Knowledge Generation as a Means to Improve Development Processes of Industrial Product-Service Systems

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Abstract
In business-to-business and also business-to-customer markets there is a tendency towards combined offers of products and services, which are sold in one package to fulfil customer needs. These combinations of products and services are called product-service systems (PSS) or industrial product-service systems (IPS^2) in case of industrial application. Feedback approaches for knowledge which can be captured during the delivery and use phase of IPS^2 are discussed in this paper. This knowledge is notably valuable for the development process of IPS^2. The focus is on knowledge generation systems capturing information related to products and processes anywhere available. These, so called Virtual Life Cycle Units (VLCU) collect operation data of products and services and generate knowledge about the systems behaviour or usage. Both development and operation benefit of captured information and generated knowledge to improve systems development and operation projects. The role of the knowledge generation, enabled by the VLCU, in the IPS^2 development process will be described in detail using different PSS examples and business models.

Keywords:
Industrial product-service systems, manufacturing system, development processes, knowledge generation

1 INTRODUCTION

In business-to-business and also business-to-customer markets there is a tendency towards combined offers of products and services, which are sold in one package to fulfil customer needs. These combinations of products and services are called product-service systems (PSS) [2] [3] or industrial product-service systems (IPS^2) in case of industrial application. The adaptation of products and services to continuously changing technical requirements, application areas and user demands is crucial to select the right PSS business model (e.g. an availability-oriented PSS offer). This requires new integrated methods, process models and tools for planning, development, delivery and use of PSS to exploit their full potential and to ensure the competitiveness of these systems.

Knowledge feedback approaches for PSS development are focused in this paper. Knowledge can strategically be collected during the delivery and use phase of a PSS. This knowledge is notably valuable for the development process of a PSS and for its delivery. Different loops of feedback will be characterized and discussed. First, customer feedback integration, and second, knowledge generation systems capturing information related to products and processes. Such systems collecting operation data of products and services anywhere available to generate knowledge about the systems behaviour or usage are called Virtual Lifecycle Units (VLCU). Developers can benefit of information and knowledge provided by VLCUs to improve their systems in further development projects. Furthermore, they have the ability to request missing information by designing a proper VLCU integration during the PSS development.

1.1 Basic ideas of product-service systems

In the area of high cost machinery PSS are sold instead of stand-alone products or services to exploit earlier unused economical and technical potentials or to enhance the value for the customer, cf. [1]. As in other branches, customer needs are not any longer simply reduced to a single need for product ownership. The lifecycle-orientation of PSS leads to aspects like availability, flexibility of system reconfiguration or sustainability. This requires the partial substitutability of products by services and vice versa. Those aspects are considered in a PSS scope. Additionally, proper feedback mechanisms to capture important or missing lifecycle information have to be implemented.

In research product-service systems are often linked to sustainable development or eco-design [3]. For instance, smart product (e.g. car) sharing strategies combined with supporting services could be used as an example to demonstrated potential of dematerialisation to face lesser resources.

Potentials to differentiate from competitors and to implement anti-piracy measures [4] lead to new business models. These help to bind customers for a longer period than typical with traditional product purchase and they offer new ways for economic benefits.

Social aspects are also often linked into PSS by various authors. Terms like ‘social responsibility’ or ‘green business’ become new drivers to focus on new forms of system characteristics, which seem to be relevant in PSS marketing.

1.2 Research in PSS-related areas

Close to product-service systems we find technical disciplines like 'Service Engineering (SE)' [5] [6], 'Integrated Product and Service Engineering (IPSE)' [7], 'Functional Sales (FS)' [7] or 'Functional Product Development' (FPD) [8].

The research project SFB/TR29 'Engineering of Industrial Product-Service Systems', funded by the German Research Foundation (DFG), focuses on the integrated planning, development, delivery and use of products and services [9]. The central idea in this research project is that the potential of product-service systems can only be fully exploited if the processes and methods for the development of products and services are adjusted to each other. The integrated view on products, services and their immanent software assemblies in all of the four phases planning, development, delivery and use is considered as an essential characteristic of PSS, cf. [1].

