Lifecycle-Based Requirements of Product-Service System in Customer-Centric Manufacturing

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Abstract. Managing through-life information of products and services has become an important competitive means in customer-centric industries. The need for managing new types of product-service requirements for sustainability, traceability and performance have widened the traditional perspective of PLM information to integrate new issues, e.g. service information. In this study we examine how the diverse and through-life requirements information could better be integrated in product and business processes of customer-centric manufacturing. The study is based on a literature review and two case interviews. The objective is to elicit requirements information for Product-Service System (PSS). The study introduces the concepts of product-service system, and outlines through-life requirements in customer-centric business. PSS is a new concept for customer-centric business to improve the performance of sustainability, traceability, reusability and repeatability.

Keywords: Requirements information management, lifecycle-based requirements, sustainability, traceability, reusability, product-service system (PSS), product lifecycle management (PLM), customer-centric manufacturing

1 Introduction

In today's global and competitive market, companies are facing many challenges especially in shortening the time to market, changing regulations, price competition, increasing product complexity and diversity, support and maintenance of products, sustainability and environmental concerns and end of life issues. As response to these challenges, manufacturing companies are striving for accelerating innovation and developing lean supply and product processes through lifecycle.

One related challenge is the effective and efficient management of scattered information on product requirements through lifecycle. Product related requirements and available information is a key factor for business success and competitive advantage. However, requirements are always on the move. Customers often change their mind; market drivers change; authorities keep adding new constraints related to environmental or safety concerns; and sometimes the project encounters difficulties that require a revision of the initial targets.

Effective use of through-life information is an important means to response faster to changes in customer needs and product related requirements in customer-centric manufacturing environment [1]. Product lifecycle requirements also include service-based requirements throughout the lifecycle forming the concept of a product-service system (PSS).

In this study, we focus especially in the less studied topic of requirements information, related to the upcoming demand of integrative products and services in the context of customer-centric strategies. We utilize the concept of through-life requirements to describe the integration aspects throughout lifecycle, e.g. sustainability, traceability, reusability and repeatability.

The objective of this paper is to examine:

(1) What are the trends and drivers for managing information of new lifecycle-based requirements in customer-centric industry?

(2) What kind of through-life requirements are to be considered for product-services in project-based business (ETO) and mass-customizing business (ATO)?

This study is based on a literature review on product lifecycle requirements, and the characteristics of customer-centric manufacturing business. The study introduces trends and drivers for managing information [2-3], concepts of product-service system [1, 4-6] and outlines through-life requirements in customer-centric business. PSS is a new concept for business in improving the performance of sustainability, traceability, reusability and repeatability.

A comparative study on requirements information for the PSS was based on interviews in two B2B case companies. The companies represented two different kinds of customer-centric industries: low-volume project-oriented manufacturing mostly based on engineer-to-order (ETO) strategy, and high-volume mass-customization, typically based on assemble-to-order (ATO) strategy [7-9].

2 Literature review of related work

In the following sections, the theoretical background of the paper is introduced from three viewpoints. First, some of the trends and developments leading to new product information requirements and customer-centric PLM are discussed, second a comparison of the typical features of customer-centric manufacturing strategies (ETO and ATO) is presented, and third, the characteristics of requirements management are clarified for this study.

2.1 PLM in customer-centric manufacturing

Product knowledge management throughout the lifecycle of the product and the related services has attracted increasing consideration in research and (mainly manufacturing) company practices in recent years. There is a variety of related concepts and definitions in the literature on product lifecycle management, depending on the focus of the authors. Novel customer needs and the interest of the end customer towards sustainability and lifecycle aspects of both consumer products and business to business investment products has led to increasingly complex information requirements covering the whole value network [10]. However, current practices for product-related information management in manufacturing and service organizations are still mainly focused on developing internal processes and information flows, and are not always adaptable for a larger network of organizations during the lifecycle of the product.

