Lecture Notes in Production Engineering

Horst Meier
Editor

Product-Service Integration for Sustainable Solutions

Proceedings of the 5th CIRP International Conference on Industrial Product-Service Systems, Bochum, Germany, March 14th–15th, 2013

Springer

Lecture Notes in Production Engineering

For further volumes:
http://www.springer.com/series/10642

Horst Meier (Ed.)

Product-Service Integration for Sustainable Solutions

Proceedings of the 5th CIRP International Conference on Industrial Product-Service Systems, Bochum, Germany, March 14th–15th, 2013

Springer

Editor
Horst Meier
Ruhr-Universität Bochum
Lehrstuhl für
Produktionssysteme Universitätsstraße
Bochum
Germany

ISSN 2194-0525 e-ISSN 2194-0533
ISBN 978-3-642-30819-2 e-ISBN 978-3-642-30820-8
DOI 10.1007/978-3-642-30820-8
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2013931227

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Product-Service Integration for Sustainable Solutions

Worldwide, a change toward more value-oriented thinking has recently been taking place. This goes along with a structural change from a product-centric to a service society, which affects private life as well as industry. Companies in mechanical engineering and plant manufacturing have recognized the great potentials which lie in the paradigm shift of providing customer value instead of selling products. Thus, established industrial companies are pursuing the integration of products and services and develop innovative business models for solution-oriented businesses. This development is further driven by the recent progress of important enablers for IPS^2, such as wireless data transmission, mobile devices and applications, and other advances in information and communication technology. These enable new forms of location-independent collaboration and smart products, which already have and increasingly will influence value creation in various branches.

One considerable motivation for product-service integration is seen in a significant potential for sustainability gains, both for provider, customer and society as a whole. Increased economic sustainability can be achieved by prolonged and intensified partnerships with customers and suppliers, which brings along a beneficial combination of individual competences and sustainable competitive advantages. Prolonged lifecycles with continuous product updates and reuse services during IPS^2 closure increase resource efficiency and contribute to environmental sustainability. Integrated products and services provide solutions to systematically support and qualify inexperienced machine users. This grants companies in developing countries with low technical qualification access to advanced technologies and allows them to raise their performance in the global competition.

In order to allow providers and customers to make use of the full potential of product-service integration, methods and tools for the planning, development, operation and delivery of IPS^2 need to be developed, evaluated and applied. The organization of IPS^2, their marketing and selling, risk management, knowledge management, business models for IPS^2 and many more relevant topics pose various challenges and offer promising approaches for the engineering of IPS^2. Therefore, methods and tools from various disciplines, e.g. mechanical engineering, economics and computer science need to be combined to exploit the full potential of product-service integration.

I am very delighted to see that this strong interdisciplinarity is reflected in the growing scientific community of researchers and practitioners around the world. For the fifth time, this international community has come together at the international CIRP Conference on Industrial Product-Service Systems to discuss recent developments, research findings, visions and applications in the field of IPS^2. After previous conferences in Cranfield (2009), Linköping (2010), Braunschweig (2011) and Tokyo (2012), this year's conference is to be held at Ruhr-Universität Bochum, Germany, which is the place of foundation of the Collaborative Research Centre / Transregio 29 "Industrial Product-Service Systems (IPS^2) – Dynamic Interdependencies between Products and Services in the Production Area". Transregio 29 has been funded by the German Research Foundation (DFG) since 2006. Around 40 researchers from Ruhr-Universität Bochum and Technische Universität Berlin in 15 subprojects and 3 transfer projects have dedicated their common effort to this challenging, interdisciplinary field of research. Therefore, I am particularly excited about hosting this year's conference in Bochum and look forward to many presentations on cutting-edge research, lively discussions and enlightening insights into the various facets of Industrial Product-Service Systems.

Prof. Dr.-Ing. Horst Meier
Chairman and Organizer of the 5th CIRP Conference on Industrial Product-Service Systems

Organization

Chairman

Prof. Dr.-Ing. Horst Meier

International Scientific Committee

Prof. M. Abramovici / DE
Prof. T. Arai / JP
Prof. J. Aurich / DE
Prof. T. Böhmann / DE
Prof. D. Brissaud / FR
Prof. J. Duflou / BE
Prof. Å. Ericson / SE
Prof. C. Herrmann / DE
Prof. S. Kara / AU
PD R. Knackstedt / DE
Prof. S. Kumara / US
Prof. T. Larsson / SE
Jun.-Prof. K. Laurischkat / DE
Assoc. Prof. M. Lindahl / SE
Prof. K. Matyas / DE
Prof. N. Mishima / JP
Prof. J.-G. Persson / SE
Prof. M. Rese / DE
Prof. R. Roy / UK
Prof. H. Rozenfeld / BR
Prof. T. Sakao / SE
Prof. G. Seliger / DE
Prof. Y. Shimomura / JP
Prof. W. Sihn / AT
Prof. R. Stark / DE
Prof. M. Steven / DE
Prof. S. Takata / JP
Prof. T. Tomiyama / UK
Prof. E. Uhlmann / DE
Prof. U. Wilkens / DE
Prof. E. Zahn / DE

Chief Organizers

Thomas Dorka
Henning Lagemann

Organizing Committee

Maik Auricht
Michael Herzog
Simon Husmann
Dr.-Ing. Dieter Kreimeier
Marina Preusche
Akamitl Quezada
Thomas Süße

Contents

Keynotes

Planning and Development – Concept and Design

Planning and Development – Networks

Planning and Development – Methods and Know-How Protection

Planning and Development – Eco Design and Sustainability

Business Model – Design

Business Model – Implementation

Operation

Service Engineering

Strategy and Sustainability

Knowledge Management

Software and Information Systems

Modeling and Simulation

Marketing and Economic Aspects – Lifecycle Perspective

The Human Factor

The Future of Maintenance for Industrial Product-Service Systems

Rajkumar Roy, John Ahmet Erkoyuncu, and Andy Shaw

EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services,
Cranfield University, Cranfield, Bedfordshire, MK43 0AL, UK
{r.roy,j.a.erkoyuncu,a.shaw}@crandfield.ac.uk

Abstract. This paper aims to present a landscape of interests that are emerging for the future of maintenance in Industrial Product-Service Systems. Across manufacturing industries there is growing interest to integrate products and services, where maintenance has a key role in delivering performance driven solutions (e.g. availability). It is observed that industry is aiming to gain competitive advantage, and the customer is increasingly intending to transfer the risks and uncertainties as reflected in contracts. The shift towards services is also putting more pressure on industry to accurately predict service requirements in terms of resulting cost and performance that enables the service provision. In light of these drivers, technologies and organisational themes are emerging to reduce uncertainty and cost for the in-service phase as explained and discussed in the paper.

Keywords: Maintenance, Through-life Engineering Services, Industrial Product-Service System, Uncertainty, Availability, Cost.

1 Introduction

Manufacturers are increasingly recognizing that the in-service phase of the life cycle offers increased revenues and profitability [1]. This has promoted the need to understand the processes, resources and technologies that are required to sustain and enhance the equipment health and performance over the life cycle. This paper focuses on the Industrial Product-Service Systems (IPS^2) context and aims to present an overview of the trends in product maintenance research to support the integrated product and service offering. Maintenance serves as the major engineering service in the IPS^2 delivery model. Maintenance involves a combination of technical, administrative and managerial actions during the life cycle of an item with the aim of retaining it in, or restoring it to, a state in which it can perform the required function [2]. Also, Maintenance, repair, and operations (MRO) or maintenance, repair, and overhaul involves resolving any sort of mechanical, plumbing or electrical device issues in the case of becoming out of order or broken. Whilst the customer is typically acknowledging the large cost burden experienced from maintenance, innovative forms of contracting are increasingly emerging that puts further pressure on the solution provider to extend the product life cycle through services and so reduce the overall cost [3,4]. The

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 1–15.
DOI: 10.1007/978-3-642-30820-8_1

motivation of this paper is to guide both academia and industry to understand the role of maintenance in IPS^2 type contracts and to explain how the cost and performance targets can be achieved. Section 2 presents an overview of maintenance and associated targets. Section 3 presents the emerging themes for the future of maintenance. Finally, Section 4 covers concluding remarks.

2 Understanding the Role of Maintenance

2.1 Research Background in Maintenance and MRO

Research interest in maintenance and MRO within the engineering domain (including aerospace, defence and engineering) has been growing dramatically since 2005, as demonstrated in Figure 1. The search was conducted in Scopus with the keywords: maintenance or MRO and aerospace or defence or automotive. It is also recognized that the USA has produced over 600 articles, whilst the two other highest article producing countries have been China and the UK with over 200 articles from each.

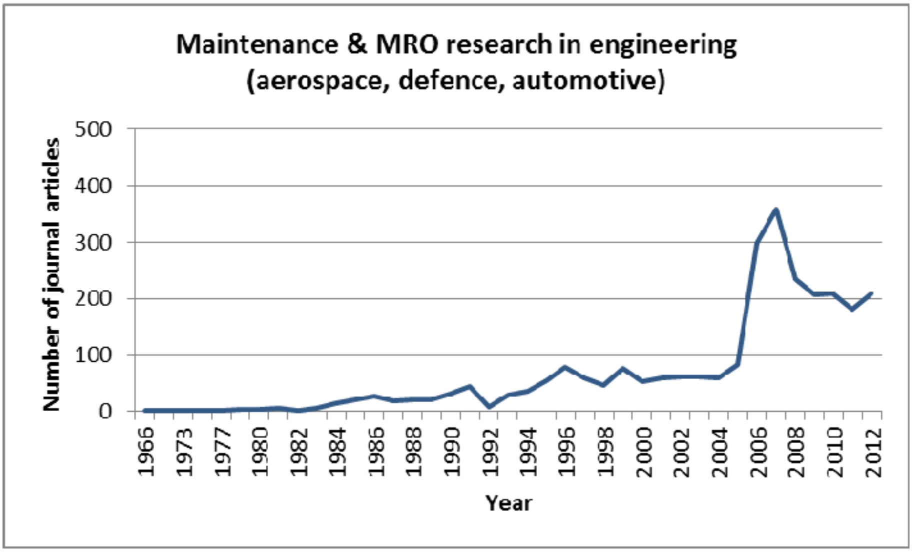


Fig. 1. Number of publications in maintenance and MRO

There are a number of dedicated research centres within the area, which highly influence the publications, including: EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services (UK), Integrated Vehicle Health Management Centre (UK), Aviation Services Research Centre (China), Fraunhofer Innovation Cluster MRO in Energy and Transport (Germany), Center for Advanced Life Cycle Engineering (USA), Luleå Railway Research Center (Sweden) and The Center for Intelligent Maintenance Systems (USA).

2.2 Shifting Customer Targets: The Role of Contracts

The IPS^2 literature classifies the types of business models into three categories [1, 3]. Firstly, the function-/product-oriented model concentrates on selling the product in a traditional manner, while additional services are included (e.g. maintenance, repair). The second model, known as use-/availability oriented (e.g. Contracting for Availability – CfA), focuses on selling the use or availability of a product that is not owned by the customer (e.g. leasing, sharing). Thirdly, the result-oriented model offers the sale of a result or capability instead of a product (e.g. selling parts instead of the facility for manufacturing them). These models can be subdivided into several individual business models, where the models differ for various reasons (e.g. ownership of product, payment method, supply of operating personnel) [3]. However, it is worth recognising that there is currently an emphasis in industry to enter into CfA type agreements [4].

When the solution provider takes decisions such as whether to bid for a contract or accept one when offered, they need to do so based on an understanding of the uncertainty in maintenance for the duration of service delivery [5]. This necessitates better prediction of uncertainty for IPS^2 than has been typical of traditional contracts in the past because the contract timescales are much longer, and ownership of uncertainty has been transferred from customer to the solution provider - typically on a fixed-cost basis [4, 5]. Furthermore, as major agreements with large financial burdens, driven by cost and schedule estimates, can be agreed at the bidding stage, there is a need to apply rigorous steps to take account of the influence of uncertainty on cost [6].

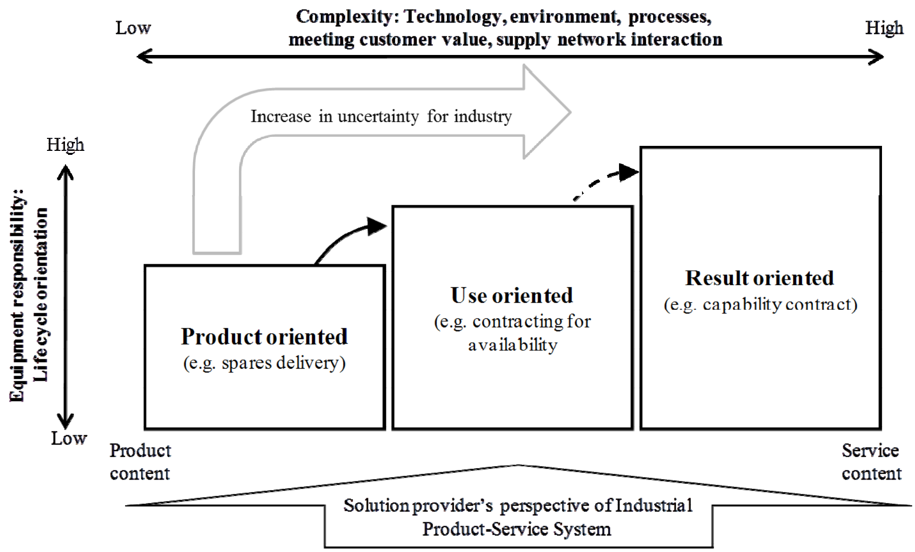


Fig. 2. Uncertainty and types of solutions in IPS^2 [5]

The IPS^2 context offers a larger set of uncertainties that industry needs to manage, due to the enhanced scope and complexity of the service solution being offered [5]. Some of the areas to consider include assessing the performance and the requirements of the service delivery, and the enhanced dependence on external sources. For instance, obsolescence is increasingly becoming challenging to manage and is creating large cost implications. Obsolescence, which is most often experienced in electronics equipment's, refers to the state of being which occurs when an object, service or practice is no longer available even though it may still be an effective technical solution [7]. Its mitigation requires an integrated supply chain and flexibility in the design of equipment with a view on how to tackle the obsolescence issues that may arise in a planned or unplanned manner. Driven by such aspects the delivery of service is less well understood at the early stages compared to the traditional model, due to the increase in the experienced uncertainties [5].

Table 1. Types of contracts and associated challenges in IPS²

	Contract type		
Contract name	*Fixed price contract*	*Cost plus contract*	*Performance based contract*
Characteristics	- Maximum risk on suppliers - Greatest incentive to reduce cost - No performance incentives	- Risk is shared - Least incentive to reduce cost - Moderate performance incentives	- Moderate risk on suppliers - Moderate incentive to reduce costs - Greatest performance incentives
Challenges	- Inaccurate cost estimates, - Technological unknowns, - Changing requirements - High financial risks	- Adequate cost control that promotes cost sustainment and reduction - Cost overruns experienced often	- Accurate estimate of % for pain/gain share - Adequate penalty and incentive limits - Risk of not meeting performance

CfA are currently being awarded on the basis that they span the manufacturing and in-service phases of the CADMID lifecycle but the bids are often prepared and submitted in earlier phases [5]. The move towards CfA has followed an iterative transition, which has experienced a shift from providing the traditional business model into spares inclusive maintenance contracts (e.g. product oriented), CfA (e.g. use oriented) and contracting for capability (e.g. result oriented), as represented in Figure 2. The traditional business model stands at one extreme where the product and the service are considered separately and the service is an add-on feature to products that are sold. Roy and Cheruvu [3] identified different IPS² contract types from the literature and various industries, as illustrated in Table 1. These are classified into three types: fixed price, cost plus and performance. Fixed price contracts, concentrate on delivering the solution at the agreed price and pose the highest risk option for the solution provider. As a result, adequate measures (e.g. technology adoption) need to be taken in order to reduce cost and control service delivery. The cost plus approach introduces risk sharing between the customer and the solution provider, where costs/savings are shared for certain scenarios as specified in the contract. Thirdly, performance contracts are highly driven by incentives and promote further collaboration along the supply chain. Among these approaches, there is an emphasis to agree fixed price contracts, which can span the whole lifecycle of the equipment. Table 1 also presents the major challenges that are experienced across all the presented contract types. Datta and Roy [6] highlighted that the main parameters considered during the process of agreeing contracts are responsibility, cost of performance and incentives.

2.3 Targets of Maintenance in IPS^2

Maintenance is currently increasingly being included as part of the OEM's responsibility for most fixed priced long-term contracts that guarantee the performance of the system [2]. Therefore manufacturers are beginning to enhance maintenance activities to reduce the whole life cost [4,5]. The wide range of maintenance activities include inspection, testing, measurement, adjustment, repair, upkeep, fault detection, replacement of parts, servicing, lubrication, and cleaning. The service system for maintenance consists of materials (parts), tools, people and equipment/machines [2]. Furthermore, an infrastructure needs to be built, which varies from deterministic production models into one that copes with high variability. This infrastructure needs to cater for the material flow, storage, repair, transportation, communication and information systems [5]. Due to these reasons it has commonly been suggested that delivering after sales service is more complex than delivering the products themselves. The service delivery process is challenged by uncertainties that arise from demand and supply. McManus and Hastings [8] defines uncertainty as "things that are not known, or known only imprecisely", where it encompasses aspects including "liability to chance or accident," "doubtfulness or vagueness," "want of assurance or confidence; hesitation, irresolution," and "something not definitely known or knowable". The uncertainty in demand may occur from the complexity (dependent on know-how) of the delivered equipment, the machine usage conditions/environment, or usage levels, along with the customer's willingness to pay. From a schedule point of view, the solution provider faces challenges particularly in terms of meeting reliability, maintainability, and availability targets that are typically agreed at the outset of agreeing a contract [5]. As follows, the sources of cost reduction will depend on materials and labour requirements (driven by failures) and the confidence in estimating these [6]. Labour is considered in terms of skill level and scale of labour requirements. Material estimates tend to be based on similar historical projects and follow the equipment breakdown structure. The estimated labour and materials demonstrate performance related targets, which are driven by meeting cost and schedule targets. Figure 3, illustrates a framework for targets in maintenance, which are associated with increasing predictability (driven by technologies), availability (driven by reliability) and reducing or sustaining cost (driven by strategies/contracts/failure). On the other hand, the uncertainty in supply may be influenced by supportability, resource availability and the capacity across the service supply chain [9]. As follows, service quality is a function of the scale and scope of customer demand and supplier capacity to respond to the demand.