In this paper the research topics and approaches of two project partners of the SFB/TR29 will combined: The 'Development processes of Product-Service Systems' will be linked to the 'Automated Knowledge Generation'.

2 KNOWLEDGE EXCHANGE BETWEEN PSS DEVELOPMENT AND DELIVERY PROCESSES

As in every development process knowledge about the systems lifecycle (ramp-up, use, optimization, etc.) is vital to develop effective, highly efficient systems, cf. [10]. In contrast to traditional product purchase PSS business models allow the PSS provider a closer contact to its PSS. This offers PSS providers opportunities to learn more about their product-service systems. A PSS business model which implements for instance availability-oriented product use (product possessed by the provider and 'used' by a customer + availability ensuring service delivered by the provider) gives them a platform to collect information which earlier was only accessible for the customer or by feedbacks of service personnel. VLCUs are an enabler to support direct feedback additionally to feedback from technicians and customers, see Figure 1.

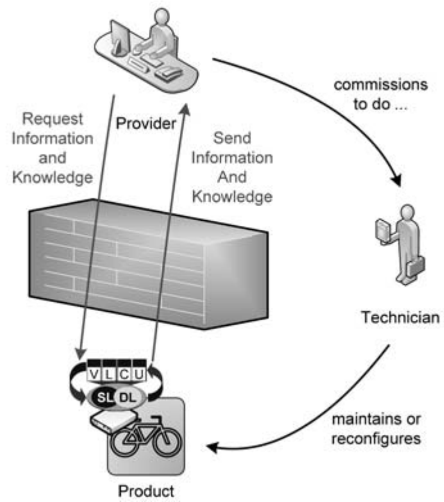

Figure 1: Direct feedback from a product enabled by a VLCU.

2.1 Floating borders of the development process

A closer look shows that there are two different types of knowledge and information exchange.

1. Knowledge and information 'circulating' within the delivery process of a PSS used to manage the delivery process.
2. Knowledge and information about the delivery process flowing into following or ongoing development processes.

Additionally the borders between the PSS development and delivery phase are dissolved by two other aspects:

1. The close contact between the provider and its PSS enabled by applied services (executed by technicians or technical devices).
2. The continuous customer integration already during development: The customer integration is often mentioned as very important for PSS development [11], cf. Figure 5. It is important to gather customer needs and to make customer activities (as external factor, cf. [12]) during the systems use visible to the designer of a PSS [2] [13].

Figure 2 visualises the overlap of development and delivery and the information flow. The PSS is designed and later introduced into the market. During the systems operation (delivery and use phase) feedback on the operation can be used for reconfiguration (extension or a down-grading of service contents or product modules), redesign or further development of the PSS during its lifecycle. Thus, the PSS development phase does not end with the preparation of the production and operation documentation as e.g. in the general approach of VDI 2221 [14]. Production and consumption, in contrast to product manufacturing and purchase, are not clearly separated, caused by the characteristic of services that production and consumption is simultaneous [2].

The dynamic character of product-service systems finally determines a kind of 'fuzzy-backend' [15] of the development process. Simplified it is shown in

Figure 3, which is an adoption of the model for Integrated Product Development by Andreasen and Hein [16].

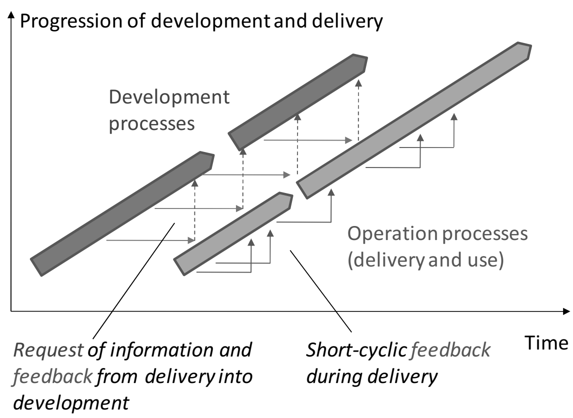

Figure 2: Information flows between PSS development and operation (delivery and use).