Also from a political view, the tightening environmental legislation in the EU and US sets new requirements for sustainable manufacturing and end-of-life considerations of all kinds of goods produced (e.g. machinery, medicine, chemicals, food, and other sectors) and the responsibility of the manufacturer is emphasized [11]. As a response to these pressures, the concepts and practices of sustainable PSS [12], closed-loop manufacturing/production/supply chains [13] and closed-loop PLM [14-15] have been developed in recent years. These approaches to manufacturing and product information management are based on the ecological ideal of a closed-loop system, which does not exchange any matter outside its boundaries. Similarly, in manufacturing context, the aim of securing the continuous material and information flows between product lifecycle stages and closing the manufacturing loop by end-of-life operations such as recycling or remanufacturing are considered as integral parts of the manufacturing process.

The need for managing new types of product and service requirements for sustainability, traceability and performance have widened the traditional perspective of PLM information to integrate sustainability issues with other PLM information. The systemic nature of the sustainability concept also poses new challenges for the PLM tools and operating processes:

"Despite advances, integration of environmental issues and tools in existing PLM operating procedures is still lacking and a significant challenge….. The 'ultimate' sustainable product life cycle design and management system would contain a variety of product and process design, modelling and analyses modules." [3]

At the same time, companies are increasingly focusing on defining their operations from the customer point of view, and rethinking their strategies in terms of customer-centricity. The concept of customer-centric PLM describes the aim to gather and utilize customer information (e.g. feedback) efficiently to streamline operations and information flows between different lifecycle stages and to create value to customers along the lifecycle of the product [16].

2.2 Customer-centric strategies and business models

The degree of customer orientation is determined by the customer coupling point and the amount of customer-oriented information [7], [9], see Fig. 1. The more and earlier the customer is involved in the business process (design-fabrication-assembly-distribution), the more customer contact and information is needed.

In pure customization most intensive customer orientation is achieved by engineer-to-order (ETO) strategy and products. ETO production is suitable for unique products that have similar features, and the production is based on receiving a customer order and developing a technical specification accordingly. Customer orders are often organized as projects [17-18].

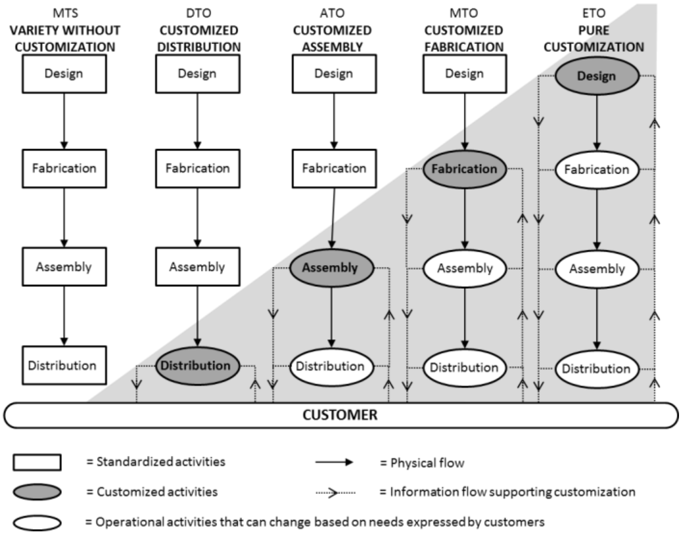

Fig. 1: Scope of customization along customer coupling point (adapted Forza et al. [7], p.10)

Another important customer-centric strategy in this study is the customized assembly (ATO) or customized configuration (CTO). In this case, customer requirements directly influence the assembly activities, not the design and manufacturing process. Products are made with a set of standard components and modules, but the assembly of this set is customized to satisfy specific customer needs. [7]

Managing strategies in manufacturing companies are often too product oriented and pay relatively little attention to services as part of the product offering. Due to the growing servitization of products, manufacturers need to better understand the nature of services and their impact on the design and operation functions [19]. Differences in characteristics of ETO and ATO have been analyzed by Haug et al. [8], especially from the point of transitions in strategy choices and business models. General characteristics of these customer-centric strategies are adapted in Table 1.

Table 1. General characteristics of customer-centric strategies (adapted Haug et al. [8]).