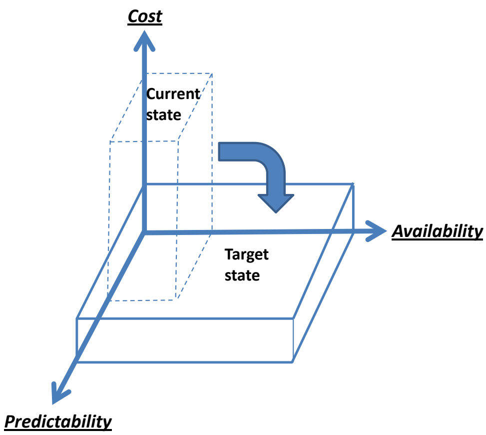


Fig. 3. Current vs Target state performance for IPS² contract

2.4 New Challenges for Maintenance in IPS²

The shift in maintenance requirements promotes new challenges for industry. The solution provider needs to account for the performance driven requirements and predict the life cycle of components. This requires detailed uncertainty management through information flow between the customer and solution provider about the equipment health [10]. This is necessary in order to derive proactive maintenance strategies that reduce life cycle cost. Also, extending the life cycle and adequate application of MRO holds an important role in achieving reduced costs, and meeting performance requirements. The flow of data and the feedback across projects facilitates establishing maintenance cost models at the earliest possible phases of the lifecycle and evolves as the lifecycle progresses and in agreeing new contracts [6]. However, it is essential that companies take account of the new challenges that are driven by uncertainties. These relate to the new uncertainties experienced with agreeing CfA and involve, for example, the role of availability on cost, payment based on performance, end user equipment usage, change in capability requirements, supplier

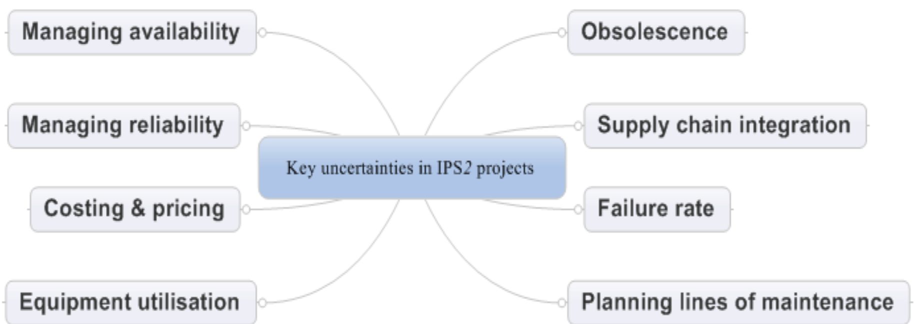


Fig. 4. Key uncertainties in IPS² projects (Adapted from [5])

dependence, and training for availability [5]. In addition to many other reasons, accurate prediction of such new challenges is proving to be demanding in developing reliable cost and schedule estimates for contracts. In order to further emphasise the issues Figure 4 lists the key uncertainties that have been highlighted by four organisations in the defence industry that are involved in IPS^2 projects [5]. Failure rate, managing obsolescence and gathering data about equipment utilization emerge as some of the key areas to focus on.

3 Emerging Themes for the Future of Maintenance

It is increasingly recognized that the in-service phase of the life cycle creates the largest amount of cost. Maintenance, which is a driver of in-service costs, to a large extent cannot be avoided due to a number of reasons such as consumables, wear, plug and play technology upgrades, and standardization of interfaces. As a result the customer has become increasingly interested in minimizing the cost of whole life cycle ownership of assets. On the one hand, strategies have moved towards reduction of maintenance (e.g. schemes to avoid failure – design for zero failures), and higher predictability (e.g. visualize future wear) that drives availability. Such aspects need fundamental questions to be answered including:

1. Is it possible to avoid replacing “consumable” components (e.g. engine oil, windscreen wipers)?
2. Is it possible to prolong the life of systems and components?
3. Is it possible to avoid the replacement/refurbishment of worn components?
4. Is it possible to eliminate wear?
5. Is it possible to reduce maintenance activity through improved autonomy?
6. Is it possible to predict and build in possible upgrades of parts/systems during the design process?
7. Is it possible to have modularity to insert new capabilities with developing technologies?

On the other hand, the significance of cost has promoted changes in contractual arrangements. Like so, the literature has emphasised that ownership and use/employment (e.g. CfA) are increasingly being separated. Research within this area has focused on the role of the bidding stage. For instance, research has been made to incorporate the influence of uncertainty [5], and of obsolescence [7] to cost, and to provide guidance on contract selection [3]. Furthermore, standards certification has also been an area of interest where research has been conducted for cost engineering related terms [10]. It is worth recognizing that the shift towards services has generated further aftermarket business opportunities for the solution provider and supply chain. The following section provides a detailed account of the emerging themes for maintenance, as illustrated in Figure 5.

Failure is the tip of the iceberg where maintenance has a role to reduce the impact of many issues such as wear, play, slackness, leakage, dust, dirt, corrosion, deformation, adherence of raw materials, surface damage, cracking, overheating, vibration, noise and other abnormalities. Developing a detailed maintenance plan can assist in handling of component and system failure. This particularly becomes essential in IPS^2

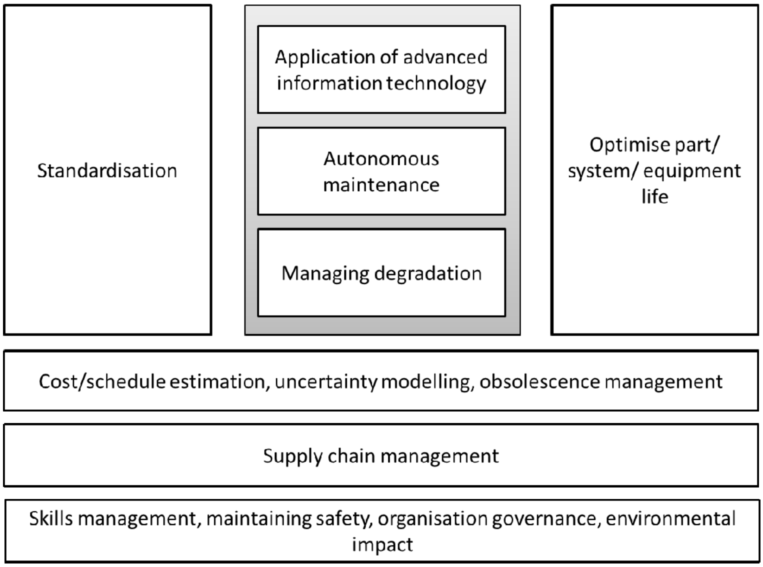


Fig. 5. Overview of future themes for maintenance within an IPS² contract environment

in order to meet the cost pressure and performance requirements. Adequate measures taken can assist in achieving fewer failures and unplanned breakdowns, the increase in robust diagnoses and prognosis, a shorter waiting time until the system works, a better working environment, and less environmental pollution (e.g. lower energy and raw material consumption). Furthermore, the design and manufacturing phases are increasingly being acknowledged to drive the impact on the service provision, whilst feedback from the service is progressively playing a key role for each of these phases.

3.1 Standardisation

Putting in place a mechanism for standardization, supports with determining technical specification, quality management for an engineering project or a safety standard and with many other aspects [10]. Furthermore, it may result in early adoption of novel technologies, reduced costs, improved uptime and to avoid major disasters. Within the maintenance area standards are required in a number of areas including [11]:

1. Interoperability of diagnostics data
2. Quality of diagnostic systems and data
3. Backward compatibility
4. Maintenance using remote monitoring
5. Wireless protocols for system monitoring and remote repair
6. Obsolescence management
7. Terminologies for new technologies
8. Whole life costing

In order to achieve these targets there is a need to perform a gap analysis on the existing standards landscape, to develop a delivery plan to fill the gaps and to educate regulatory bodies on the direction to be followed.

3.2 Application of Advanced Information Technology

Maintenance as a concept has experienced a major philosophical transformation from the traditional view of "fail–and–fix" maintenance practices to "predict–and–prevent" e-maintenance based strategies. This has promoted a network based architecture that shares, integrates and synchronizes the vast number of maintenance and reliability applications to gather and deliver asset related information as designed. This network of information sharing is illustrated in Figure 6. The network refers to the link between the customers operations and the feedback that is collected from remote customer sites and analysed in order to plan suitable maintenance steps. A key role that assists the flow of information is enabled by e-maintenance. This can be achieved using Personal Digital Assistant (PDA) devices that enhance the applicability of mobile maintenance management [11]. The main technologies that assist the application of e-maintenance include the internet, wireless devices, smart tags, micro-size MEMS sensors especially designed for maintenance purposes and low-cost online lubrication analysis sensors [11]. Also, information processing tools enable the continuous data flow through a distributed and collaborative web platform system at the higher end of the processing hierarchy. These assist in re-designing maintenance strategies in a cost effective and environmentally friendly manner. Such approaches have been comprehensively reported in the literature, however Redding et al., [12] highlight that the application of such technologies has in comparison been below expectations. Though, it is expressed that there is a large desire to adopt such technologies.

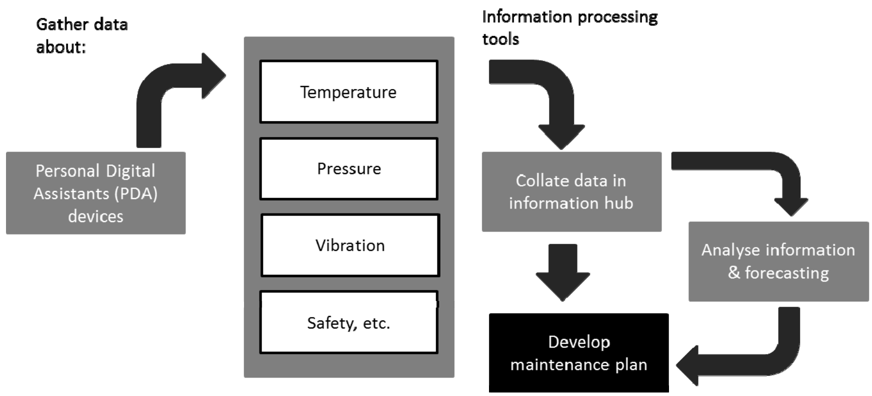


Fig. 6. Process of information gathering

Sensors may be in the form of wired or wireless sensors, whilst both have commonly been acknowledged to offer large potential to sense, store, and analyse equipment data to predict health status [11]. However, the reliance on sensors for condition monitoring requires robust and reliable sensors and data processing. In parallel a shortcoming has been observed with sensor failures happening between the time intervals of check-ups [13]. Additionally, within the nuclear power plant context, issues have been observed with electromagnetic and radio frequency interference (EMI/RFI), cyber security, and installation issues such as the coverage of the wireless signal [13]. Redundancy has been considered to be an approach where a wired sensor is used as the primary source, whilst in the case of a breakdown (e.g. due to a loss-of-coolant accident) wireless transmission of data may offer a more reliable option.

Increasingly commonly are sensors which collect information about vibration and apply diagnostics techniques that enable the trending of equipment health. However, the shortcoming of the approach lies in the cost of full physical check-ups. Apart from the technology requirements, there is also a need for vibration experts, who are typically highly educated and costly. Thus, a cost-benefit analysis is required in order to decide whether adding a sensor to the monitoring program will be beneficial. It is also worth recognizing the value of reducing uncertainty and facilitating the delivery of IPS² that meets cost and performance targets.

3.3 Optimise Life

The maintenance strategy needs to facilitate the optimization of the life cycle of the equipment. For this purpose the future of maintenance will need to concentrate on a) developing suitable simulation approaches; b) schemes that facilitate adaptability; c) modular maintenance and d) disposal decision making [11]. Figure 7 shows an overview of these concepts.

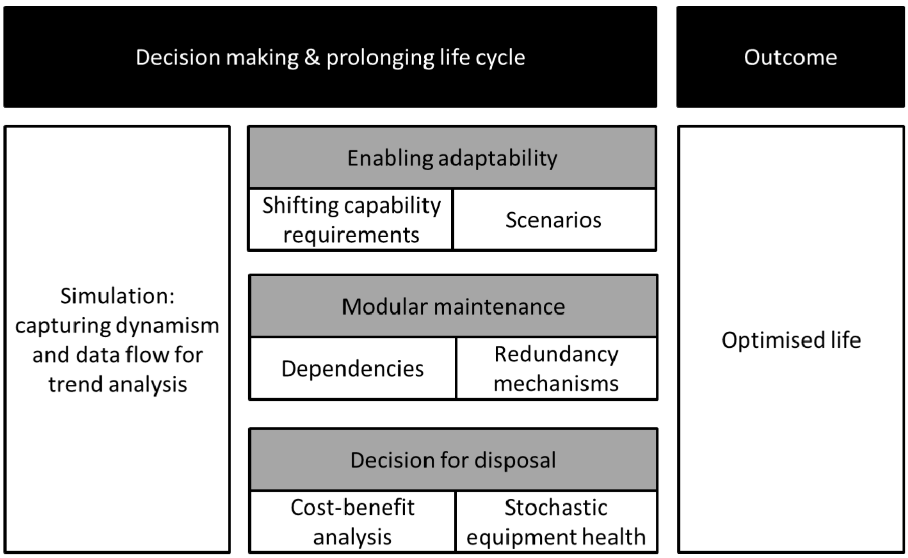


Fig. 7. Achieving optimized life

During the life cycle of maintenance, with up to date information about the equipment health, suitable simulation approaches need to be adopted in order to develop trend analysis and to predict reliable life expectations. Various techniques such as a

Bayesian probabilistic approach and Markov chains have increasingly been applied [11]. In particular the Bayesian approach is gaining much interest due to its ability to dynamically update data based on the monitoring of outcomes on specified model parameters and thus revising the probability of damage for each substructure. The parameters may be directly related to the process such as temperature, pressure, vibration or humidity, or be higher level descriptors such as process safety, efficiency, or level of output [14]. This approach allows the tracking of gradual changes, such as fatigue and corrosion, and offers the opportunity to detect issues at an early stage well before the risk of failure. As an outcome such information enables to determine the spare parts demand and supply schedules to reduce time and amount of maintenance.

A common feature of the life cycle is the need to modify the equipment because of changes in capability requirements, affordability issues, or technological advancements for example. However, recognizing the costs of change at the outset and the implications on the duration of the life cycle are challenging. In order to reduce these challenges researchers have applied rule-based systems to define the potential range of modification strategies [11]. Though, building a comprehensive scope of modification strategies and recognizing the dynamic nature of this scope is also challenging. For this purpose, optimization studies have a valuable role in guiding decision making with such issues. Nevertheless, selecting optimal rule refinements is an unsolved problem that requires further research.

Modular maintenance refers to a procedure that allows replacement of major assemblies, called modules, with a minimum of amount of expenditure and time. Furthermore, the removed modules follow a cycle by being returned to the repair facility, bench test, repair, and inserted back in to the equipment [9]. However, designing this procedure is challenging because one has to consider the sub-modular cost structures that capture the dependencies between various components and modules in the system. It is also important to design suitable redundancy mechanisms and appropriate schemes to resolve maintenance issues such as obsolescence.

Decision making for disposal is also challenging and requires simulation studies that take account of the stochastic nature of the condition of the equipment. The optimal point for disposal occurs when the carrying cost exceeds the disposal cost. There are a number of aspects that need to be considered including (a) product recovery operations require expensive and skilled labour; (b) timing and quantity of discarded products; (c) cost of recovered components resulting from the unpredictable disposal of products and stochastic demand; (d) costs originating from surplus inventory; (e) stock-outs causing lost sales; (f) disposal cost of leftover and obsolete inventory; (g) competition from OEMs, and (h) restrictive environmental regulations [15].

3.4 Autonomous Maintenance

Autonomous maintenance means developing capability within a high value system to maintain itself and also developing maintenance systems that collaboratively provide autonomous capability to perform maintenance on a high value system with minimum human intervention. This improves robustness of a system and influences the ability to meet performance and cost targets. Among autonomous maintenance approaches self-healing is highly attracting attention. Self-healing systems aim to mitigate, detect and recover from failures [16]. The initial step involves defining an appropriate architecture that specifies components, their relationships within a system coupled with topology (with number and placement of components in a system). This architecture helps to mitigate the effects of failures by providing guidance with increasing system redundancy. Subsequently, failure detection techniques are applied and involve monitoring component health and uncertainty analysis in order to realize the remaining life in a reliable manner. This leads to recovery techniques, which define actions to a component in order to address suspected failures. Self-healing systems comprise consistent mechanisms that provide a means to maintain a synchronized state among distributed components by propagating state changes to remote components. Research has concentrated on robotics and software development that establishes connections between failure and healing mechanisms [16]. Furthermore, large engineering systems in safety critical situations already have a level of self-diagnosis (built in self-test or BIST) and self-fix, if not self-immobilisation to prevent more serious damage. However, the migration of self-repair to lower value systems is a process which engineering is just beginning. Future research will need to concentrate on solutions that are easy, cheap and quick to adopt.

3.5 Degradation

Degradation refers to the process of deterioration of characteristics of an object with time; gradual decline in quality; breakdown of matter due to the impact of external forces in conformity with the laws of nature and time. The degradation issue could be categorized in to component and system level. At the component level the degradation mechanisms are wear, cracks, corrosion etc. At the system level the degradation manifests as no fault found (NFF). Given the variety and complexity of mechanisms, there is a need to understand their drivers and ways to mitigate their implications.

In the process of investigating the mechanisms there is a growing interest in realising NFF. NFF refers to system or component that has been returned to the manufacturer or distributor for warranty replacement or service repair, but operates properly when tested in laboratory environment [11]. Investigations have shown the occurrence of NFF in coupled whole systems with electronic, electrical and mechanical sub-systems. Solutions have always proved difficult. The root causes can be diverse and many are specific to particular industries, but the problem can occur from incorrect diagnostic techniques or tests, poor training, incorrect processes, operational pressures poor design. The costs can be significant particularly when assets are now being contracted at a fixed price per hour of their availability. An investigation by the Royal Air Force showed some 60,000 man-hours being attributed to nugatory maintenance activity on NFF. Similar wasted efforts will be occurring in the Army and Navy, Railways, Wind Turbines and High-end car industries. There are three different classes of NFFs, all of which will be addressed here: a) Intermittent faults, a fault is indicated but ‘goes away’ a short time later, b) Integration faults, a component or subsystem works fine on test but shows faults when incorporated with other systems and

c) BITE (Built-in-Test Equipment) indicates a fault but there is insufficient information available to locate the exact unit or component to be replaced [11]. Various technologies can be employed to investigate NFF decisions including environmental test chamber and, intermittent fault detection, as shown in Figure 8.

Fig. 8. Technologies for the system and component level degradation reduction

3.6 Additional Themes

Apart from engineering based issues that are faced in maintenance there is also interest in more soft issues including how to design the skill set to deliver the maintenance solution, how to structure the organization to meet the requirements, maintaining safety and how to organise the supply chain. There is also growing interest in aligning with environmental requirements. In particular, the role of maintenance in meeting regulations is a challenging area that requires further research. Furthermore, from a financial point of view, with the wide application of carbon trades the significant role of maintenance in producing environmental pollution will be further assessed and may yield financial benefits to trade pollution. Maintenance does not only have a role to ensure reliability of equipment, but it also requires consideration of providing a safe and healthy environment for the maintainers [17]. The maintenance requirements due to failures and failure expectations within the plant are evolving and the potential risks are transforming. Future research will need to assist in assessing the technical risks but also in determining what is acceptable risk by society.