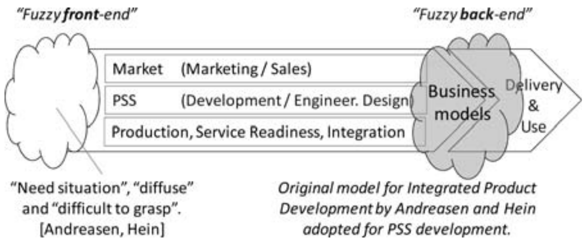

Figure 3: Integrated PSS development incl. fuzzy back-end.

Despite the 'fuzzy back-end', the development process has to be well coordinated and PSS releases have to be consistent after every reaction on (cyclic) effects which 'return' from the lifecycle of a particular PSS (Figure 4). According to our view different types of information flows are characterized by Figure 5. Next to mechanisms to capture customer feedback technical solutions, especially VLCUs, can be used to generate a continuous flow of information from the delivery and use phase into further development or system adoption/reconfiguration. This can be information of service personnel states, service quality and time or information on machine operation details (e.g. processed vibration or load details). Designers of PSS profit by using these conditions to request missing information based on 'feed-forward' mechanisms to enhance the PSS further development. 'Random' feedback and requested information together build a broader basis for efficient PSS design.

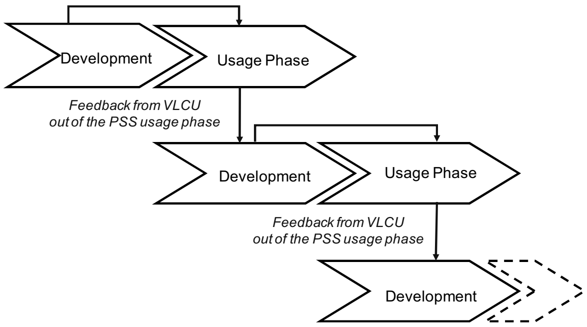

Figure 4: Example of feedback waterfall.

Both variants of information feedback (customer feedback and requested information feedback enabled by technical devices like VLCUs) has to be planned smartly in order to support decisions on how to react to findings gained from delivery processes. Reactions, for instance, can be marginal short-term changes in the coordination of delivery processes or result in heavy impacts on the development processes of a product-service system.

In the following sections there will be a focus on the capabilities of VLCUs to show which information can be requested by PSS designers and how additional (unexpected) knowledge can be generated. Two brief examples will be used to describe situations motivating this approach. One detailed example demonstrates the influence of different PSS business models on the PSS.

3 KNOWLEDGE GENERATRION DURING OPERATION

3.1 Fundamentals about the VLCU

Effective and efficient adaptation can help to reduce resource consumption by e.g. extending the product's life span and by supporting usage-oriented business models. As manufacturers and PSS providers are confronted with increasing demands for product and process availability, reliability and safety, the assessment, prediction, diagnosis, monitoring and control of past, current and future product and process behavior is desirable. Moreover these data and information deliver potential sources to find knowledge like inferences about conditions, wear or quality aspects and deliver so knowledge about the behavior and usage of their products.

Adaptation is facilitated by product accompanying information systems which are integrated into products and components and that are capable of acquiring, processing, and communicating relevant product and process data and information and generate knowledge during the entire life span [18].

The VLCU is a concept for a PSS accompanying information system for knowledge generation and automation, see Figure 6. A VLCU acquires via sensors or IT-Documents data and information from PSS operations, wherein the term operation includes products and services. This may include technical, economical, environmental and social product and process

