requirements management meets not only horizontal product integration processes through the lifecycle, but also a complete set of capabilities that establish a strong vertical link across diverse engineering activities (Abramovici and Bellalouna 2007). The capabilities needed for vertical integration between RQM and PLM can be described as follows:

- Capturing the needs and searching for available requirements for re-use
- Refining, flowing down, and validating requirements;
- Allocating requirements, e.g. to support and optimize the overall product quality requirements in the lifecycle (Tan and Yun 2008);
- Ease of use for broad adoption;
- Verifying the design and product against the requirements;
- Managing and tracing the changes impacting the requirements;
- Representation and transformation of requirement data.

5 Case Study

Many companies are facing technical changes in terms of moving more and more towards the development of integrated mechatronic products with a strong interaction of systems. The case company AVL has moved over the last decade from a specialized combustion engine development company into a “whole powertrain” company. Close to portfolio enhancement, additional “interlocking boundaries” address product-related structures, processes, methods and tools, as well as organizational aspects.

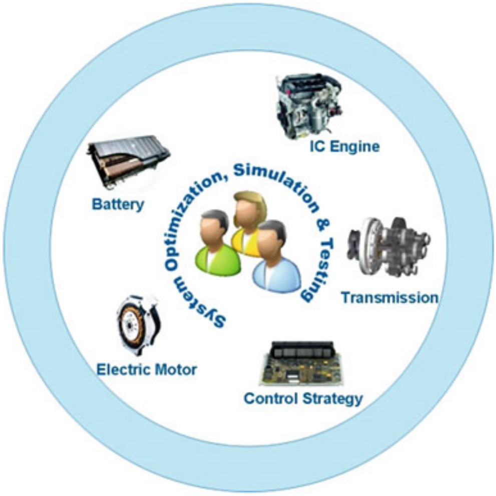

Fig. 5 The five elements of the powertrain

The goals of addressing the interlocking boundaries are related to optimizing the overall system function, increase development efficiency, as well as to raise quality of work. Additional aspects, next to business goals, are driven by upcoming standards and regulations, e.g. safety (ISO 26262).

An integrated systems engineering approach is seen as a methodical fundament within this scope. Some specific integration challenges related to requirements information management throughout the lifecycle, utilizing the integration approach of Fig. 4, are introduced in this section.

5.1 Product-Related Structures

Offering solutions to today's market demands for vehicle electrification and hybridization, AVL develops and validates entire powertrain solutions, including all individual elements forming a powertrain (see Fig. 5).

Whereas in e.g. traditional internal combustion engine (IC Engine) development project requirements are usually stated by customers, hybrid powertrain projects have often a different approach. Based on vehicle properties and goals (e.g. drivability, performance, etc.), requirements engineering activities are performed to develop advanced powertrain technology concepts that fulfill customer needs concerning e.g. decreased fuel consumption or emissions. Among others, this requires a methodical approach including defined structures to document and communicate requirements throughout the organization, to customers and suppliers.

Furthermore, the structuring and cascading of requirements has to be addressed by a multidisciplinary approach including the creation of different views. Here, a challenge is to combine different structures such as product structure (Bill of

Material) and functional structures based on requirement structures. Some goals hereby are to reach full traceability, to identify and communicate interdependencies, as well as to perform specific analysis.

5.2 Product-Related Processes

Taking know-how from experts of all five powertrain elements into consideration, leads to an optimal electrified or conventional powertrain, and furthermore to specified requirements for the element development.

The goals are to develop best-in-class engineered products with outstanding quality, in a minimum of time and by optimized cost. State-of-the-art development processes are a necessity for this. Increased simulation and testing efforts require efficient development methods such as frontloading, systems engineering or requirements management embedded into an integrated engineering environment.

Development processes are often based on tasks rather than delivered information in terms of task output. This is due to a close integration of methods within processes. In order to e.g. allow adequate tool support of processes, it is seen as a necessity to move towards information based processes. Furthermore, the anchoring of requirements engineering as a value adding core process, as well as requirements management as a main supporting process is seen as a challenge to be faced.

5.3 Supportive Applications and Tools

Integrating requirements management into an overall information management strategy is a necessary step in order to support efficient product development. However, there are also some challenges that come along with such steps. Taking a closer look at the elements of a powertrain shows that several domains are involved during the development. Whereas the software domain has experience of the structured methodology of requirements management and the use of supporting tools, (e.g. ALM & RQM including requirement structures), the hardware domain is more centered on methodologies and tools around the product structure (e.g. PDM). From the system point of view, the functional interaction (function structure) of elements under certain driving maneuvers is an additional view as a basis for the deviation of hardware and software requirements. Therefore a proper methodology for the classification of requirements that clearly defines interactions and relations between the requirements, function and product structure is a necessity. Since requirements engineering is performed within distributed development teams, the challenges concerning the consistent formulation of requirements, as well as simple and user-friendly representation are additional needs to be considered. This is seen as one of the core functionalities of a tool environment to efficiently support engineering development processes.

5.4 Organization

Last but not least, the above-mentioned challenges also require an adequate level of organizational aspects to be addressed. In the end, PLM is not only a software but a strategy that combines methods, processes and tools by putting the human resource in the center of adding value to product development—to optimize the product function, increase efficiency and raise quality.

6 Conclusions

As a major result of this study, we comprised an organized picture of the various challenges of customer-oriented requirements management (RQM) and the integration of RQM with product lifecycle management (PLM) in the environment of manufacturing industry. To categorize the challenges, we introduced a table of requirements classification and a framework for product structure integration through the lifecycle.

Implications for facilitating and solving the problems of integration can be defined at different managerial levels: product-related structures, product processes, supportive applications for lifecycle directed integration, and capabilities for vertical integration of diverse engineering activities. To illustrate the specific integration challenges of RQM with PLM, a case study of a power train company acting in the automotive industry was introduced.

Academically, this chapter provides a larger picture of various types of a multifaceted requirements bundle which should be integrated with many stakeholders along the product lifecycle. It also adds to the understanding of the many linkages between requirements and their inconsistency.

As a final conclusion, the study shows the core points where and how the concepts of PLM and RQM should be developed, from the requirements point of view of the customer, design, manufacturing, use /service, and environment etc., to support the whole lifecycle process better. Further, on the basis of this study, future work will be focused especially in finding solutions for integrating product- related requirements completely as an embedded part of extended products and systems.

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