4 Concluding Remarks

Maintenance as a service is a major driver for the whole life cost of an IPS²project. There are new and revised challenges in the form of customer requirements and uncertainties that needs addressing to make an IPS² project a success. Some of these aspects relate to meeting availability requirements, managing reliability, obsolescence mitigation, achieving supply chain integration, supporting and guiding customer equipment utilization. Maintenance activity needs to further develop to address these additional challenges and that could be achieved through technological and organizational development. The major technological trend in the maintenance that is expected to influence the future includes application of advanced information technology, autonomous maintenance, managing degradation and mechanisms to optimize life. Also, there is an increasing need to standardize the maintenance terminologies and technological processes to support the supply chain and implement best practice.

Acknowledgments. The authors would like to express their gratitude to the EPSRC for funding the EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services. Additionally, the support of colleagues in the Manufacturing and Materials Department at Cranfield University is acknowledged.

References

1. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems - IPS^2. CIRP Annals – Manuf. Tech. 59(2), 607–627 (2010)
2. Takata, S., Kirnura, F., van Houten, F.J.A.M., Westkamper, E., Shpitalni, M., Ceglarek, D., Lee, J.: Maintenance: Changing Role in Life Cycle Management. CIRP Annals—Manuf. Tech. 53/2, 643–655 (2004)
3. Roy, R., Cheruvu, K.: A competitive framework for Industrial Product Service Systems. Int. J. of Internet Manuf. and Serv., Special Issue on Product Service Solutions in Life-Cycle Activities 2(1), 4–29 (2009)
4. Ng, I., Yip, N.: Identifying risk and its impact on contracting through a benefit based model framework in business contracting: Case of the Defence industry. In: Proceedings of the 1st CIRP IPS2 Conference, Cranfield, pp. 207–215 (2009)
5. Erkoyuncu, J.A.: Cost Uncertainty Management and Modelling for Industrial Product-Service Systems. PhD Thesis, Cranfield University (2011)
6. Datta, P.P., Roy, R.: Cost modelling techniques for availability type service support contracts: A literature review and empirical study. CIRP J. of Manuf. Sci. and Tech. 3(2), 142–157 (2010)
7. Romero Rojo, F.J., Roy, R., Shehab, E., Cheruvu, K., Mason, P.: A cost estimating framework for electronic, electrical and electromechanical (EEE) components obsolescence within the use-oriented product–service systems contracts. Inst. of Mech. Eng. Part B J. of Eng. Manuf. 226, 154–164 (2011)
8. McManus, H.L., Hastings, D.E.: A Framework for Understanding Uncertainty and its Mitigation and Exploitation in Complex Systems. In: Fifteenth Annual International Symposium of the INCOSE, Rochester, NY, pp. 1–20 (July 2005)
9. Kececioglu, D.: Maintainability, Availability, & Operational Readiness Engineering. Prentice Hall PTR, Upper Saddle River (1995)
10. Shaw, A., Pliska, A., Pandey, A., Rigatti, C., Chuku, G., Matar, F., Alajmi, N., Qian, W., Tang, W., Roy, R., Sheridan, B.: Through-life engineering services standards development. In: Proceedings of the 1st International Conference on Through-Life Engineering Services, Shrivenham, pp. 166–173. Cranfield University (2012)
11. Shaw, A., Roy, R.: Think Tank Report, EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services. Cranfield University, UK (2012)
12. Redding, L.E., Tiwari, A., Roy, R.: Identifying the the challenges in Through-life Engineering Services. In: Proceedings of the 1st International Conference on Through-Life Engineering Services, Shrivenham, pp. 159–165. Cranfield University (2012)
13. Hashemian, H.M.: What you need to know about sensor reliability before and after an accident. IAEA, Nuclear Power Engineering Section (2009)

14. Vanik, M.W., Beck, J.L., Au, S.K.: Bayesian probabilistic approach to structural health monitoring. J. of Eng. Mech., 738–745 (July 2000)
15. Gupta, S.M., Vadde, S., Kamarthi, S.V.: Pricing decisions for product recovery facilities in a multi-criteria setting using genetic algorithms, Paper 94 (2006), http://hdl.handle.net/2047/d10009991
16. McWilliam, R., Purvis, A., Jones, D., Schiefer, P., Frei, R., Tiwari, A., Zhu, M.: Self-repairing electronic logic units based on convergent cullar automata. In: Proceedings of the 1st International Conference on Through-Life Engineering Services, Shrivenham, pp. 353–360. Cranfield University (2012)
17. European Agency for Safety and Health at work: Working Environment Information Luxembourg: Publications Office of the European Union (2010) ISBN 978-92-9191-338-14, doi:10.2802/3897

The Structure of a Fully Integrated Production System for Industrial Services in the Machine Tool Business

Karsten Tonn

TRUMPF Werkzeugmaschinen GmbH+Co.KG, Johann-Maus-Str. 2, 71254 Ditzingen
karsten.tonn@de.trumpf.com

Abstract. Coming from the very successful Toyota Production System (TPS), the presented thesis is dealing with the design of a fully integrated production system for the use of industrial services which emphasize/assume the idea of services being produced like any other real hardware products.

To increase profit margin from the machine sales and furthermore creating additional customer value, industrial Services are gaining more and more attention among the machine tool manufacturer. Due to this business development, an efficient delivery of industrial service products in terms of time, quality and cost are becoming essential for the success of one's business.

Keywords: Industrial service, production system, lean management, optimization, continuous improvement, lean service, systematic rationalization.

1 Introduction

A couple of years ago industrial services in the capital goods industry were not really recognized as a very important part of the business. However, today services is a one of a kind instrument for the differentiation among competitors and beyond that, services make up quite a share of the total revenue for most of the machine tool manufacturers.

Stagnation in the core product market, due to homogenization among competitive products on the one hand and a shift in demand towards services on the other hand has been leading to decreasing product margins for years. At the same time margins in the services business have been increasing. While services can reach net profit margins of 20%, the earnings out of new machine sales are leveling off at plus/minus 1% [1-2].

From a manufacturer's point of view, the reasons for the higher profit margins in the services business are multilayered. Due to the fact that services are not easy to imitate they fulfill one of the most important characteristics for premium products. Therefore they are unique and thus, differentiating [1].

Further, increasing competition in the machine tool business is forcing manufacturers to launch new and innovative product lines in very short sequences. Consequently, the product engineering and design process also needs to be cut down. Due to this market development, amortization times for engineering costs can be decreased. The active sales of industrial services products such as consulting, financing, training, maintenance etc. and a smart way of linking those services to the hardware product

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 17–26.
DOI: 10.1007/978-3-642-30820-8_2

helps to increase the average profit margin and thus, to keep the amortization times down [3].

Changed customer expectations in the capital goods industry have led to a respective change in demand. Customers are no longer looking for a machine with specialized functions constantly increasing performance alone. More and more, customer focus lies on integrated solutions and the optimization of lifecycle costs. Therefore, the design and sale of industrial-product-service systems is the key for most machine tool supplier. Today's demand for maximized productivity and machine availability can only be fulfilled with the help of services components [4].

In the discussion of industrial-product-service systems industrial services such as maintenance, repair, machine installation and ramp up, as well as the spare part supply, training and application consulting are taking over an important part to achieve the customer's expectations [5].

Seeing the importance of industrial services the efficient delivery of services in comparison to the hardware product is becoming a crucial part for the success of business models based on the idea of industrial-product-service systems. Operating figures such as delivery time, output quality and the price for services should be focused on to keep up with the very efficient production processes in the manufacturing of hardware products.

Standardization as well as process automating needs to be a main focus of the management of industrial services in the future to ensure an efficient delivery of the product-service bundle.

Management approaches such as „Total Quality Management", "Lean Production" as well as "Business Reengineering tools" need to be transferred to industrial services delivery processes in order to make them become more professional in the way of competitive advantages [6-7]. Coming from the very successful Toyota Production System (TPS) the design of a fully integrated production system for the use of industrial services will be discussed in the following chapter.

2 The Technical Service in the Machine Tool Business

The industrial service or technical service department in the organization of a machine tool manufacturer is one of the main service delivery units which takes care of all technical service issues around the company's core product: the machine.

According to the definition of MUSER and KLOSTERMANN, technical service is one kind of industrial services, a secondary service, which is always linked to capital goods such as machines or any kind of production equipment [5,8].

Thus, technical services are delivered on objects and are therefore different in comparison to consumer services such as medical treatments or a haircut which are usually conducted on human beings. Having a look at the input factors, technical services are mainly dominated by human beings and their technical experiences. In addition to the human factor, the right information- and communication technologies become a crucial success factor. This is especially true for the field force in terms of teleservice or reporting functions.

While *the time of the service delivery* is mainly concentrating on the after sales phase the *place of delivery* can vary from customer to customer which is one of the biggest challenges when focusing on the optimization of the technical service organization.

Hence, the standardization of the workplace of a service engineer is much more complicated than in a factory where the surroundings and needed tooling can be arranged and adjusted as needed. Unpredictable working conditions combined with the autonomy of external factors often lead to unsteady cycle times and make the resource planning process very difficult to manage.

Further, technical services are not always supplied by the manufacturer of the machine tool; parts of the services, such as the logistics of spare parts are frequently provided by subcontractors. Besides the outsourcing, the worldwide delivery of technical services is characterized by co-operational networks where agencies or sales and service subsidiaries around the world are working together to provide services on the installed machine base [9].

In general, the classical scope of technical services can be narrowed down to maintenance and repair procedures including the spare part supply and logistic. According to the DIN 31051 the maintenance and repair services are defined by inspections and the attendance [10].

Building upon the general definition of technical services by MUSER and KLOSTERMANN and having the constitutive characteristics of services, such as immateriality, the integration of an external factor as well as the simultaneity of delivery and consumption in mind, important implications for the design of a fully integrated production system for technical services can be derived. Table 1 is summarizing these implications by focusing on the three service dimensions (potential, process and solution), comparing these with the characteristics of a hardware product.

Table 1. Implications for designing an integrated production system for service

Serivces dimensions	Technical Service	Hardware Product
Potentials (Input-Factors)	• Dominated by human resources and their technical experiences • Fluctuation in demand is immediately reflected in the capacity utilization	• Dominated by raw materials and capital intensiv resources • Fluctuation in demand can be balanced out through reserve inventory
Process (Delivery process)	• Constantly changing workplaces are the cause for unpredictable work conditions • Autonomy of the external factor is causing additional uncertainty in the delivery process • Cycle times are most of the time <u>not</u> really predictable	• Stable production surroundings make perfect working conditions possible. • All factors are supplied and controlled by the manufacturer • Cycle times are most of the time predictable and determined
Solution (Output)	• The immaterial character makes it difficult to measure the output quality	• The measuerment of the output quality is possible through objectiv criterias

3 General Structure of Fully Integrated Production Systems

Today's interpretation of the term "production" includes a lot more than just the manufacturing and assembly of products. According to SPATH, production incorporates "all tasks of the production process" [11].

Therefore, value-adding as well as non-value adding tasks, such as the production planning and control, the disposal, material logistics, maintenance and quality control functions are playing an important role in today's production systems.

The integrated reflection of the term "production" is closely connected with a process-orientated value creation approach. Within this, the processes have to flow no matter how many IT and organizational interfaces exist. Thus, an almost waste-free process flow with zero defects is the main idea to follow up on. The most important elements in this value-creating process are the people, the organizational structure as well as the single processes and the technology which have to be in line with the proposed production strategy [11].

Following the system theory, HEINRICH defines a fully integrated production system as "the sum of all elements and relations between which are directly influencing the production "[12].

Taking the definitions by HEINRICH and SPATH in consideration, PFEIL came up with a rather general framework structure for integrated productions systems which can be applied for services as well as hardware products [13] (see Figure 1).

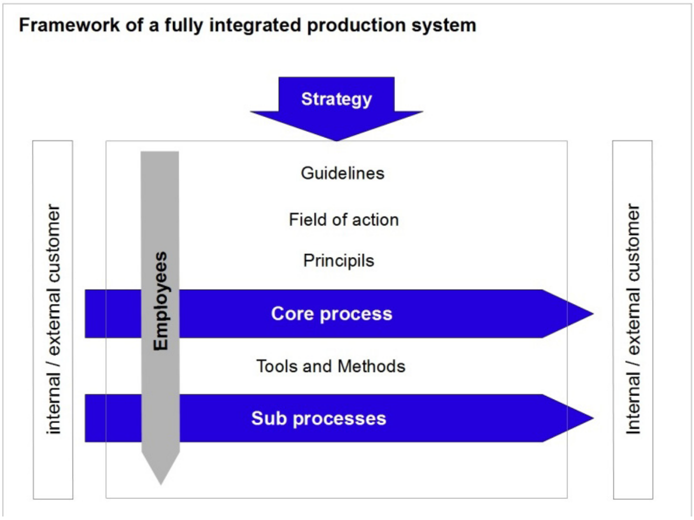


Fig. 1. General framework of an integrated production system

The single elements of this structure can only reach their full potential when, aligned among each other, forming an integrated system, which secures the quality- and productivity goals of an established *production strategy*.

Integration of employees as well as the activation of their abilities is one major challenge in the process of designing an integrated production system [11].

Behavioral guidelines within a production system serve as general guiding principles for employees and management within the whole value-chain whereas production efficiency is playing a major role for defining operational behavioral guidelines. Following SKINNER [14], the dimensions quality, cost, time and flexibility are crucial in order to quantify efficiency.

Today, every integrated production system is built upon a variety of *principles and methods* derived from the lean management approach. Principles are overriding the methods and applied on a higher level of abstraction in all core- and sub-processes, such as well-known principles like Just-in-time (JIT), flow production, etc. The tools for successful implementation of the principles within a production system are represented by the methods. They describe a standardized process for the handling of problems and usually lead to a solution, which closely tie the principles to the processes.

Permanent alignment of the behavioral guidelines, principles and methods with the production strategy ensure the optimal indentation of these elements. Only a consequent alignment with the company structure can guarantee a high degree of efficiency in the whole system [13].

4 An Integrated Production System for the Technical Service

Derived from the structure of an integrated production system according to PFEIL, as well as from the known service dimensions (potential, process, solution/output), integrated production systems are a promising approach for the technical service as well. In the context of product-service bundles they enable a systematic optimization of the delivery processes by the use of well proven lean management principles and methods.

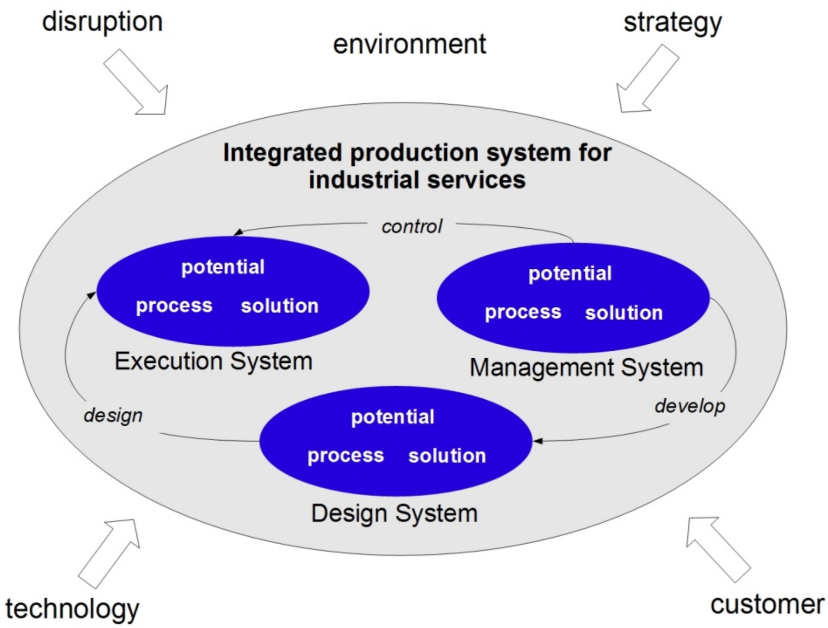


Fig. 2. Model of an integrated production system for industrial services

A possible concept for a fully integrated production system for the technical service as well as the adaptation of the lean principles will be discussed in the following chapters. The framework in figure 2 was therefore developed to structure this discussion.

The integrated production system for technical service mainly consists of three main sub-systems such as the *execution-, design- and management system* which are closely interlinked with each other.

The operative controlling is essentially representing the link between the management and the execution system. By controlling, the management can navigate and correct the operative processes, as well as give input for system design and development.

In addition to the controlling, the management system is responsible for shaping the execution system regarding evolutionary and/or revolutionary needs [15]. Here, a special developed design system with needed methods and tools supports the operative management.

4.1 Execution System

The execution system is generating the services and is the unit where systematic optimization measures are being applied. In essence, the execution system consists of three process types:

The *supporting processes* are responsible for building up the Service capacity and capability. The recruitment of service technicians, their first qualification and the advanced trainings are of crucial important for a technical service department. Although IT infrastructure with smart software applications are widely in use for supporting service technicians throughout the problem solving process, service performance is still heavily depending up on the competence and experience of every single technician.

The *operational core process* is building upon the initial work of the supporting processes of the execution system.

Beyond the machine setup at the customer's side including the first ramp up and the customer training the technical service department is taking care of the machine throughout the whole product life cycle. Meanwhile, the intensive interaction with the machine products and the customer is one of the most essential characteristics of the technical service. Unpredictable incidences as well as the need for customized solutions are causing undefined cycle times which make the capacity planning in service even more difficult.

Lastly, the *service planning and control process* is the overriding element within the execution system. Similar to a control center, this is where all service assignments are being planned and coordinated. Software-based planning tools and manually maintained planning tables support this complex task. Main challenges for this process are the in-time availability of qualified technicians, the organization of spare parts and respective service tools as well as the travel planning. Aligning service dates with clients, as well as planning routes for differently specialized technicians is therefore part of the challenge [16].

Similar to the planning of production programs for real products the service planning is also striving to minimize delivery and waiting time for maintenance, repairing and machine installation. However, in contrast to production, service planning does not have the opportunity of stock-keeping in order to absorb fluctuations in demand [17].

4.2 Design System

Just like the well-known Toyota production system, the derivation of a design system for the above-presented execution system is substantially based on the lean philosophy.

In a first step, the different types of waste (non-value adding work) such as overproduction, stock-keeping, rework, waiting time etc. known from production are adapted to the processes and outputs of an industrial service delivery system. Once this is established, lean principles, like pull, flow, cycle tact, leveling, etc. and their methods can be assigned to the industrial service delivery processes.

Defining *overproduction* for material goods as generating more output than is being demanded by the market at a certain point in time, the definition of output in terms of services has to be clarified before the lean principles can be applied to industrial services.

The output of services could be a machine, which is functioning fault-free after the maintenance, as well as the number of repairs provided within a previously defined time frame. But how can overproduction even exist in this context, where services are simultaneous being delivered as well as consumed?

When approaching technical failures of a machine, a technician often needs numerous attempts until the cause of the problem is identified. Consequently, overproduction arises, when the technician needs more than one attempt in order to solve the problem. This can be due to lacking experience or complicated failures. Thus, the "trial and error principle" can be defined as one form of overproduction within Industrial services. Similar to "trial and error", working techniques which vary strongly in output and time represent a form of overproduction as well as.