Customer-centric strategy	High-volume mass-customizing business strategy (ATO/CTO)	Low-volume project-based business strategy (ETO)
Product variety	Increase variety	Limit variety
Customer view	Create valuable variety	Create adequate variety
Manufacturing cost	Slight increase	Decrease
Business purpose	Increase sales	Optimize processes
Configurator challenge	User interfaces	Knowledge base

2.3 Characteristics of requirements management

Requirements management is a critical part of a development process for all products, not only for software [20], where the requirement management practices are traditionally well known. According to Grady [21], perhaps the greatest mistakes in system development performance in industry appears in requirements management. Requirements practices include requirements elicitation, analysis, prioritization, documentation, verification and management. These practices are often discussed together under the umbrella 'requirements management' (RQM). Halbleib [22] states that it is important to treat RQM as a process and not a single event, since requirements change and their status must be tracked throughout the project.

Requirements management support is needed in engineering design [23]. Literature covers several practices, techniques and methods to support the critical process of requirements management. In addition, there are a large number of proposals for managing requirements, and several commercial software tools are available for requirements management [23]. Requirement management methods and tools enable procedures to document requirements and check their progress through the product development project [23].

According to Jiao and Chen [24], understanding and fulfilling customer's requirements individually has recognized as a compelling challenge for companies across industries. Poor understanding and analysis of customer requirements during the elicitation and analysis of requirement information have negative implications on design and manufacturing of a product in terms of quality, lead time, and cost [24]. One of the biggest challenges in requirements management is that the requirements change; customers or other stakeholders require new requirements or want to remove the original ones at any phase of development lifecycle. Other challenges related to requirements management are e.g. inadequate processes, shortage of resources, poor communication (such as a communication gap between customers and developers), complexity of requirements and lack of support from executive management [25].

3 Concepts of product-service systems

Product-service systems (PSS) represent "a marketable set of products and services capable of jointly fulfilling a user's need. The product/service ratio in this set can vary, either in terms of function fulfilment or economic value." [5]

PSS are seen as an excellent mean to enhance the competitive ability "and to foster sustainability at the same time" [6]. This implies a dualistic approach on attracting the customer's attention. The feature-driven product perspective is supported by the more solution-oriented service perspective [26]. Mont summarizes five characteristics for PSS as followed: [27]

- A PSS may consist of products, services, or various combinations of them. Products substituted by services are largely an ideal category without many practical or consistent examples, because any service, even nonmaterial per se, requires material or energy inputs.

- Services, at the point of sale, comprise personal assistance in shops, financial schemes provided to customers, explanations about product use.
- Different concepts of product use consist of two categories: use oriented, where product utility is extracted by the user, and result oriented, where product utility is extracted by the utility provider for the user.
- Maintenance services include servicing of products with the goal of prolonging product life cycle, comprising maintenance and upgrading.
- Revalorization services include offers that aim at closing the product material cycle by taking products back, secondary utilization of usable parts in new products and recycling of materials if reuse is not feasible.

Therefore, Tukker [6] characterizes eight types of PSS in his work – a range from product-related services to a functional result for the consumer.

According to Meier, Roy & Seliger [28], in the domains of mechanical engineering and plant design, "product-related services are usually considered as an add-on to the actual product. Industrial PSS deal with dynamic interdependencies of products and services in production. Research areas cover new concepts and methods which enable the machine producers to design the potential services in an optimal way, already during the development of the machine. This paradigm shift from the separated consideration of products and services to a new product understanding consisting of integrated products and services creates innovation potential to increase the sustainable competitiveness of mechanical engineering and plant design. The latter allows business models which do not focus on the machine sales but on the use for the customer e.g. in form of continuously available machines. The business model determines the complexity of delivery processes. Characteristics of industrial PSS allow covering all market demands." [28]

4 Research process

Two case studies were employed to illustrate and compare the key characteristics and differences of product-service requirements of through-life information by two different strategy choices. Initial description of the case companies is introduced in Table 2.

Table 2. Description of case company characteristics

Case company characteristics	**Company A**	**Company B**
Main business area	Global designer, manufacturer and distributor of agricultural equipment and related parts	Supplier of a complete range of machinery, systems and technology for plywood and veneer production
Strategic choice of Business and product	High-volume mass-customizing ATO/CTO/BTO strategy	Low-volume project-based ETO strategy
Special characteristics	Individual products for individual use by customer order system	Long term installed bases

The primary data was collected by making semi-structured interviews in the case companies. In total, 10 persons were interviewed. Interviewees were chosen from the key functions, representing at least by one person related to both case companies.