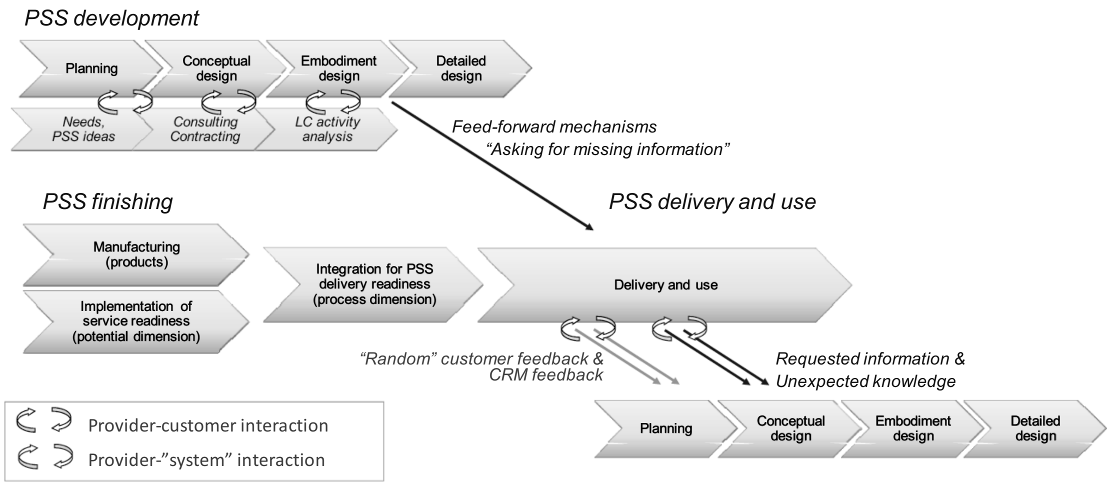

Figure 5: Stream/Cycle of PSS development, finishing, delivery and use – Classification of feedback mechanisms.

attributes and parameters [17] e.g. location, utilization, efficiency, emissions, condition, malfunctions and failures.

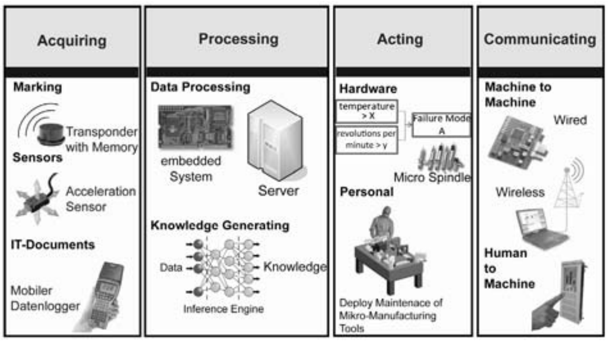

Figure 6: Modular concept of a Virtual Life Cycle Unit.

The acquired data and information will be processed with the objective to generate knowledge, e.g. inferences between product or process parameters and failures. Acquired and processed data, information and knowledge is being communicated for further evaluation or to inform the PSS management. With the help of condition prognoses the need of maintenance can be identified and automatically deployed. It is also possible to set up so called “failure modes” to prevent damage, which will be triggered if generated knowledge forecasts this on a running process. These data, information and knowledge can also be used to assist processes of the value creation chain such as development, redesign, production, recycling and disposal, and supporting processes such as logistics, quality management, controlling and sales. VLCUs improve usage-oriented business models like PSS including enhanced maintenance services.

The described architecture can be realized as a distributed network of embedded systems. More powerful and more processing power requiring algorithms can run on servers, executing the data and information evaluation [18].

In the PSS use phase the VLCU is able to acquire potential information about the usage behavior, resource needs, services and workers. This sets a base for the search of inferences, e.g. worker qualification, service efficiency or flowcharts regarding the user demands and requirements. This knowledge is invaluable for cost and resource reducing in service planning or redesign of the PSS. The goal is to increase the use-productivity of resources in PSS by finding inferences about adaptations between different usage phases.

3.2 Data acquisition in PSS

The problem of acquiring and processing data from complex machines can be solved by concentrating on standard components. Standard components like bearings, gears, compressors, pumps, dampers, filters, hose lines or pneumatic components are integrated into various more complex products, e.g. assembly systems, ground conveyors or industrial robots. By focusing on the assessment of data on standard components of machines, the development effort for the assessment of complex products is distributed technically and economically on many applications. Also, less overall expertise is needed in order to develop a VLCU system for complex products or components, because each subsystem can be examined almost independently of the others. The solution space is significantly reduced for each VLCU designer, Figure 7.