Due to the simultaneous of delivery and consumption of technical services, it is not possible to store or to build up stock of these services as described above. However, the concept of stock-keeping becomes relevant when referring to the availability of qualified service technicians. The long qualification and training process for technicians within the machine tool industry requires long-term capacity planning as well *"stocking"* a certain number of technicians within this process.

Coming back to the "trial and error principle", stock-keeping becomes essential for effective supply of possible solutions in order to reduce overproduction in the sense of numerous attempts within the problem solving process. Thus, providing stored knowledge just in time supported by IT-based solution structures and linked with respective solution-probabilities is a relevant approach to minimizing overproduction.

Beyond that, bad Quality and rework are types of wastes, which also have to be interpreted in the context of technical service before principles and methods for optimization can be applied. Rework is taking place, as soon as *long solution-times and* *multiple service attempts*[1] tie up the scarce capacity of the service technicians. This may be caused by missing information and standard procedures, delays in organization of spare parts, or by lacking qualification of the technicians.

Long solution times and planning-intensive multiple field missions can be approached within the framework of a design system, e.g. by the usage of teleservices and automatic applications for diagnosis. Further, the introduction of so-called "Standard Operating Procedures"(SOPs) and standardized tool kits can help in minimizing lead time in the field in the sense of keeping the "Mean Down Time" (MDT) to a minimum.

Further classical types of waste can be discussed in similar ways in the context of industrial services, and building upon the Lean principles, approaches for optimization can be derived.

4.3 Management System

The operative management as an essential part of a fully integrated production system for industrial services is responsible for control and steering the execution system. Also, depending on external influences and strategic inputs, it is accountable for the continuous evolution of the existing elements within the design system.

On the way to developing a lean production system for technical service, it is indispensable to define *measurable performance indicators* for identifying divergences of the set objectives and judging of effectiveness of applied measures.

In the literature known as *"Performance-Measurement"*, two significant aspects within the framework of any management system can be identified. AUSTIN is referring to „motivational measurement" on the one hand and "informational measurement" aspects on the other hand. Performance indicators are motivating employees and management and can influence positive behavior by given the measurement of the correct indicators. Whereas the informing aspect of performance indicators forms the basis for well-grounded management decisions and guarantees certain effectiveness in the decision-making process [18].

The integration of all employees in the performance measurement process is a crucial success factor for a consequent alignment of the execution system with the defined performance indicators and the implementation of a continuous improvement culture.

The Shopfloor-Management approach is hereby focusing directly on the place of value-creation with the objective to enable employees to solve current problems sustainably for a better performance. In order to make this approach work, the respective management has to be present [19] and management and shopfloor employees together have to get to the bottom of the problem [20]. Thus, primary concern is the further development of the improvement abilities of the employees. The manager is functioning like a trainer and enables his employees to use respective methods for systematic problem-solving and thus, to continuously improve processes.

---

1 Multiple field missions or support attempts can come up when a technical problem cannot be solved by the first attempt.

Besides Ishikawa-diagrams and the A3-method, the most cited method in literature for problem-solving within shopfloor management is the *PDCA-cycle*. Starting with description and analysis of the issue at hand (PLAN), followed by the implementation of respective measures (DO) and the comparison of the achieved result with the initial situation (CHECK) and lastly the repetition of this cycle (ACT) when deviation is detected. This process forms a crucial and substantial element within shop floor-management. However, the improvement potential to be realized via the PDCA cycle is heavily depending on the frequency of application and the repetition within short cycles.

5 Summary

The development of a fully integrated production system for the delivery of technical services is a possible approach for the systematic optimization of services delivery processes within the machine tool industry. Derived from the Toyota Production system for real products, this paper introduced a possible framework, which is composed of three subsystems called execution-, design- and management system and described their interrelation as well as emphasizing their interactions.

To increase profit margin from the machine sales and furthermore creating additional customer value, industrial Services are gaining more and more attention among the machine tool manufacturer. Due to this business development, an efficient delivery of industrial service products in terms of time, quality and cost are becoming essential for the success of one's business. The systematic optimization of core processes such as machine installation and ramp up, maintenance, as well as repair will be a challenge for all machine tool manufacturers in the near future. While the production and assembly processes of real products such as cars, machines and any kind of consumer white products were undergoing a constant industrialization process over the past decades a fully integrated production approach needs to be developed for the effective and efficient delivery of industrial services in the future. Only manufactures who are able to transform their service organization into an effective working integrated production system will gain benefits from a product-service system.

References

1. Schuh, G.: Fit for service: Industrie als Dienstleister, 1st edn. Hanser, München (2004)
2. Speth, C.: Gestaltung industrieller Dienstleistungen im Spannungsfeld zwischen Kundennähe und Effizienz, Bamberg (2001)
3. Meier, H., Lanza, G.: Kooperative Geschäftsmodelle zu Integration von Sach- und Dienstleistung. VDMA-Verl., Frankfurt (2009)
4. Lanza, G., Behmann, B., Peters, S.: Verfügbarkeitswirksame technischen Dienstleistungen: Potenzialanalyse bei KMU im Maschinen- und Anlagenbau. Zeitschrift für Wirtschaftlichen Fabrikbetrieb (5), 421–425 (2010)
5. Klostermann, T.: Optimierung kooperativer Dienstleistungen im Technischen Kundendienst des Maschinenbaus. Optimierung Kooperativer Dienstleistungen im Technischen Kundendienst des Maschinenbaus (2008)

6. Haller, S.: Dienstleistungsmanagement: Grundlagen - Konzepte - Instrumente, 4th edn. Gabler, Wiesbaden (2010)
7. Meier, H.: Dienstleistungsorientierte Geschäftsmodelle im Maschinen- und Anlagenbau: Vom Basisangebot bis zum Betreibermodell. Springer, Heidelberg (2004)
8. Muser, V.: Der integrative Kundendienst: Grundlagen für ein marketingorientiertes Kundendienstmanagement. FGM-Verlag, Augsburg (1988)
9. Kaiser, A., Schramm, J.: Kooperationen innerhalb der Service-Chain. In: Dienstleistungsorientierte Geschäftsmodelle im Maschinen-und Anlagenbau, pp. 191–205
10. DIN Deutsches Institut für Normung e.V.: Grundlagen der Instandhaltung (Fundamentals of maintenance). Beuth, Berlin 03.080.10(31051) (2011)
11. Spath, D.: Ganzheitlich produzieren: Innovative Organisation und Führung. Logis, Stuttgart (2003)
12. Henrich, P.: Strategische Gestaltung von Produktionssystemen in der Automobilindustrie. Shaker, Aachen (2002)
13. Pfeil, T.: Controlling Schlanker Produktionssysteme (2009)
14. Skinner, W.: Manufacturing - Missing Link in Corporate Strategy. Harvard Business Review (1969)
15. Bleicher, K.: Das Konzept integriertes Management: Visionen, Missionen, Programme, 6th edn. Campus-Verl., Frankfurt/Main (2001)
16. Verein Deutscher Ingenieure (VDI): Kundendienst aus einem Guss. VDI-Verlag, Düsseldorf (1991)
17. Voigt, K.-I.: Industrielles Management: Industriebetriebslehre aus prozessorientierter Sicht. Springer, Berlin (2008)
18. Austin, R.D., DeMarco, T., Lister, T.R.: Measuring and managing performance in organizations. Dorset House Publishing, New York (1996)
19. Peters, R.: Shopfloor-Management: Führen am Ort der Wertschöpfung. LOG_X, Stuttgart (2009)
20. Suzaki, K.: The new shop floor management: Empowering people for continuous improvement. Free Press, New York (1993)

Toward Product-Service System Engineering: New System Engineering for PSS Utilization

Yoshiki Shimomura and Fumiya Akasaka

Department of System Design, Tokyo Metropolitan University, Asahigaoka 6-6, Hino-shi, Tokyo 191-0065, Japan
yoshiki-shimomura@center.tmu.ac.jp

Abstract. The introduction of engineering methods is considered a promising approach to the effective and efficient design of Product-Service Systems (PSSs). The authors have conducted studies on Service Engineering in Japan in order to provide a fundamental understanding of services as well as concrete engineering methods to design and develop them. This paper denotes the need to progress from Service Engineering to PSS Engineering. In addition, methods and tools that can contribute to PSS design are discussed.

Keywords: PSS Engineering, Design, Service Engineering.

1 Introduction

As society advances, services and knowledge have become increasingly important in many industries [1]. Indeed, the term servitization indicates [2] that the service and information provided through a product are more important than the product itself, even in the manufacturing industry. For this reason, Product-Service Systems (PSSs), which create value by coupling a product and a service, have attracted much attention [3]. For the effective and efficient design of PSSs, the introduction of engineering methods is considered a promising approach. However, compared with the existing research on product design, there have been fewer studies on the design of services from the engineering perspective [4-6].

2 Practical Scientific Approaches

2.1 Genesis

Due to the situation mentioned in Section 1, we began in 2001 to conduct research on Service Engineering (e.g., [7]), the aim of which is to provide both a fundamental understanding of services and concrete engineering methods to design and develop them. Here, we define a service as the provision of a means to integrate a tangible object (a physical product) with an intangible object (an action product) that realizes some required value for a customer. The goal of our work is to develop a design methodology of services under this definition.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 27–40.
DOI: 10.1007/978-3-642-30820-8_3

During the first stage of our research, from 2001 to 2005, we established a generic procedure for modeling and analyzing services based on our research background in Design Engineering. Furthermore, we developed the basic structure of a service computer-aided design (service CAD) software system called Service Explorer [8, 9]. We used scientific design methodology and service engineering to develop tools to identify the values that are required and the societal and artificial systems that are needed to achieve the values.

In the second stage, from 2005 to 2011, engineering methods to support service designers were implemented in Service Explorer as plug-in software modules. In this stage, we focused on analyzing and designing a one-to-one relationship between a provider and a receiver.

Now the door to the third stage of our research has opened. Whereas in the previous stage we focused mainly on the one-to-one relationship between two specific stakeholders, in the third stage we are concentrating on the system aspect of PSS. Our focus is the complex network of multiple stakeholders, such as product manufacturers, service suppliers, and original equipment manufacturers, in a PSS structure. In the next stage of our research, we will establish methods to design an integrated product-service business that realizes win-win relationships among multiple stakeholders.

2.2 From Service Engineering to PSS Engineering

The concept of PSS is sometimes regarded as merely the combined provision of a product and service that fulfills customer needs (e.g., machine and maintenance). However, such a view of PSS shows an insufficient understanding of the original PSS concept, the essence of which is a social system where all stakeholders, including providers and receivers, can receive sufficient values through cross-offerings of products and services. This system, represented by the last S in PSS, consists of various stakeholders who provide and / or receive products and services Thus, in the current study, a PSS can be defined as a social system that enhances social and economic values for stakeholders through the co- and cross-offering of products, services, and product-services within the system. Here, a product-service means an integrated offering of product and service.

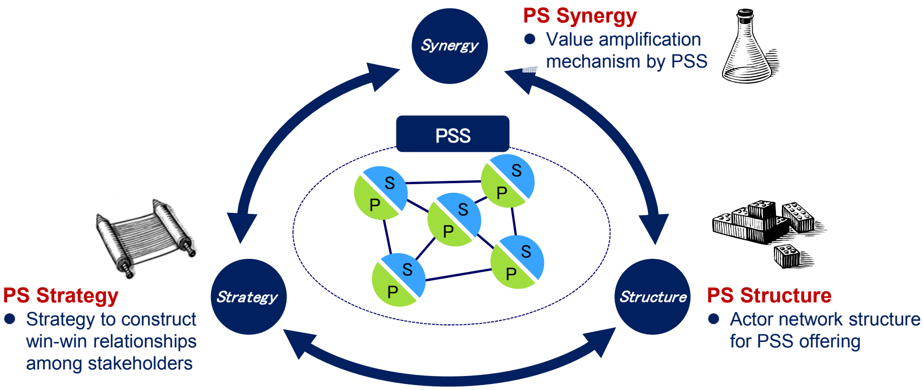


Fig. 1. The concept of PSS[3]

From this viewpoint, Service Engineering progresses to Product-Service System Engineering. In the new approach, we regard PS System design as the design of (1) PS Synergy, (2) PS Strategy, and (3) PS Structure: PSS^3. The concept of PSS^3 is illustrated in Figure 1. Here, PS Synergy is a value amplification mechanism by a PSS offering. PS Structure indicates a stakeholder network for value offering, and PS Strategy means a strategy to construct win-win relationships among stakeholders.

2.3 Research Strategy Map

As mentioned in 2.2, we regard PSS^3 as the set of PSS design dimensions. In PSS design, a PS Strategy is designed by determining the concrete values to be provided to stakeholders by integrating product and service. Thus, a Value Analysis is needed. The design of a PS Structure is performed through a discussion of how to embody the PSS offering structure (i.e., PSS Embodiment). PS Synergy can be clarified and the design improved through the evaluation of the synergy effect. Based on these discussions, Value Analysis, Embodiment, and Evaluation are regarded as practical realization phases of PSS^3.

Figure 2 illustrates the research strategy map of our research team. On the map, methods and tools that have already been developed or that are now being developed are classified in the PSS design phases and from a design perspective. The PSS design phases are composed of three steps: Analysis, Embodiment, and Evaluation. However, the three design perspectives—those of the Customer, Business, and Environment—are included in the map. The core modules of Service Explorer, which is the most important achievement of our research, are shown in the center area of the map. Methods and tools that support designers in specific design phases are mapped as satellite modules. Methods and tools illustrated as satellite modules are explained in Sections 3, 4, and 5.

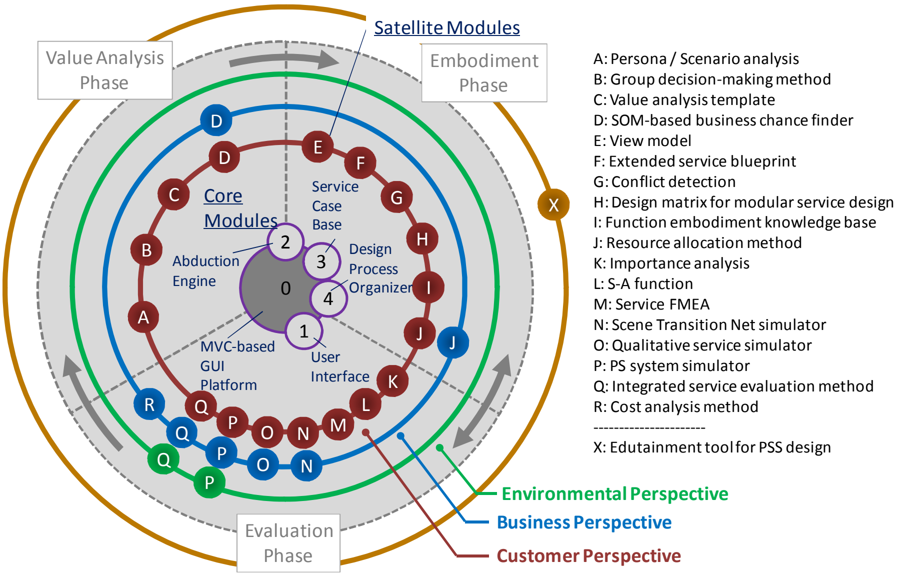


Fig. 2. Research strategy map

3 Value Analysis Phase

3.1 Customer Perspective

Module A: Persona / Scenario Analysis. To extract the requirements of service receivers, a persona is described for each agent that works as a receiver in the service. The persona is a tool used mainly for software interface design to give a simplified description of a customer. It works as a compass in a design process [10]. According to this persona, subsequently, a scenario is developed to clarify the context in which the service is received. The scenario is described in the form of a graph representing a scene transition. For each described scene, the receiver's state is represented as a set of parameters (Figure 3).

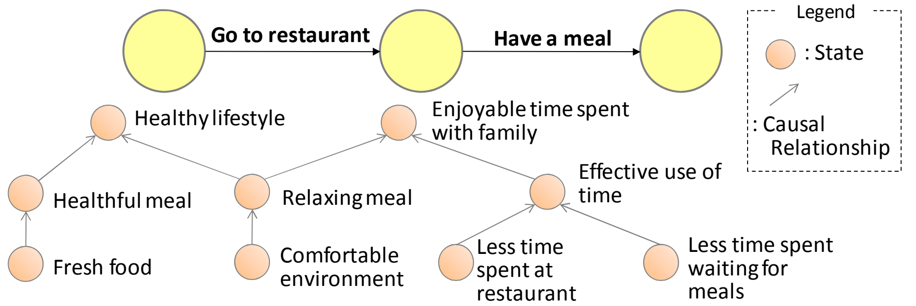


Fig. 3. Scenario model

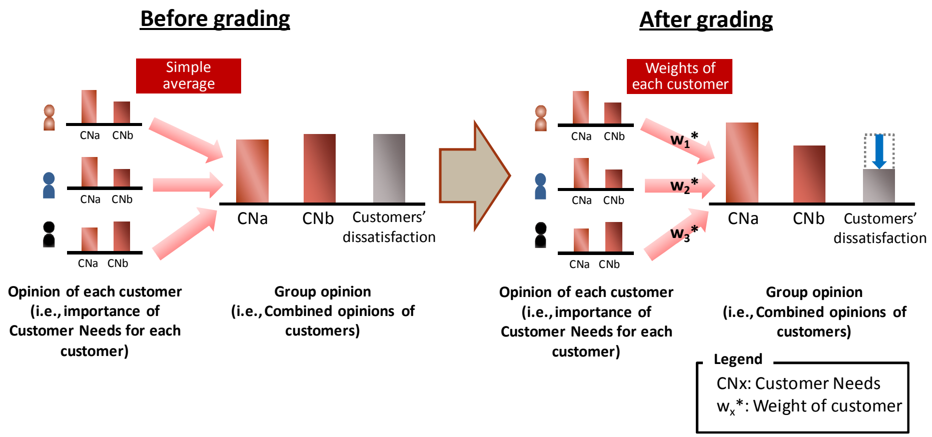


Fig. 4. Group decision-making method

Module B: Group Decision-Making Method. This method attempts to derive the group opinion and to minimize customer dissatisfaction by using grading scores [11]. The grading score is the weighted value of each customer that would influence the total opinion of the group [12]. The total dissatisfaction of all the customers is defined as the sum of the distances between individual opinions and the group opinion, which is affected by the grading score. This method is used to derive the requirement values for a target service by minimizing the dissatisfaction of all the customers. It is particularly effective for the design of public services (Figure 4).

Module C: Value Analysis Template. While the persona model and scenario model are scientific methods for extracting receivers' requirements, they use a form of representation based on natural language. Their use, therefore, requires a certain amount of training given the diversity of vocabulary selection and the difficulty of determining synonymy. To describe these models more simply, we developed templates as a convenient means of preparing data corresponding to each stage of model building. We developed a framework consisting of five templates, shown in Table 1, that assist in the tasks of (1) describing personas, (2) describing scenarios, and (3) extracting receivers' requirements. We are, thus, able to implement a system that supports the comprehension and analysis of personas, scenarios, and provided values.