The topic areas of the interviews were as follows: Business model/strategy transition; Structuring of product and product related information; Lifecycle related requirements; Role/accountability of services and lifecycle business; Practices of product-service information sharing in company networks; Principles of modularization of products/services/processes/information; Expanded product data (3D+) in design-manufacturing - service; Applying ECM processes in product/service specifications. The elicitation of the requirements information for PSS was based on combining literature results, earlier research in the manufacturing industry, authors' particular experience and insights, and the company-specific results discovered in the case companies.

5 Derived requirements for product-service system

As a result of the interviews, requirements on product, service and product-service in ATO and ETO strategy are identified and classified. Derived requirements are presented in Table 3. The capabilities suitable for each requirements class (product, service, PSS) were selected. The derived requirements were analyzed for ETO and ATO strategies in terms of customer coupling-point, structuring base of product-service and related information, principles of product modularization, sustainability of PSS and managing through-life PLM processes and networks.

Several differences in ATO and ETO strategies were found in the study. For instance, in ATO strategy offered requirements are frozen in the early stage of development which enables better utilization of module-based PSS for customer needs. Respectively, in ETO strategy the challenge is to manage simultaneously frequent requirements changes and through-life requirements related to e.g. sustainability, reusability, repeatability and traceability. The key observation found in this study is that the timing of the customer-coupling point affects strongly on the possibilities of modularity and utilization of through-life requirements.

6 Conclusions

This paper combines the knowledge on requirements information management and PLM by examining the research questions through literature and two practical case examples. The questions were answered by a literature overview identifying the trends in the business environment of manufacturing companies and following changes in new product information requirements, mainly focusing on sustainability, traceability and performance. Changes in strategy towards more customer orientation, legislation changes towards environmental sustainability, and closed-loop manufacturing /PLM have had a profound effect on information needs and product information management practices in manufacturing companies.

Table 3. Through-life requirements for product-service systems

Capabilities for PSS	ATO Strategy	ETO Strategy
Product requirements		
Customer coupling-point	Product offering as-designed	As-ideated functionalities, performance proposition
Structuring base of product and related information	eBOM & mBOM structures, Requirements & Features	Design for supply /installation processBOM
Principles of product modularization	Ready-designed modules to be ATO as product variants	Through-life knowledge base of ETO as \`reference project-products\`
Managing through-life PLM Processes	Reusability of product information: designs / structures / changes	Repeatability of processes related to \`project-products\`
Service requirements		
Customer coupling-point	Service order as-maintained	Service contract as-maintained
Structuring base of service and related information	dBOM & sBOM of individual product delivered	ProcessBOM of service & operation
Principles of service modularization	Serviceability of component / module /system /product	Serviceability for usability of machinery and production
Role of services and lifecycle business in company	Accountability for concurrent product & service development	Accountability for lifecycle support of product & service
Product-service requirements		
Customer coupling-point	Combined product-service offering as-ordered	Combined lifecycle support of product-service system
Structuring base of product-service and related information	Global BOM integrated by concurrent product & service eBOM,mBOM,dBOM,sBOM	Global processBOM of \`extended project product\`
Sustainability of PSS	Closed-loop concurrent design of module based product, components and related services	Closed-loop concurrent design of through-life \`project product\` and lifecycle services
Managing through-life PLM processes and networks	Through-life traceability of product & service structures	Through-life traceability of extended 'project-product' with service processes

Eliciting product-service lifecycle requirements in customer-centric business models is based on the literature and empirical findings, confirming the practical relevance of the findings. A comparison between ETO (project-based) and ATO (mass-customized) operating strategies and their influence on the product-service system requirements was presented based on literature and empirical findings from two case companies.

The results of the paper can be utilized in companies planning and developing their product-service offering, and related requirements and processes both on business strategy level and technical information management level. The elicitation of product service requirements acts as basis for comprehensive data structure planning. Although the empirical results of this study are limited on two case studies, they are selected to highlight typical features of different customer-centric manufacturing strategies and thus provide a possibility for adapting the results wider in similar companies.

Further research is needed to develop a framework for data structures in companies following ETO and ATO strategies, as well as for testing the applicability of the findings in other contexts.

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