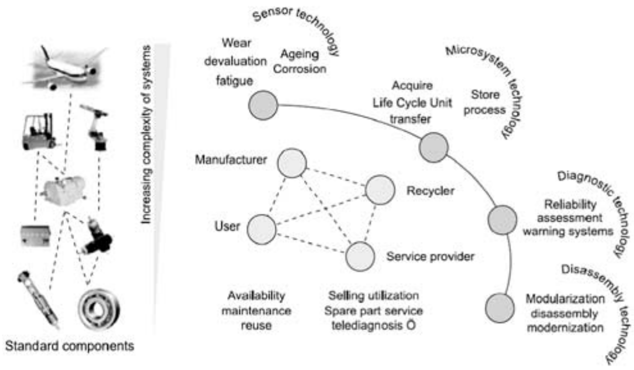

Figure 7: Products, standard components, interest groups, and business areas [19].

Maintenance processes on those standard components are a ‘door’ for data acquiring of a service. This enables a direct connection to the standards component, failure prognoses and to detect critical system parameters, inferences between services on a component and its condition, e.g. remaining life time or failure rate.

For VLCU implementations there are four major groups of services of a PSS, as shown in Figure 8. The indicators for those services are almost similar and basing on simple dimensions like time, amounts, evaluation levels and qualification classes. These information are in most instances already acquired in service documentary by the technician and the customer. Combining these information with the product condition data of the standard components, enables a failure diagnosis and prognosis with influences of the service applied to the product. Further, this facilitates to find inferences between standard components and services.

The PSS helps organization profits of knowledge of the use phase. This enables to set up the best service at the right time, location and with the optimal tools.

Figure 8: Services applicable to products in a PSS and relevant criteria for the knowledge generation.

3.3 Key steps of the automated knowledge generation

The knowledge generating procedure is divided into eight steps:

1. **Data Acquisition:** acquire data from sensors on the product and product related information, e.g. datasheets
2. **Data Cleaning:** remove noise and inconsistent data
3. **Data Selection:** select the part of the data that are relevant for the PSS
4. **Data Integration:** combine multiple data sources to information
5. **Data Transformation:** transform the data into a suitable format (e.g. a single table, by summary or aggregation operations) and store them in a database for further processing and access
6. **Data Mining:** apply machine learning and machine discovery techniques, e.g. inference engines
7. **Pattern Evaluation:** evaluate whether the found patterns or inferences meet the requirements (e.g. interestingness)
8. **Knowledge Presentation:** present the mined knowledge to the PSS provider (e.g. visualization)

The PSS provider receives new identified knowledge and is enabled for an effective and efficient redesign or reconfiguration of his PSS to changing customer needs and requirements.

To facilitate a high profit of a VLCU the designer has to take care about product and process related information. Sensors on process related or system critical components enable to generate information and knowledge. The PSS designer has specially to integrate such considerations into his design.

4 PSS (RE)DESIGN INCLUDING KNOWLEDGE GENERATION IN THE USE-PHASE

A product used in daily life has been chosen to demonstrate the capabilities of VLCU applications. The real demonstrator bases on a bicycle equipped with sensors and other VLCU components. This example is transferable to other mobile systems in the areas of transportation or construction e.g. cars, ships, cargo etc., but also to stationary systems like manufacturing system influenced by the dynamics of their environment.

4.1 Motivating examples

Especially systems running in processes with not clearly described boundary conditions (e.g. mobile systems as road construction machinery) or systems implementing new technologies (micro-manufacturing systems) have huge potential for VCLU use in a PSS business model and for PSS further development:

Mobile construction machines: The execution of numerous experiments covering all potential operation situations (e.g. machine-soil pairs with different soils all over the world) is often too expensive and a lot of findings are gained randomly in the field. A VLCU can help to build up a broad database to investigate inferences of different operation influencing parameters to design enhanced operation surveillance systems to raise the systems operation quality.

Micro-manufacturing systems: A down-scaling from macro-manufacturing is not in all cases possible. Environmental influences affect for instance the repeatability accuracy in manufacturing processes, but which factors are relevant and which are not is yet sometimes unclear. 'Asking' selectively for information on interfering factors which is missing in development can support designers to develop better systems (quality evolution). Especially for systems including modern technologies which are not to their full extent 'understood' by the designers this could be helpful to build up specific design, implementation or use guidelines.