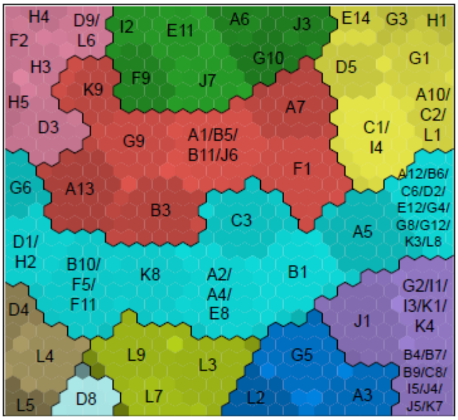
The original value analysis template was developed for B2C service design. Akasaka et al. [13] extended the original template and developed one for B2B service design.

3.2 Business Perspective

Module D: SOM-Based Business Chance Finder. We have developed a method to support designers in generating business design ideas [14]. In this method, the similarities of business seeds are visualized on a two-dimensional map using the Self-Organizing Map (SOM) technique [15] (Figure 5). The similarities of business seeds are calculated as the similarities of values offered with business seeds. By using the map, designers can identify business seeds that may fulfill receivers' requirements. For example, the green cluster includes business seeds A6, E11, F9, G10, I2, J3, and J7. These business seeds can provide values such as Reduction of Noise, Flexibility of Installation Space, and Reduction of Operating Cost. Therefore, if a designer has to design a way to reduce operating costs, the business seeds in this cluster can be applied.

Table 1. Value analysis template

Template	Summary
Persona template	A template to define a persona that represents a hypothetical client as an individual. A persona is defined by describing demographic data, e.g., name, gender, and carrier, as well as psychological data, e.g., personality and life-style.
Character / Intent template	A template to configure the character / intents of the defined persona using a prepared vocabulary list.
Script template	A template to describe detailed behaviors (including the service-receiving context) that the persona, defined in the persona template, performs to achieve specific goals or objectives.
Keyword template	A template to convert the described script into unified lexical expressions by arranging keywords based on six phases in the Phases of Service Encounter and 4W1H (What, What like, Where, When, How).
RSP extraction template	A template to associate required items / qualities and quality elements with the keywords identified in the keyword template.



A1-13: Technologies in gas turbine business
B1-11: Technologies in motorcycle business
C1-9: Technologies in robot business
D1-9: Production technologies
E1-17: Technologies in plant business
F1-13: Technologies in ship business
G1-12: Technologies in machinery for ships and motor cycle
H1-5: Technologies for fluid power systems
I1-5: Technologies for environmental consciousness
J1-8: Technologies in train business
K1-10: Technologies for aerospace
L1-11: Technologies for robot systems

Fig. 5. An example of a map of PSS business seeds

4 Embodiment Phase

4.1 Customer Perspective

Module E: View Model. The view model [7-9] is a model to design a functional structure of a service that fulfills receivers' requirements. Figure 6 shows an example of a view model consisting of functions, described as 'verb + noun' (e.g., 'brew + coffee'), and entities that have been used in product design methodologies (e.g., [16]). In this model, preliminary functions that fulfill receivers' requirements are described and deployed into sub-functions. Human resources (e.g., staff) and physical products (e.g., monitoring camera and sensor) are associated with the lowest-level functions as function carriers.

Module F: Extended Service Blueprint. The extended service blueprint is a modeling method to describe a service process which consists of service activities and product behaviors [17]. The origin of the concept is the service blueprint, which is commonly used in service marketing to describe service activities undertaken by a customer, a front-line [Note: What is meant by a "front-line"? Please clarify], and a support team in the performance of a service [18]. However, no service blueprint is available to describe the role of products in a service process. Thus, the extended service blueprint was developed to describe not only service activities performed by human resources and related software but also product behaviors performed by hardware and related software. The notation of the extended service blueprint is based on Business Process Modeling Notation (BPMN) [19]. The extended service blueprint represents the parallel and interactive activities and behaviors of employees, customers, and product. In Figure 7, the interactions among the activities of floor staff and kitchen staff and the behavior of a coffeemaker are illustrated using BPMN.

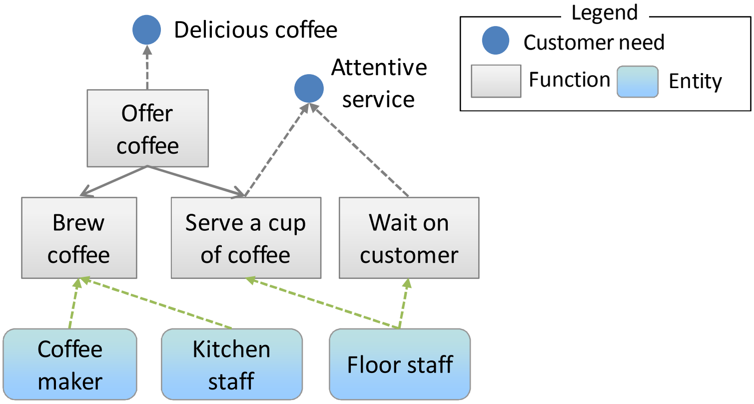


Fig. 6. View model

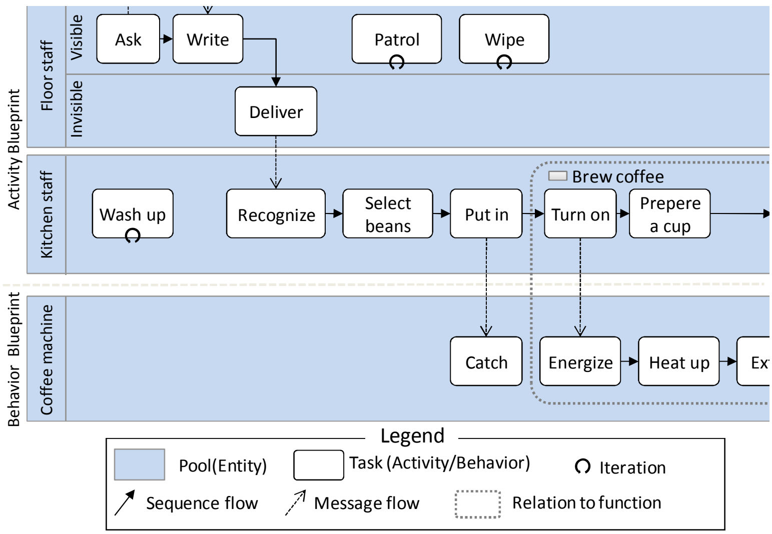


Fig. 7. Extended service blueprint model

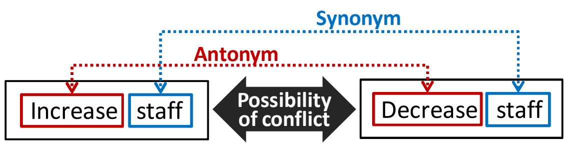


Fig. 8. Conflict detection with the lexical expression of functions

Module G: Conflict Detection. When a service that fulfills receivers' requirements is designed, conflicts can be found. For example, two functions, 'increase staff' and 'decrease staff,' may exist in separate service models of the same service. To avoid this problem, the conflict-detection method analyzes objects and predicates of functional expressions using the lexical expression database [9] (Figure 8). In addition, a method to solve the extracted conflicts with TRIZ [20] has also been proposed.

Module H: Design Matrix for Modular Service Design. The design matrix method is used to optimize the composition of service modules based on Suh's axiomatic design [21]. In service engineering, a module is determined in terms of the (function / attribute) relationship. Table 2 is the design matrix for service design which shows the (function / attribute) relationship with the character 'X.' To determine service components, service designers first determine modules from the (function / attribute) relationship. A module uncoupled from the others is defined as a single component which is the minimum subset of decoupled modules to satisfy the Independence Axiom [21]. By means of this matrix, service designers can configure a flexible and reliable service structure.

Module I: Function Embodiment Knowledge Base. We have developed a method and prototype system for knowledge-based PSS design [22] to support the acquisition of new PSS design solutions by integrating design knowledge managed within a knowledge base. In this method, a unit of information is represented by a set of three elements--function, entity, and delivery process--which enables designers to manage knowledge of both product and service shares in PSS cases. The desired knowledge is sought based on similarities between functions and is provided in catalog form. By using this system, designers can find alternatives to PSS design solutions.

Table 2. A simple example of a design matrix

	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5		
Function 1	X					M1*	Component 1
Function 2		X				M2	Component 2
Function 3		X	X			M3	
Function 4				X	X	M4	Component 3
Function 5				X	X	M5	

*M: Module

4.2 Business Perspective

Module J: Resource Allocation Method. Resource distribution is not easily designed because of the vast search space and the complexity of the problem to be solved. Therefore, a method to determine the optimal value of the resource distribution by means of the Genetic Algorithm (GA) has been proposed [23]. This method optimizes resource distribution from two viewpoints: customer satisfaction and internal resource constraints.

5 Evaluation Phase

5.1 Customer Perspective

Module K: Importance Analysis. Based on the view models, a method to analyze the importance of design parameters by means of Quality Function Deployment

(QFD) [24] and the Analytical Hierarchy Process (AHP) [25] to improve a service structure has been proposed. QFD is a systematic analysis method to translate customer needs into the requirements and specifications of a design object. Meanwhile, the AHP method numerically computes the importance weights of receivers' requirements according to bilateral comparisons among parameters. After the importance of receivers' requirements is obtained, it is converted into the importance of functions and entities by using the matrix of the QFD [24]. The matrix is created based on the specifications described in the view models.

Module L: S-A Function. Unlike the importance analysis method, which evaluates the relative importance of requirements, the function of S-A (Satisfaction-Attribute) is to evaluate directly the satisfaction of service receivers [26, 27]. The S-A function describes the condition of service receivers' satisfaction in terms of their expectations of the service and the type of service function. The receivers' expectations are used as comparison standards to determine whether the receiver is satisfied or dissatisfied. Namely, the function is divided into a gain side and a loss side at the expectation value. This type of service function was originally proposed by Kano [28], who identified three categories of product or service functions: attractive, one-dimensional, and must-be. Figure 9 shows the differences in the shapes of functions. The shape of an S-A function is determined by the analysis of the service function type. By means of S-A functions, the numerical evaluation of a service receiver's satisfaction can be performed.

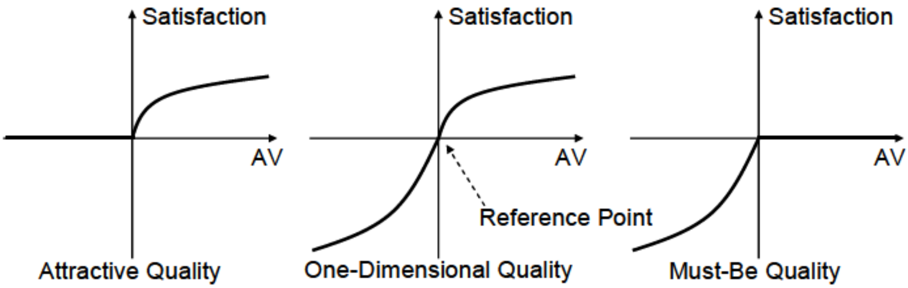


Fig. 9. S-A functions

Module M: Service FMEA. Failure Mode and Effect Analysis (FMEA) [29] is a method to analyze the failure mode, which may cause a product or service to malfunction. Since the structure of a service is complicated, various causes of malfunctions can be considered. Service FMEA (Table 3) attempts to analyze and prevent potential malfunctions. In Figure 9, failure modes of a service are listed in the far left column. Influences on and causes of the failure modes are also listed.

5.2 Business Perspective

Module N: Scene Transition Nets Simulation. The evaluation of a service should be done in both a static and a dynamic manner. We adopt the Scene Transition Nets

(STN) as a simulation model of a service process [30]. STN is a graphic modeling method for discrete-continuous hybrid systems [31]. Figure 10 shows the components of STN, which uses tokens called actors to describe discrete state changes and differential equations triggered by the movements of the actors to describe continuous state changes. STN is suitable for a service process simulation since it can describe both the process transition and the state change of each stakeholder simultaneously. For example, in Figure 11, the service processes of a nursing case service is modeled as a discrete event system. At the same time, the dynamic nurse walking distance in a scene is modeled as a continuous system.

Table 3. Service FMEA

Failure Mode	Time				Result	
	External cause				Cause of the fault	
	Influence			Elapse effect		
	Input	External influence	Structural Influence		Relative cause	Absolute cause
Information is not shared among staff members	･lack of communication skills ･failure to convey information ･rush	･customer's erroneous order ･unexpected rush	･staff's erroneous order ･conflict among staff members ･coercive behavior	･failure to communicate ･Many new employees	･inadequent training for new employees	･insufficient staffing
The situation is not understood properly	･Failure to understand customer's order	･an objection ･unexpected congestion ･inapprpriate placement of lighting	･lack of information sharing ･lack of teamwork	･lack of attention ･a lot of newcomers	･insufficient staffing	･inappropriate positioning of refueling aircraft
Cash register is jammed with bills and coins	･diffusion cash card ･forget filling up	･increase exchange ･unexpected congestion ･payment with bills			･cannnot express "near empty"	･Insufficient number of staff member available for restocking
Staff member cannot responsibly serve customer	･lack of responsibility ･disinclination for sales of goods ･no consequences	･interruption of other work	･have poor support		･insufficient staffing	･lack of responsibility ･inadequent training manual

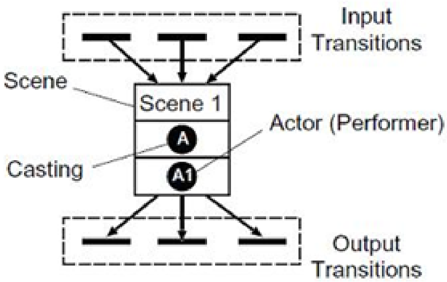


Fig. 10. Components of Scene Transition Nets Simulator

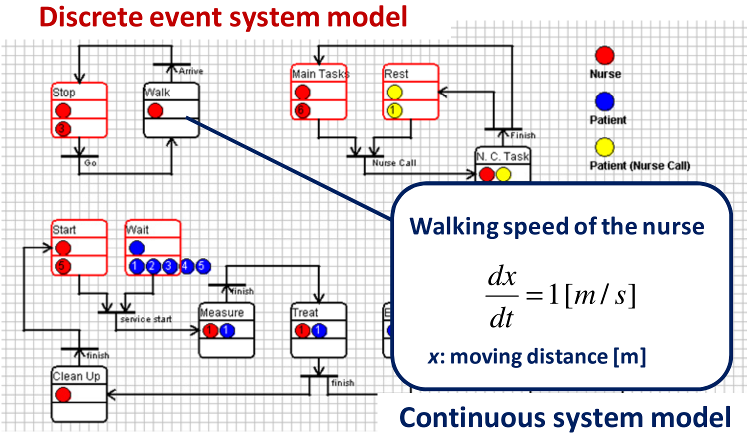


Fig. 11. Scene Transition Nets Simulator

Module O: Qualitative Service Simulator. We have developed a qualitative service simulator that enables designers to evaluate the designed service qualitatively. Qualitative simulation predicts the set of possible behaviors consistent with a qualitative differential equation model of the world. Its value comes from the ability to express natural types of incomplete knowledge and the ability to derive a provably complete set of possible behaviors in spite of the incompleteness of the model [32-34].

Module R: Cost Analysis Method. In order to make services successful, service designers need to consider economic costs. A cost evaluation method [35] has been proposed on the basis of Activity-Based Costing (ABC) [36], which is used to trace overhead costs for objects such as products, processes, and departments. Unlike the original ABC, which is a method to calculate costs of business processes, our proposed method enables designers to calculate the cost of each function and entity, with the entity including both human resources and physical products.

5.3 Environmental Perspective

Module P: PS System Simulator. To realize a sustainable business through PSS, it is important to create a business situation in which each stakeholder receives values through the provision of PSS. The designers must have a holistic view and consider the total value created within the system. Therefore, a design method for a PSS that has a high value for each stakeholder has been proposed. In this method, a PSS is designed using System Dynamics simulation [37] under the simultaneous consideration of values received by various stakeholders. Here, the global environment is also regarded as a stakeholder in the system so that the designers can consider the environmental impact of PSS provision.

Module Q: Integrated Service Evaluation Method. The Integrated Service Evaluation Framework (ISEF) is used to evaluate service design solutions from the viewpoints of multiple stakeholders in an integrated and quantitative manner. In ISEF, service processes of stakeholders are described based on IDEF0 [38], a well-known functional system modeling method used to describe the influences of various stakeholders. This service process model covers the entire service process, which includes pre-activities before the main service activity, such as manufacturing, distribution of products, hiring, and training of employees, and post-activities, such as maintenance, disposal, and after-sales service. The service is evaluated through the STN-based simulation technique (see Module N in 5.2).

6 Crossover Phase

We have developed an edutainment tool for PSS design called EDIPS (Edutainment for Integrated Provision of Product-service System) (Figure 12(a)). This tool is illustrated as Module X in Figure 2. EDIPS is a kind of business game through which players can learn the importance of the integrated provision of product and services to gain profit and learn how to integrate product and services. Figure 12(b) shows a picture taken in an international test game played by PSS researchers.

(a) Overview of the EDIPS (b) Playing the EDIPS

Fig. 12. EDIPS: An edutainment tool for PSS design

7 Concluding Remarks

This paper denotes the need to progress from Service Engineering to PSS Engineering. Our idea is to design a PSS with three dimensions: (1) PS Synergy, (2) PS Strategy, and (3) PS Structure (PSS^3). We have provided an overview of methods and tools that can contribute to PSS design. However, few methods have been proposed that support value analysis and embodiment from the environmental perspective. To design a PSS that helps to reduce environmental impact, it is important for designers to consider environmental friendliness in the early stage of PSS design. Therefore, our future research will include the development of methods to support designers' consideration of environmental impact in the value analysis and embodiment phases of PSS design.

References

1. Tomiyama, T.: A Manufacturing Paradigm Toward the 21st Century. Integrated Computer Aided Engineering 4, 159–178 (1997)
2. Vandermerwe, S., Rada, J.: Servitization of Business: Adding Value by Adding Services. European Management Journal 6, 314–324 (1988)
3. Goedkoop, M.J., van Halen, J.G., te Riele, H., Rommens, P.J.M.: Product Service Systems, Ecological and Economic Basics. Report for Dutch Ministries of Environment (VROM) and Economic Affairs, EZ (1999)
4. Spohrer, J., Maglio, P.: The Emergence of Service Science: Toward Systematic Service Innovations to Accelerate Co-creation of Value. Production and Operations Management 15, 329–343 (2006)
5. Aurich, C., Fuchs, C., DeVries, F.: An Approach to Life Cycle Oriented Technical Service Design. Annals of the CIRP 53(1), 151–154 (2004)
6. Tukker, A.: Eight Types of Product-Service System: Eight Ways to Sustainability? Experiences from Suspronet. Business Strategy and the Environment 13, 246–260 (2004)
7. Shimomura, Y., Tomiyama, T.: Service Modeling for Service Engineering. In: Proceedings of the 5th International Conference on Design of Information Infrastructure Systems for Manufacturing, DIISM 2002, pp. 309–316 (2002)
8. Shimomura, Y., Hara, T.: Method for Supporting Conflict Resolution for Efficient PSS Development. CIRP Annals-Manufacturing Technology 59(1), 191–194 (2010)
9. Shimomura, Y., Hara, T., Arai, T.: A Service Evaluation Method using Mathematical Methodologies. CIRP Annals - Manufacturing Technology 57(1), 437–440 (2008)
10. Cooper, A.: The Inmates Are Running the Asylum: Why High Tech Products Drive Us Crazy and How to Restore the Sanity, Sams (1999)
11. Yamamoto, S., Kimita, K., Shimomura, Y.: An Importance Decision Method of Customer's Demands for Highly Public Service. In: Proceedings of the 15th Design for Manufacturing and the Lifecycle Conference -DFMLC 2010. CD-ROM, The American Society for Mechanical Engineering, ASME (2010)
12. Nakanishi, M., Kinoshita, E.: An Application of the Group Decision Making Stress Method to the Analytic Hierarchy Process. Journal of the Operations Research Society of Japan 41(4), 560–571 (1998) (in Japanese)
13. Akasaka, F., Hosono, S., Yamamura, K., Shimomura, Y., Arai, T.: A Method for Analyzing Customer Requirements in a B2B Service. In: Proceedings of the 9th Japan Korea Design Engineering Workshop, pp. 7–12 (2009)
14. Akasaka, F., Fujita, K., Shimomura, Y.: PSS Business Case Map: Supporting Idea Generation in PSS Design. In: Proceedings of the 2012 International Design Engineering Technical Conference -IDETC 2012. CD-ROM, The American Society for Mechanical Engineering, ASME (2012)
15. Kohonen, T.: Self-Organizing Maps. Springer Series in Information Science, vol. 30. Springer (1997)
16. Pahl, G., Beitz, W.: Engineering Design: A Systematic Approach. Springer (1988)
17. Shimomura, Y., Hara, T., Arai, T.: A Unified Representation Scheme for Effective PSS Development. CIRP Annals –Manufacturing Technology 58(1), 379–382 (2009)
18. Shostack, G.L.: How to Design a Service. In: Donnelly, J.H., George, W.R. (eds.) Marketing of Services. American Marketing Association (1981)
19. Havey, M.: Essential Business Process Modeling. O'Reilly Media, Inc. (2005)
20. Mann, D.: Hands On: Systematic Innovation. CREAX Press, Ieper (2002)

21. Suh, N.P.: Axiomatic Design Theory for Systems. Research in Engineering Design 10(4), 189–209 (1998)
22. Nemoto, Y., Akasaka, F., Chiba, R., Shimomura, Y.: Establishment of a Function Embodiment Knowledge Base for Supporting Service Design. Science China Information Sciences, Special Focus on: Design and Digital Engineering 55(5), 1008–1018 (2012)
23. Holland, J.H.: Adaptation in Natural and Artificial Systems. Univ. of Michigan Press (1975)
24. Akao, Y.: Quality Function Deployment. Productivity Press (1990)
25. Saaty, L.: The Analytic Hierarchy Process. McGraw-Hill (1980)
26. Tateyama, T., Shimomura, Y., Kawata, S.: Development of Scene Transition Nets (STN) GUI Simulator for Service Flow Simulation. In: Proceedings of the 17th International Conference on Engineering Design - ICED 2009, pp. 337–346 (2009)
27. Yoshimitsu, Y., Kimita, K., Hara, T., Shimomura, Y., Arai, T.: Proposal of a Measuring Method of Customer's Attention and Satisfaction on Services. In: Proceedings of the 14th CIRP International Conference on Life Cycle Engineering - LCE 2007. CIRP, pp. 417–422 (2007)
28. Kano, N., Seraku, N., Takahashi, F., Tsuji, S.: Attractive Quality and Must-Be Quality. Journal of the Japan Society of Quality Control 14(2), 39–48 (1984)
29. Stamatis, D.H.: Failure Mode Effect Analysis: FMEA from Theory to Execution. ASQ Quality Press (2003)
30. Tateyama, T., Kawata, S., Shimomura, Y.: Service Flow Simulation Using Reinforcement Learning Models and Scene Transition Nets. In: Proceedings of International Conference on Instrumentation, Control and Information Technology 2008 (SICE Annual Conference 2008), pp. 2056–2061. CD-ROM (2008)
31. Kawada, S., Kawata, S., Watanabe, A.: A Manufacturing System Modeling Using a Scene Transition Net. New Direction in Simulation for Manufacturing and Communication (1994)
32. Kuipers, B.: Qualitative Simulation. Artificial Intelligence 29(3), 289–338 (1986)
33. Fobus, K.: Qualitative Process Theory. Artificial Intelligence 24(3), 85–168 (1984)
34. de Kleer, J., Brown, J.S.: A qualitative physics based on confluences. Artificial Intelligence 24(1), 7–83 (1984)
35. Kimita, K., Hara, T., Shimomura, Y., Arai, T.: Cost Evaluation Method for Service Design Based on Activity Based Costing. In: Proceedings of the 41st CIRP Conference on Manufacturing Systems. CIRP, pp. 477–480 (2008)
36. Cooper, R.: The Rise of Activity-Based Costing-Part One: What is an Activity-Based Cost System? Journal of Cost Management 2(2), 45–54 (1988)
37. Sterman, J.D.: Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hill (2000)
38. FIPS PUB 183, Integration Definition for Function Modeling (IDEF0) Federal Information Processing Standards. United States National Institute of Standards and Technology (NIST), Computer Systems Laboratory, Gaithersburg, MD (1984)

Knowledge-Based Design Support System for Conceptual Design of Product-Service Systems

Yutaro Nemoto, Fumiya Akasaka, and Yoshiki Shimomura

Department of System Design, Tokyo Metropolitan University,
Asahigaoka 6-6 Hino-shi, Tokyo, 1910065, Japan
nemoto-yutaro@sd.tmu.ac.jp

Abstract. Product-Service Systems (PSS) are regarded as an attractive business concept for manufacturing companies to enhance the value of their products. As both tangible products and intangible services are included in the design space, various alternatives have to be considered when it comes to developing design solutions for PSS, especially in the conceptual design phase. Therefore, in PSS design, designers require a broader range of knowledge to generate several design solution ideas. Taken this issue into consideration, a PSS conceptual design support system is developed in this paper. The basic feature of the system is managing and reusing case knowledge of PSS. The design support system is developed on the basis of the analysis results of the PSS design experiment. The effectiveness of the proposed system was analyzed using an example application.

Keywords: Product-Service Systems, PSS design, design support, design knowledge base.

1 Introduction

Product-Service Systems (PSS) [1-3] are attracting much attention from manufacturing firms as a competitive and sustainable business model because they can offer high value-added products and benefit long-term customer relationships. For design, development, and operation of an effective PSS, it is important to search for value provision opportunities in the entire product life cycle and offer appropriate services to customers at each opportunity.

As pointed out in product design research, design knowledge obtained from past product cases provides helpful information to designers, especially in the conceptual design phase [4]. Thus, many studies in the product design area have focused on knowledge-based design support (e.g., [5-6]).

Compared to product design, a broader range of knowledge is required in PSS design because both products and services are included in the design space. To identify an appropriate design solution or enhance the quality of a design solution, designers should have many kinds of design knowledge and consider various alternatives for design solutions.

This paper aims at the development of a knowledge-based design support system for the conceptual design of a PSS. The authors have already proposed a method to

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 41–52.
DOI: 10.1007/978-3-642-30820-8_4

represent and manage PSS case knowledge [7]. In this paper, this method is extended to support designers more holistically and effectively. The extension is carried out according to the features of PSS design operation obtained from design experiments. Then, the design support system is developed based on the extended knowledge management method.

The reminder of this paper is organized as follows. Chapter 2 explains the theoretical background of this study. In Chapter 3, the existing method and the approach in this paper are presented. Chapter 4 introduces the developed knowledge-based design support system. Chapter 5 reports an application of the design support, Chapter 6 discusses benefits and issues arising from this study, and Chapter 7 concludes the paper.

2 Theoretical Background

2.1 Definition of PSS

Currently, there is no commonly accepted definition of a PSS. With respect to some definitions in the literature [1-3], the terms related to PSS in this paper are defined as follows:

- PSS: Social systems to enhance social and economic values received by each actor in the network through the mutual provision of product, service, or Product-Service (PS)
- PS: an integrated combination of tangible products and intangible services
- Actor: an individual, group, or organization that is actively engaged in the PSS (e.g., a provider, partner, or customer)

2.2 Conceptual Design of PSS

Methodologies for Conceptual Design of PSS. Some studies have addressed the conceptual design of PSSs; these emphasized that designers have to consider what should be offered to the customer and how to realize this offering in the conceptual design phase of the PSS (e.g., [8-9]).

To model and design the offering in the PSS, the concepts of function and entity, which are originally used in product design methodologies (e.g., [10-11]), have been highlighted in many of these studies (e.g., [8, 12]). “Function” is an abstract concept, which represents what should be offered to fulfill the customer’s needs. “Entity” is a concrete measure to realize a function; namely, it represents the required resources to prepare, operate, and maintain the PSS offering (e.g., staff, technicians, machinery, and facility).

Design Operations in PSS Design. To understand the features of design operation in the conceptual design of PSS, the authors have analyzed the protocol data, which is the recorded dialogue among the designers involved in the design experiments for a

PSS design [13]. The term “design operation” means the derivation of one concept from another concept in the design object.

The following list outlines the three typical design operations in the conceptual design of PSS that have appeared many times in the data. Figure 1 presents an example of these operations.

- Design operation 1: functions are derived from the customer’s needs.

Designers propose functions to fulfill the customer’s needs by considering existing business cases.

- Design operation 2: entities are derived from a function.

Designers associate physical products and/or human resources with particular functions.

- Design operation 3: functions are derived from an entity and an actor.

Designers determine how functions can be offered by the entity and its supplier, i.e., the actor. Then, they consider the possibility of additional fulfillment of the customer’s or other actors’ needs by offering these functions. This operation is aimed not only at enriching the offering in the PSS, but also at evaluating whether the entity and the actor should or should not be adopted.

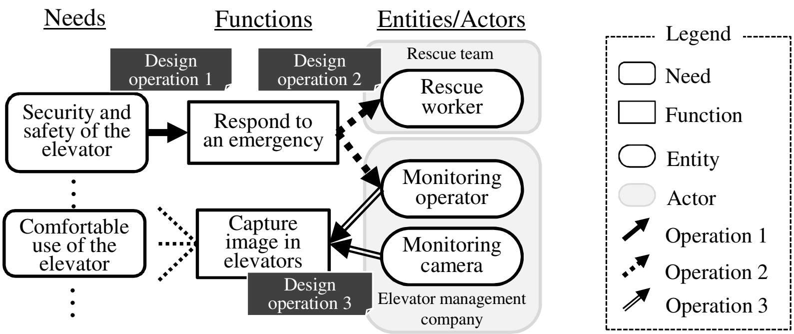


Fig. 1. Three typical operations observed in conceptual design of PSS

3 Knowledge-Based PSS Design Support Method

3.1 Existing Method and Challenges in This Paper

For the purpose of supporting PSS designers in the conceptual design phase, the authors propose a PSS design knowledge management method [7]. In this method, a piece of PSS case knowledge is represented as the set of a function, entities, and actors. Pieces of collected knowledge are provided to designers on the basis of two classification criteria: value and phase. The criterion “value” represents the types of value produced by the function. Table 1 shows the seven types of value used in this method. On the other hand, the criterion “phase” represents the phases of the product’s life cycle targeted to provide the offering. This criterion is constructed from the following

10 phases: extraction, manufacture, transport, sales, installation, use (pre), use (during), use (post), maintenance, and disposal. These two criteria enable designers to identify the functions, entities, and actors that are directly related to the required value or customer's needs in their own business. This method is comparable to the support for the design operation 1. However, the design operation 2 and 3 are not directly supported in this method. Therefore, designers conducting these operations have to rely on their own experience and knowledge.

To support designers more holistically and effectively, this paper extends the knowledge management method to support design operations 1-3. This extension helps designers to consider various alternatives to generate a high-quality design solution in the conceptual design of PSSs.

Table 1. Seven types of value produced in a PSS

Type		Explanation
PI	Performance improvement	Performance, capability, or condition of products or customers is enhanced.
CR	Cost reduction	Purchasing, operating, and managing costs of the product are reduced.
CS	Comfort and simplicity	Customers' lives are made easier.
CV	Convenience	Time is saved, and frustration is avoided.
RR	Risk reduction	The likelihood of accidents involving products and customers is reduced.
EE	Emotional experience	The use of the product or reception of the service increases the pleasure felt by customers.
EF	Eco-friendliness	Negative effects on the environment are reduced.

3.2 Proposal

Overview. In this study, a piece of PSS case knowledge is represented as the set of four elements: need, function, entity, and actor. Each element has two frames to describe the PSS case. The first frame describes the detailed content of the PSS case. The second frame is aimed at the connection with the tags. These tags are used as keys to search for the desired knowledge.

The remainder of this section explains the kinds of tags that are used to represent knowledge and how each design operation is supported using the knowledge of the operation.

Design Support for Design Operation 1. The design support for this operation is fundamentally the same as the previous method reported in 3.1. Thus, the tags to search knowledge contain "value" (seven types) and "phase" (10 phases). In this study, these tags are associated with "need" in the framework of knowledge representation. Designers search for pieces of knowledge using the tags value and phase. Then, they refer to the functions included in the found knowledge.

Design Support for Design Operation 2. The design support for this operation is conducted as follows: Designers search for pieces of knowledge that have a similar function to that of the target function of this operation. Then, they refer to the entities and their actors included in the found knowledge.

In the method introduced in 3.1, a function is freely expressed by natural language. This approach can flexibly describe the detail of a function but lead to a different expression of similar functions in some cases [14]. To effectively search for the knowledge as stated above, tags to unify the expression of the function are required.

Thus, the tags associated with "function" are introduced in an input-output approach to function representation [15]. In this approach, a function is defined as an input-output relation among materials, energy, and signal/information [10]. This approach can help to unify the expression of both the product and the service function, although it limits the flexibility of the description [15].

In this approach, the function tags include three elements: input, input/output, and output. Table 2 shows the terms used in each tag.

Table 2. Terms to represent functions by input/output approach

Items	Content
Input/output elements	Materials, energy, and signal/information
Input/output relations	Separate, distribute, import, export, transfer, guide, couple, mix, actuate, regulate, change, stop, convert, store, supply, sense, indicate, process, stabilize, secure, and position

Design Support for Design Operation 3. In this operation, designers search for new functions from not only an entity, but also its supplier i.e., actor. This extended method provides support for designers from both the aspects of entity and actor. To be more precise, this method helps designers to search for pieces of knowledge that include: (1) an entity that is the same as the target entity, and (2) an actor who can supply the target entity. By referring to the detailed content on the function in the searched knowledge, designers can find new functions or functions not considered previously. To search for knowledge that includes a description of the specific entity and the actor, each entity's and actor's name is used as the tags in this study.

3.3 Summary

As mentioned in this chapter, a piece of PSS case knowledge in this study is represented by a set of four elements: need, function, entity, and actor. The content of each element is described in detailed, and the tags are used to provide support in each support of the three design operations. Table 3 represents a piece of knowledge extracted from a PSS case involving incinerators. In this case, the customer's need was for a lower incidence of sudden failures. The detailed contents are described in the second column of Table 3. The third column denotes the tags associated with each element.

Figure 2 illustrates the elements used to support each design operation. The tags enclosed by a bold line were used to search for knowledge. The elements under the arrows from these tags enabled the designers to generate some ideas and alternatives in each design operation.

Table 3. An example of knowledge representation (case: PSS of incinerators)

Elements	PSS case knowledge	
	Detailed content	Tags
Need	Lower incidence of sudden failures	• *Phase*: Maintenance • *Value*: Risk reduction, convenience
Function	Design a maintenance plan based on analyzed data	• *Input elements*: Information • *Output elements*: Information • *Input/output relation*: Change
Entity	Staff, maintenance record, database	• *Entity's name*: Staff, maintenance record, database
Actor	Heavy industries company	• *Actor's name*: Heavy industries company

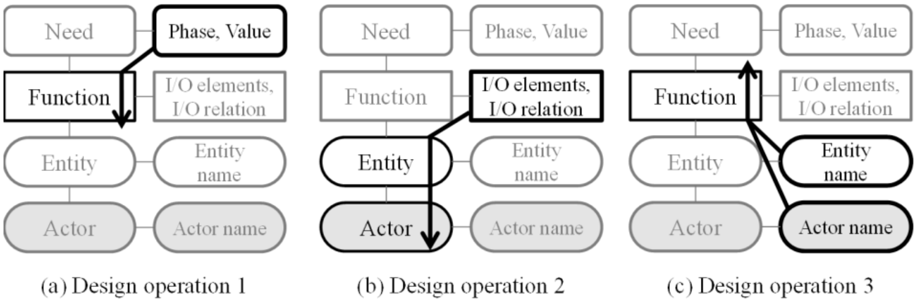
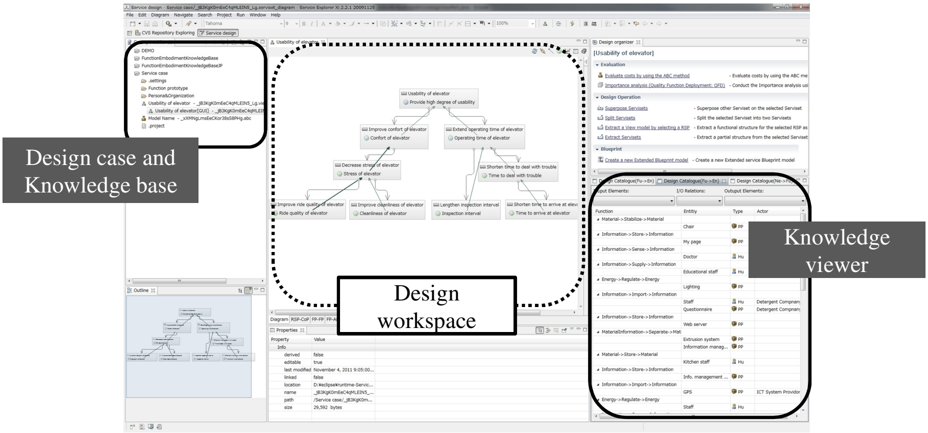


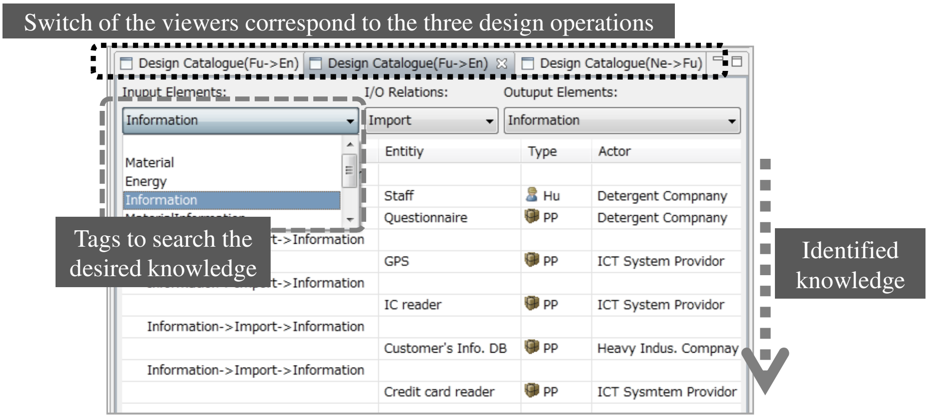
Fig. 2. Elements used to support each design operation

4 Implementation

On the basis of the approach reported in Chapter 3, a prototype of a knowledge-based PSS design support system is developed. This system consists of three modules: (1) a design workspace, (2) a design knowledge base, and (3) a knowledge viewer. The design workspace supports the PSS's design activities, i.e., the operation and integration of the design elements such as functions and entities. This module already provides the main functionality for Service Explorer, which is the CAD system for PSS design [8, 16]. The second and third modules, the design knowledge base and the knowledge viewer, respectively, were additionally developed in this research. The design knowledge base enables designers to edit and accumulate knowledge. The knowledge viewer provides the area to search for and refer to the desired knowledge. Figure 3 shows a screen shot of the developed design support system.