In both cases/examples the customer finally gets product-service systems of better quality based on better controlled technologies and delivery processes, if the provider uses options like VLCUs to turn the close contact to its PSS into a design benefit.

4.2 Bicycle in a PSS business model

To provide people a bicycles-based mobility PSS is commonly offered by several companies around cities in Europe, e.g. 'Call-A-Bike' (Germany) [19], 'Vélo'v' (Lyon, France) [20] or 'Velotaxi' [21]. The availability of mobility is offered, the products are located around the inner cities and services are done in time intervals. However, there is no product accompanying information system installed and damage or knowledge for redesigns of the bicycles depends on comments of the customer or by technicians frequently inspect the product to check its condition.

A VLCU installed on those products can deliver valuable knowledge and information about the product condition and the usage of the bicycles, see Figure 9. With a few data interesting information can be generated, e.g. with data of acceleration and damper deflection it could be identified if the bike has been used as designed on regular streets or on dirty roads, e.g. in the wood. This knowledge can be used e.g. in a redesign approach to assemble tires for dirty roads or doing a constructive adjustment to a mountain bike. By adapting the bike to the required usage the provider benefits of more customers and a higher customer satisfaction. This example shows how a VLCU enables an enhanced design by providing information and knowledge of the use phase.

In functionality-oriented PSS the provider is interested to offer mobility as function to the customer. Breakdowns can be avoided by VLCUs condition prognoses. This enables condition based maintenance of the bicycle, which enhances the use-productivity of each component and saves resources and money by this.

In availability-oriented PSS, e.g. Call-A-Bike, the provider is able to organize his maintenance crew on the basis of the product condition and arrange reconfiguration due to usage demands. The customer benefits are a product designed on his needs, more safety by having condition prognosis of critical components integrated and more features, e.g. fun-factors like damping information on his ride.

In result-oriented PSS, the provider is interested to deliver the requested option to the customer in the right time in the right place. This requires fully functional bicycles and location information to direct the customer to the bicycle or vice versa and to the desired destination. Conditioned diagnoses and GPS location information provided with the help of the VLCU, by data from sensors on the bicycle combined with worldwide available data about traffic information, enable to provide mobility to the user with highest efficiency and effectiveness.

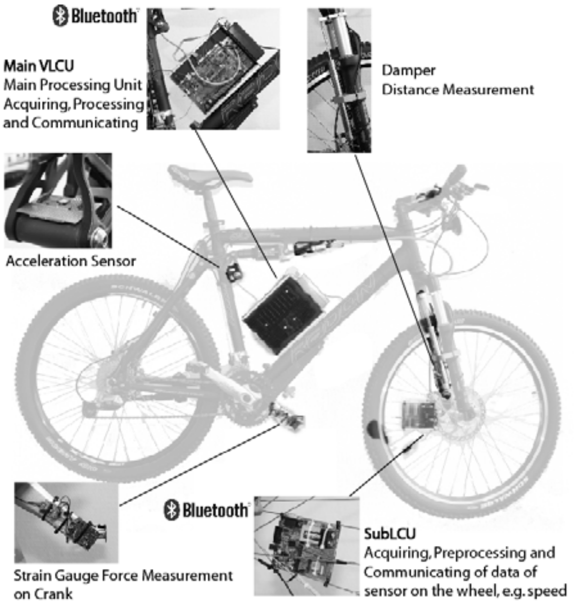

Figure 9: Conceptual VLCU application on a bicycle for use in a PSS business model.

5 SUMMARY AND PROSPECTS

In the PSS design phase the PSS designer has to check what the problems for the PSS use phase might be – where the critical points are – so that the VLCU is able to generate knowledge about the interesting points. The classical development model has to be enlarged to take into account the VLCU design and ways of information request and knowledge feedback. Further, the feedback loops from the use phase, delivered by the VLCUs set up a cascade of an ongoing enhanced design. To teach the designer adequate monitoring and knowledge generating tools, a convenient overview about sensors, algorithms, related information and indicators of components and processes is required and has to be composed.

6 ACKNOWLEDGEMENTS

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