(a) Overview of the developed system



(b) The knowledge viewer

Fig. 3. Screenshots of the developed design support system

5 Application to an Example Case

5.1 Settings for This Application

The developed system was applied to the design of an example case. For the application, the authors collected and accumulated 61 sets of knowledge from 16 PSS cases obtained from several reports in the literature [17-18].

Table 4 summarizes the settings of this application. The designer belongs to a virtual company selling agricultural and construction machinery. In this application, the designer aims to design a PSS for a farmer in a certain developing country. The settings for the target customers follow those outlined in a survey report [19].

Table 4. Settings of the provider and the target customer

Actor	Setting
Designer's company	— is a Japanese manufacturing firm producing agricultural and construction machinery — offers many kinds of machinery — has well-educated and experienced engineers — has a connection with an IT system provider — is aiming at expanding its market share in developing countries
Target customers	— are farmers in a developing country — use low-price but low-quality agricultural machines — are dissatisfied with the operability of the machines — do not have enough machinery and equipment because of operating costs — often incur losses on crops due to quality management problems — do not have enough knowledge to maintain their agricultural machinery — use low-quality agricultural materials — cannot easily access materials in stores

5.2 Application

Step 0: Preparation for the Design. In this application, first, the customers' needs were extracted from the image of the target customers described in Table 4. Then, the phase and value tags were connected with these needs. The result of the connection is shown in Table 5. For example, "longer lifetime of machines" (N7) was interpreted as the need for reducing a repairing or repurchase cost of those agricultural machines. Thus, the value tag "CR" and the phase tag "maintenance" were connected.

Table 5. Extracted customers' needs and related tags

No.	Needs	Phases	Values
N1	Lower purchasing cost	Sales	CR
N2	Deeper understanding of how to use	Installation, Use(pre)	PI, RR, CS
N3	Better quality of agricultural materials	Use (pre)	PI, RR
N4	Easier access to agricultural materials	Use (pre)	CV
N5	Lower operating costs (electricity and fuel)	Use (during)	CR
N6	Easier management of crops	Use (post)	PI, CV
N7	Longer lifetime of machines	Maintenance	CR
N8	Greater support for machine maintenance	Maintenance	CV, RR

Step1: Design Operation 1. Next, the designer retrieved pieces of knowledge on the basis of the value and phase tags, and referred to the functions included in the found knowledge. For example, the N2 listed in Table 5 was associated with the values "PI,

RR, and CS" provided in the phases "installation and use (pre)." Based on the knowledge search using these tags, the designer identified the knowledge that include similar types of the target need; and the designer could refer to the following functions: hold a training workshop, station engineers who have much experience and knowledge, indicate a rule to be respected, etc. Starting with this example, the designer could find several adoptable functions to fulfill every need, except those related to N1 and N6.

Step2: Design Operation 2. Then, the designer searched for entities and actors to realize the functions derived in Step 1. The tags of the I/O elements and the I/O relation were used in this operation. For example, the function to fulfill N5 "monitor information on the machine's use" was converted into the function "imports (I/O relation)" a kind of "information (I/O elements)." By conducting a knowledge search using these tags, the designer identified the following entities: questionnaire, wireless device with GPS, and customer's information database. As the designer's company has a connection with an IT system provider (Table 4), the designer decided to adopt a system that included the customer's information database and wireless device to realize the function, the logic being that the system could be developed easily by cooperating with the IT system provider.

Step3: Design Operation 3. Through these steps mentioned above, relationships among needs, functions, entities, and actors were constructed. In this step, to increase the value to use a specific entity and, thus, the value of the PSS, the designer explored new or not-considered functions from the viewpoint of the entity and the actor. In searching for the knowledge, the designer included the entity "customer's information database." Thus, the designer could refer to the following functions: update the information on a web page in a timely manner, store the failure record, deliver detergents house to house, etc. In this way, the designer could identity those functions that were not considered through the one-sided needs-based approach (Step 0-1).

Results of the Application. In this application, the designer considered various alternatives through the design supports stated above. Then, the final design solution was generated, as shown in Figure 4.

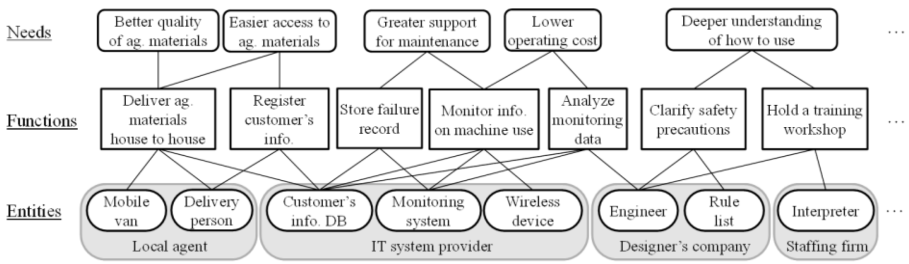


Fig. 4. Part of the design solution generated by the application

6 Discussion

6.1 Implications of This Study

Effectiveness of Knowledge-Based Design Support. By using the support for the design operation 1, the designer could identify several functions that fulfilled six of eight needs; and the designer could identify the entities and actors associated with each of the eight functions derived from the design operation 1. In addition, the designer could consider an additional five functions using the support for design operation 3. From these results of the support for each design operation, the extended method and the developed system realized effective design support for each operation in the conceptual design of the PSS.

Comparison with the Existing Method. This study contributes to designers' knowledge on the creation of design solutions by providing PSS case knowledge. The developed system provides support not only for design operations 1, but also for operations 2 and 3. Referring to the example of a design to fulfill the need "lower operating costs" (N5), the follows compare the existing method [7] with the extended method in this paper from the aspect of the result of design support.

By using the existing method, designers can find the function "obtain customer information" which is achieve by the entities "staff of an energy firm" with "a monitoring facility." This type of structure among functions, entities, and actors is almost the same as that used in past PSS case. On the other hand, by using the extended method in this paper, the designer can find other measures to realize the function (e.g., a wireless device, customer's information database, and so on). Moreover, new functions can be revealed from the standpoint of the entity and the actor (e.g., store the failure record). Thus, the extended method and the developed system may generate more alternatives, which are different to those provided in previous cases.

6.2 Remaining Issue

Lack of Support for Convergence of Generated Ideas. Designs are based on an iterative procedure of the generation of ideas and the convergence of the generated ideas [4]. This paper developed a method and system for the generation of ideas in PSS design. To enable designers to select the best solution from various alternatives, however, a method for the convergence of ideas is needed. Therefore, future work should include the development of an evaluation method to indicate the best way to select the final solution from various alternatives, so as to maximize the value produced in the PSS.

Applicable Scope of Design Operation 3. In this paper, the name of the entity and the actor are incorporated into the tags associated with them. This helps designers to search for knowledge that includes a description of the specific entity and the actor. However, each designer or constructer of the knowledge base could use a different description of these elements. Thus, it is important that the knowledge-based support system can determine similarities among each entity or actor by referring to an ontology or a thesaurus. This will support the operation of the design operation 3 if differences exist in the description of an entity or an actor.

7 Conclusion and Outlook

This paper proposed an extended knowledge-based design support method and developed a system based on that method. The extension was conducted to be able to support the three design operations. A piece of knowledge in this system is represented by a set of four elements: need, function, entity, and actor. Each element is described in detail, and the associated tags are used to ensure effective searches of the desired knowledge. The results of the analysis of the application showed that the extended method and the developed system support the three design operations. Future work should include the development of an evaluation method to select the best set of various alternatives and the integration of an ontology into the system.

References

1. Mont, O.: Clarifying the Concept of Product-Service System. Journal of Cleaner Production 10, 237–245 (2002)
2. Tukker, A., Tischner, H.: New Business for Old Europe. Greenleaf Publishing (2006)
3. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems-IPS2. CIRP Annals - Manufacturing Technology 59(2), 607–627 (2010)
4. Yoshikawa, H., Tomiyama, T.: Design Theory. The Open University of Japan, Tokyo (2000) (in Japanese)
5. Altshuller, G.: 40 Principles: TRIZ Keys to Technical Innovation. Technical Innovation Center, Inc., Worcester (1997)
6. Roth, K.: Konstruieren mit Konstruktionskatalogen. Springer, Berlin (1982)
7. Nemoto, Y., Akasaka, F., Shimomura, Y.: A Knowledge-Based Design Support Method for Product-Service Contents Design. In: Shimomura, Y., Kimita, K. (eds.) The Philosopher's Stone for Sustainability, vol. 122, pp. 49–54. Springer, Heidelberg (2013)
8. Shimomura, Y., Hara, T., Arai, T.: A Unified Representation Scheme for Effective PSS Development. CIRP Annals - Manufacturing Technology 58(1), 379–382 (2009)
9. Müller, P., Kebir, N., Stark, R., Blessing, L.: PSS Layer Method - Application to Microenergy Systems. In: Sakao, T., Lindahl, M. (eds.) Introduction to Product/Service-System Design, pp. 3–29. Springer, London (2009)
10. Pahl, G., Beitz, W.: Engineering Design: A Systematic Approach, 2nd edn. Springer, London (1996)
11. Umeda, Y., Ishii, M., Yoshioka, M., Shimomura, Y., Tomiyama, T.: Supporting Conceptual Design based on the Function-Behavior-State Modeler. Artificial Intelligence for Engineering Design, Analysis and Manufacturing 10(4), 275–288 (1996)
12. Sadek, T.: A Model Based Approach for Conceptual Development of Industrial Product-Service Systems. In: Proceedings of the 17th International Conference of Engineering Design (ICED 2009), vol. 4, pp. 155–166 (2009)

13. Kazawa, A., Nemoto, Y., Akasaka, F., Shimomura, Y.: Classification of Service Design Knowledge based on an Experimental Method. In: Proceedings of the 22nd Conference of Japan of Mechanical Engineers, Design and Systems Division, pp. 735–743 (2012) (in Japanese)
14. Lossack, R., Yoshioka, M., Umeda, Y., Tomiyama, T.: Requirement, Function and Physical Principle Modeling as the Basis for a Model of Synthesis. In: Proceedings of the 1998 Lancaster International Workshop on Engineering Design, Lancaster, pp. 165–179 (1998)
15. Nemoto, Y., Akasaka, F., Chiba, R., Shimomura, Y.: Establishment of a Function Embodiment Knowledge Base for Supporting Service Design. Science China Information Sciences, Special Focus on: Geometry Computing and Digital Media Processing 55(5), 1008–1018 (2012)
16. Hara, T., Arai, T., Shimomura, Y.: A CAD System for Service Innovation: Integrated Representation of Function, Service Activity, and Product Behaviour. Journal of Engineering Design, Special Issue on PSS 20(4), 367–388 (2009)
17. Mont, O.: Product-Service Systems, AFR report 288, Swedish Environmental Protection Agency, Stockholm (2000)
18. United Nation Environment Programme (UNEP): Product Service System and Sustainability: Opportunities for Sustainable Solution, UNEP-Division of Technology, Industry and Economics, Paris (2002)
19. Japan External Trade Organization (JETRO): Survey Report of Latent Needs for BOP Business: Agricultural Material and Machine Area in Myanmar, JETRO (2012) (in Japanese)

Battleships: An Industrial Use-Case of 'Playful' Teaching IPS^2 Concept Generation

Michael Herzog, Matthias Köster, Daniel Meuris, and Tim Sadek

Ruhr-University Bochum, Chair of Engineering Design, Universitätsstr. 150,
44801 Bochum, Germany
{Herzog,Koester,Meuris,Sadek}@lmk.rub.de

Abstract. The promise offered by industrial product service systems (IPS^2) for lasting customer retention is well known. In order to enable this potential solution providers have to use new development methods. Furthermore the cross domain thinking has to be set in the developer's mind. Providers must establish a product-service culture in their development department. This leads to the fact that new ways of teaching such an IPS^2 mindset has to be found in addition to the research of new development methods. This paper describes one such a teaching approach. Based on elements of business games it teaches engineers not to think in separate service and product domains. Furthermore it helps to overcome typical difficulties which occur in IPS^2 development project. For this reason main barriers in establishing an IPS^2 mindset are listed in this paper. Based on these difficulties a playful way of concept generation and teaching cross-domain thinking is presented.

Keywords: Teaching, IPS² mindset, conceptual design.

1 Introduction

Industrial product service systems, shortened to IPS^2, are highly complex systems which combine a wide range of different products and services in one integrated solution. This kind of integration has not only the potential of an innovative and customer-oriented way of problem solving, it also allows the adaption of system partitions during the adduction stage in case of changed requirements. Thus providers may differentiate their product portfolio from competitors by the development of IPS^2 instead of traditional solutions. This trend of transforming from a traditional to an IPS^2 provider is well known. It already has been analyzed in various contributions [1].

However, this transformation poses to be a big challenge. One barrier is located in the development stage of novel systems. The new paradigm of seeing product and service as an integrated solution requires new methodological support in order to overcome the engineers' traditional thinking patterns.

This leads to the fact that the application of new development methods must be promoted, especially in the early design stages, planning and conceptual design. Here, the tasks are dominated by the engineer's creativity instead of the product structure in its various appearances. Furthermore it is essential to describe a holistic way of

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 53–62.
DOI: 10.1007/978-3-642-30820-8_5

problem solving as early as possible. According to the 'Rule Of Ten' this should minimize changes in downstream lifecycle [2]. But the provision of methodological support in the IPS^2-conceptual design process is problematic. Developers from traditional solution providers separate strict between product and service. They are not able to see problems at an abstract level. As a result, solutions are designed which integrate services just as an addition to existing benefits in kind. Consequently, the innovation potential of IPS^2 solutions might not be fully exploited.

The problem of providing methodological support may be split into two subproblems. On the one hand there has to be a modeling approach that allows a holistic view on an IPS^2 concept at an abstract level. In particular, the paradigm of separation between product and service has to be realized. On the other hand there has to be found a more efficient and also effective way of teaching a product developer this modeling approach. How can developers in the context of industrial product service systems learn to describe such a solution without thinking in traditional product and service domains?

2 Conceptual Design of IPS^2

2.1 Modeling IPS^2 Concepts and Product Service Interrelations

The conceptual design stage's goal is the generation of a solution architecture which shows potentially realizations of the customer's needs. Thus, it has to describe the structure and the interrelationships of its system-elements [2].

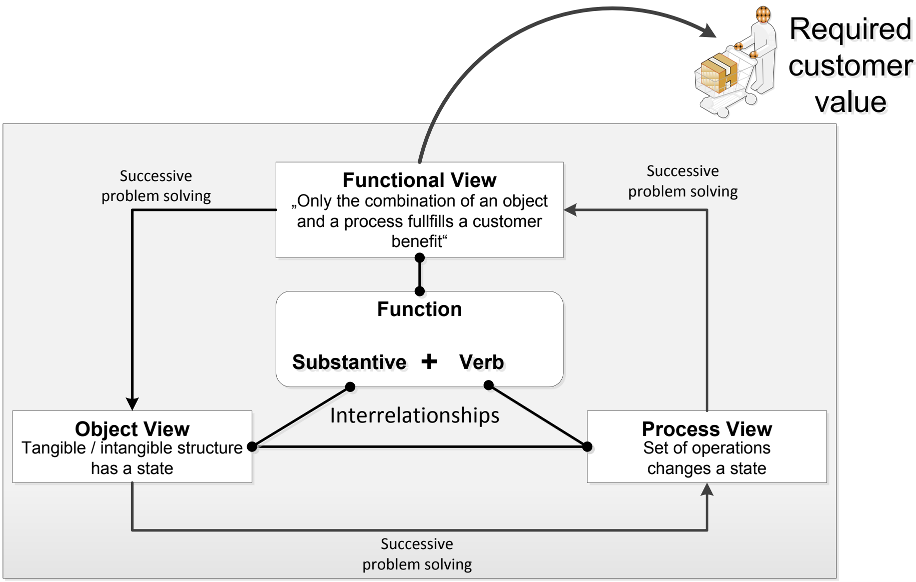


Fig. 1. Main structure of the heterogeneous IPS^2 modeling approach [3]

In this context Sadek provides a model-based approach which allows the description of the architecture [3]. The so called heterogeneous IPS^2 modeling approach supports the determination of a structure of performance artifacts that are assigned to a certain customer benefit. Because performance can be viewed from both, technical and economic viewpoint, performance artifacts are seen as a combination of an object and a process. Within an extended methodology provided by Sadek a developer is able to build structures on the functional, object and the process layer. Relationships between elements of different layers can be described afterwards. Furthermore a variation in the level of abstraction to describe elements on each single layer can be done. For this reason the approach is called heterogeneous modeling approach. Fig. 1 exhibits its main statements. Since there are various contributions to this approach, it is not an aim of this paper to explain all details in depth [3]. It has been proved to be a reliable model to describe IPS^2 in early stages of a development process. But the industrial application has shown that developers who are new to product-service applications have problems in using this approach. As a consequence there has to be special teaching approach which enables cross-domain thinking in the conceptual design stage of IPS^2. In order to generate a holistic teaching approach the difficulties in this stage are given in the following section.

2.2 Difficulties in Establishing an IPS^2 Mindset

It is brought forward the argument that using the heterogeneous modeling approach to describe IPS^2 concepts is an appropriate appliance [4]. Though, an industrial use case as it is described in [5] has shown difficulties that arise out of the circumstance that a company is new to the field of product-service systems. For this contribution it is necessary to know that this use-case is a network based development. Each network partner has no experiences in the field of IPS^2 and the goal of the development project is a highly integrated product-service system with the possibility of changeability in case of changed requirements. In the following section the main difficulties during that development are listed.

Companies which try to get into new markets by offering product-service solutions have not established an IPS^2 mindset in their developers' heads. Traditionally service is seen as a necessary evil to improve or fix technological solutions. As a consequence IPS^2 concepts do not show up with the claimed interrelationships of products and services. This leads to less innovative solutions. A new culture of product and services has to be established.

As mentioned before IPS^2 are highly complex systems. This leads to the fact that different knowledge holder have to build a team in order to make deployed competences available. Consequently, a high number of stakeholders is involved in the decision making process. Though this diversity of knowledge builds the base for innovative problem solving, it is difficult to stimulate communication between different stakeholders because each single stakeholder has a different understanding of the problem. Consequently, an approach to get in touch with the IPS^2 mindset has to support the communication within an interdisciplinary team. If there are different stakeholders involved in the conceptual design process it is essential to find higher level interrelationships as a base for communication. Furthermore an initial step of abstraction is required to reduce the complexity and emphasize essential features and properties of the problem and its environment. For this reason the team members need to get a problem perception on a higher level of abstraction. In the context of interdisciplinary teams in IPS^2 conceptual design this issue also addresses the ability of single members to communicate with each other.

The ability of each team member to describe the development problems on a higher abstraction level enables also the integration of superior viewpoints in the conceptual modeling process. Since an IPS^2 architecture also addresses strategic questions e.g. the business models that need to be integrated in the decision making process. The teaching approach has to create an awareness of these superior viewpoints. This assumes also a systemic understanding of integral solution elements. Each team member must understand the solution and possible relationships to one's own domain.

Due to the fact that an IPS^2 should provide an individualized problem solution it is very important to direct activities in the conceptual design stage towards a stringent customer orientation. Consequently, each functional element of the solution has to aim at customer benefit. Since this is a crucial key factor in the IPS^2 development the awareness of the customer's needs is a central aspect in the learning approach.

Group Skills	Identification of competences	Consideration of superior viewpoints Stringent customer orientation
Individual Skills	Problem abstraction and problem perception Systemic understanding of the whole solution	Consideration of the whole lifecycle Cross-domain thinking
	General challenges	IPS^2 specific challenges

Fig. 2. Aims of an IPS² mindset teaching approach for conceptual design

Fig. 2 summarizes the aforementioned challenges. Since there are issues which addresses the development team and individual skills it is proposed that a teaching approach for the IPS² mindset has to be realized in form of a workshop. Furthermore the high degree of individualization of IPS² solution requires the possibility of problem specific adaption of that workshop. In the following section such a teaching approach to realize these requirements will be presented.

3 Playful Teaching of IPS² Concept Modeling

Based on the initial situation portrayed in the industrial use-case, the composition of the intended teaching approach is explained in the following. In this regard one has to clarify what kind of teaching approach is suitable and what teaching mechanisms are promising to meet the defined requirements. Basically the approach avails on the idea of participatory design. Research implicates design to be necessary to support an organization to really change towards the demanded mindset [6]. Furthermore this kind of teaching implies the active involvement of the multiple relevant stakeholders within the value system, which is necessary in order to really create innovative and holistic solutions for hidden customer needs [7]. So off-key, the participants collaborate, communicate about the relevant topics and learn about the IPS²-development *“on the fly”*. However there are barriers concerning successful group performance related to psychological and social issues [8]. Especially the industrial use case describes the need for involving stakeholders both in- and outside the company who vary e.g. in view points, culture, managerial practices and domain specific languages. Therefore the considered teams mostly need support for communicating and sharing ideas and knowledge [8]. For this purpose *playful approaches* are seen to be of value. This expression subsumes a set of novel practices called gamestorming, which are commonly applied in the business world as well as design games used to support collaboration in multidiscipline design tasks [9],[10]. Brandt defines games as a play with props following specific rules, often with an element of competition between players and decided by chance, strength, skill or combination of these. Though within the addressed IPS² design task the aim is not to compete but to take advantage of the various skills and expertise´s represented in a game setting [10]. In general the concept of teaching approaches depends on the scope, the participants and the available resources [10].

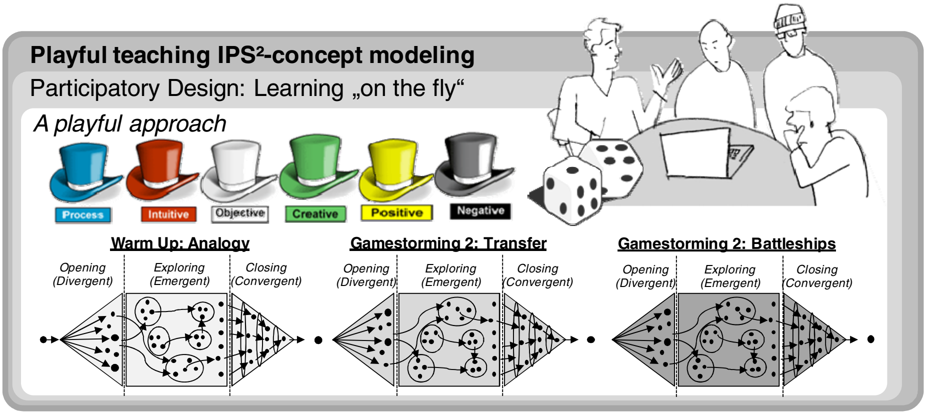


Fig. 3. Structure of the playful IPS² teaching approach

Considering the initial situation mentioned above, generic characteristics of powerful design games identified by Brandt [10] are applied and concretized to identify beneficial mechanisms for the IPS²-teaching approach addressed in this paper. Figure 3 presents the general structure which is characterized by three game phases (*Warm Up: Analogy; Gamestorming 1: Transfer; Gamestorming 2: Battleships*) played back-to-back. Each of these games follows the core principles of any gamestorming technique including an opening, exploring and closing phase [9]. The promoted teaching approach uses game boards to collect, structure and organize the information noted on multicolored post it sheets. The certain game phases are guided by a moderator, who is in charge of managing the discussion and the game rules. To ensure an efficient discourse about IPS² and to take all relevant viewpoints into account, the use of the six hats method is proposed. So the participants have to adopt the various roles (Objective, Intuitive, Negative, Positive, Creative, Process) during the certain game phases as described subsequently.

3.1 Warm Up: Analogy

Learning about the really new paradigms and dimensions of IPS² requires high cognitive effort [11]. Therefore it is suggested to combine the provision of information with mental learning mechanism [12].

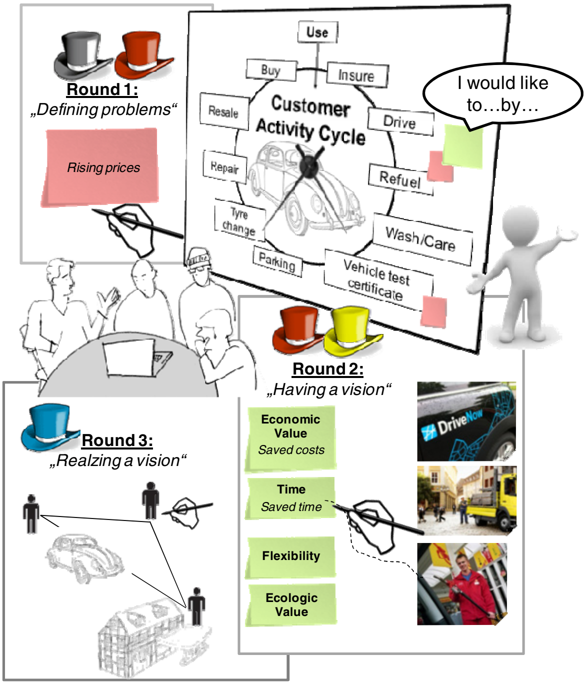


Fig. 4. Structure of the Warm Up

As shown in figure 4 an analogy of the everyday life is used to warm up the participants. So the moderator envisions the activity cycle of a fictional customer using a car. In round one it is the task of the participants to *define problems* concerning the shown activities (e.g. drive, parking, refuel). Therefore they should "wear" the black as well as the red hat, which means that they have to encourage their feelings and emotions belonging to the critical judgment of the certain activity. To overcome old habits and experience something new, the game mechanism of chance is implemented. So the participants do not know about what activity they have to think about next [10]. After identifying the emerging problems along the customer activity cycle the participants are requested to *have visions.* They have to match so called value cards, suggesting categories of IPS² specific value types (e.g. economic, ecologic, social, flexibility) with stimulating pictures showing services the participants are familiar with. By composing the appropriate pairs the participants have to complete open-ended questions (e.g. "I would like to...by…") which are estimated to lead to more open and creative dialogues about products and services supporting the customer activities and eliminate the predefined problems. This directly refers to the thinking of the red and the yellow hat which stimulate looking for benefits and positive thinking. In the last round of the warm up, the participants are asked to discuss about stakeholders who have to be involved to *realize the desired values*. So they have to decide about the relevant stakeholders and conclude the structure of the actor network including their interdependencies. In this round the goal is to teach the complex composition of the stakeholders, required to realize customer value. To sum up the first game phase of warming up teaches the awareness of the customer view, which is important to encourage the participants to gain insights into both views (product and service) in order to achieve the potentials of IPS² [7]. In addition the certain game levels are supposed to stimulate the "value thinking" which is indispensable to teach the needed IPS² mindset.

3.2 Gamestorming 1: Transfer

After introducing IPS² specific aspects in a comprehensible scenario, everybody can identify with, this mental learning mechanism is used to manage the transfer to the use-case related challenges like visualized in figure 5. Therefore in the first round the participants have to *translate the scenario activities and problems*. The white and the green hats provide the needed creative and informational viewpoint. So participants are asked to build causal loops and tell a story about the activities, the use-case customer has to deal with, problems that may occur and customer support to provide during the whole lifecycle. In round two the generic values depicted in the first game are transcribed onto the actual game board. Now the participants have to *match* their new found activities and problems with the generic value categories and hereby find some new customer values to realize or problems that did not occur before. After identifying all relevant values, the underlying problems that have not been obvious before and support activities declared to be helpful to create the focused values, the participants have to decide about the actor network needed *to realize the visions*. Thereby it is possible to rethink the composition of the participants of the upcoming game. For example it can be necessary to invite some additional partners to assure the best findings. Summing up the second game called "Transfer" the participants are confronted with the real situation of thinking about a customer in the field of galvanizing high quality sanitary fittings. The teaching approach strengthens the consideration of the relevant lifecycles, the understanding of contributing a value instead of a product as well as the need of involving certain stakeholders to really innovate.

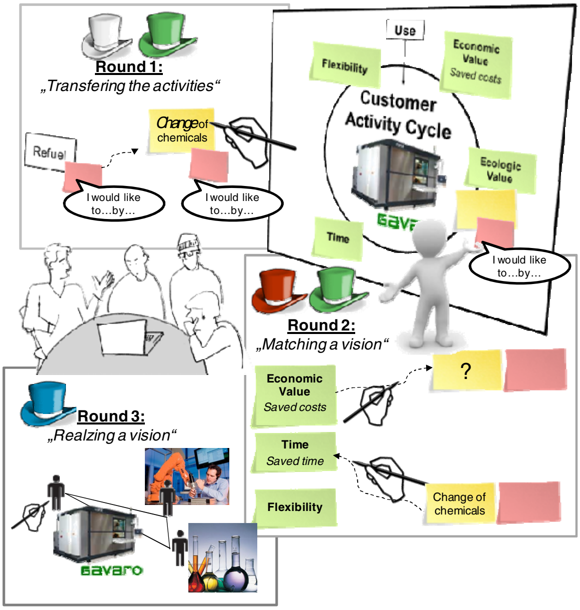


Fig. 5. Structure of the Gamestorming 1: Transfer

3.3 Gamestorming 2: Battleships

After the optional reconfiguration of the participants, the last game phase intends to identify innovative solution principles for the desired IPS² in a creative manner. In the first round it is task to draw conclusions from the game phase before and define the main functions that are necessary to satisfy the customer needs and so realize the aspired values. Therefore the participants have to collect already existing information and identify further information that may be needed. The final identified functions are transcribed onto the game board like shown in figure 6. For each function there are two possible categories, solution principles can be attached to. Either the function is fulfilled by a technical object or a human activity. So this game phase is about the "battle" of *"technical objects"* versus *"human activities"*. For the example of the analogy a car can be washed (function) by an automatic washer system (technical object) or specialized personnel cleaning the car (human activity). So at the beginning of the second round the participants have to find as much solutions principles as possible by thinking creative addressed by the green hat. Following it is requested to find flaws related to the solutions played before. Thereby the participants create barriers against the identified technical objects or human activities to hinder their chances of success. This kind of competition is considered to stimulate the debate among the certain stakeholders and to establish the needed transparency of the distributed knowledge. In order to further support this cross domain thinking, so called incentive cards e.g. force the participants to find solutions by changing their viewpoint or to reframe the function into another field of knowledge. As a result of the second round, solution principles and alternatives have been identified for each function predefined. Finally the participants have to decide about the different solutions and now are able to arrange these elements into a systematic order in round three.

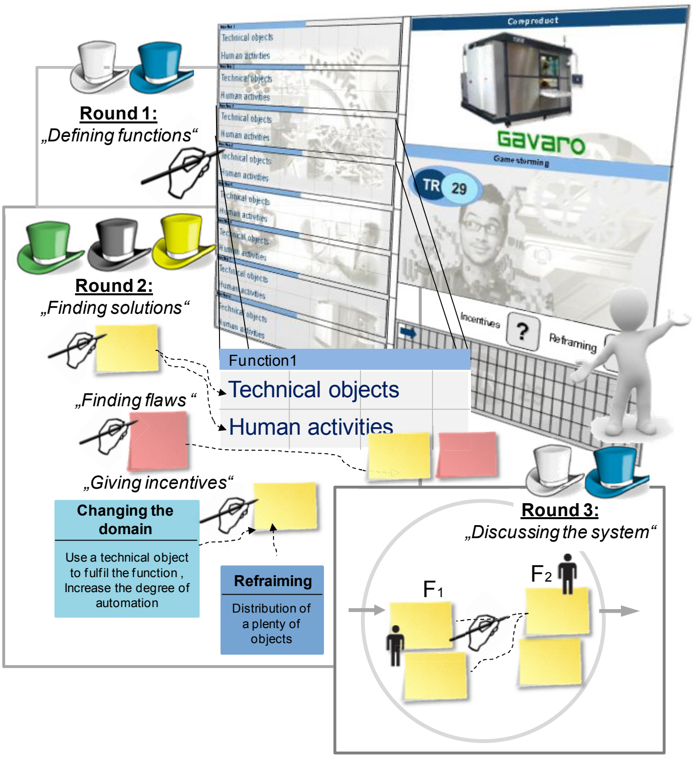


Fig. 6. Structure of the Gamestorming 2: Product vs. Service

The final aim of the addressed teaching approach is to encourage the participants not to think about products and services in a separated manner but to create a system consisting of both material and immaterial elements that are related to each other and their interdependencies have to be considered already during the concept development to really realize the desired customer values.

4 Summery and Outlook

The transformation towards offering industrial product service systems requires a change within the whole organization. Especially technology oriented thinking patterns of developer need to be broken. This is a big challenge and it already occurs in early stages of the conceptual IPS² design process. For this reason a kind of teaching new development methods is proposed in this paper. Using playful learning mechanisms the approach tries to overcome the barriers of distributed knowledge and teaches the new IPS² paradigm which is obligatory to understand if a company wants to really innovate with customer and value oriented solutions. The teaching approach is composed of certain "game modules" which can be expanded or newly arranged for various use cases. So, it is possible to consider and adapt to different stages in the transformation process (servizitation) of the particular companies. The next step is to evaluate the proposed teaching approach. It will be applied for the addressed use-case in an industrial workshop. Furthermore the "battleship" design game is tested among students to explore the potentials in the context of creativity methods. This allows a comparison of industrial and academic viewpoints. As result it will lead to new scientific questions and findings.

Acknowledgements. Financial support from the German Research Foundation (DFG) through SFB/TR 29 is gratefully acknowledged.

References

1. Meier, H., Roy, R., Seliger, G.: Industrial Product Service Systems – IPS2. CIRP Annals – Manufacturing Technology 59(2), 607–627 (2010)
2. Pahl, G., Wallace, K., Blessing, L.: Engineering Design – A systematic approach. Springer, London (2007)
3. Sadek, T.: A model based approach for conceptual development of industrial product-service systems. In: Proceedings of the International Conference on Engineering Design, ICED 2009. Stanford University, Stanford (2009)
4. Sadek, T., Köster, M.: Analyzing the practical usability of the heterogeneous modeling approach for conceptual product-service system development. In: Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, Braunschweig (2011)
5. Herzog, M., Sadek, T.: Sustainable IPS2 – Business models for galvanizing high quality sanitary fittings. In: Proceedings of the 4th CIRP Conference in Industrial Product Service Systems, Tokyo (2012) (in press)
6. De Lille, C., Roscam Abbing, E., Kleinsmann, M.: A designerly approach to enable organizations to deliver product-service systems. In: Proceedings of the 2012 International Design Management Research Conference, Boston (2012)
7. McAloone, T.C.: Teaching and Implementation Models for Sustainable PSS Development. In: Proceddings of the Sustainable Consumption and Production: Opportunities and Threats, Wuppertal (2006)
8. Shai, O., Reich, Y., Rubin, D.: Creative conceptual design: Extending the scope of infused design. Computer Aided Design 41 (2009)
9. Gray, D., Brown, S., Macanufo, J.: Gamestorming - A playbook for inventors, rulebreakers and changemakers. O´Reilly Media Inc. (2010)
10. Brandt, E.: Designing Exploratory Design Games a framework for participation in participatory design? In: Proceedings of the Participatory Design Conference (2006)
11. Zhao, M., Hoeffler, S., Dahl, D.W.: The role of imagination-focused visualization on new product evaluation. J. Mark. Res. (2009)
12. Rese, M., Karger, M., Strotmann, W.C.: HLB als Herausforderung für das Marketing. In: Meier, H., Uhlmann, E. (eds.) Integrierte Industrielle Sach- und Dienstleistungen. Springer (2012)

Extraction of Customers' Potential Requirements Using Service Scenario Planning

Kosuke Ota[1], Yusuke Kurita[1], Fumiya Akasaka[1], Koji Kimita[2], and Yoshiki Shimomura[1]

[1] Department of System Design, Tokyo Metropolitan University, Asahigaoka 6-6, Hino-shi, Tokyo 191-0065, Japan
[2] Department of Industrial Management and Engineering, Tokyo University of Science, 1-3 Kagurazaka, Shinjuku-ku, Tokyo 162-8601, Japan
kosuke-ota@sd.tmu.ac.jp

Abstract. The realization of service that adapts to a diversity of customer requirements is becoming important in many industries. A tool for extracting customer requirements, which is called a requirements analysis template, has been proposed previously. However, using this tool, customer requirements are extracted without any consideration of variable environmental factors, such as social change and macroeconomic fluctuations, even though these factors influence customer requirements. This paper proposes a supporting method that service designers can use to help consider such environmental factors and grasp customers' "potential" requirements when they build their service strategies. To achieve this purpose, the requirement analysis template is integrated with scenario planning methodology, which is a method used to consider environmental factors for business strategy planning.

Keywords: Service Engineering, Scenario Planning, Customer Requirements, Environmental Factors.

1 Introduction

As our society matures, productivity improvement in service industries, which account for approximately 70 percent of the developed world's economy and employment, is therefore, becoming a pressing issue. Thus, the importance of service industries is recognizable. On the other hand, in academic fields, many research and development projects are intended to promote the growth of service productivity. Considering this, the authors of this paper have conducted conceptual research on design services from an engineering viewpoint. This type of research is called service engineering [1-2].

In the service design phases, the analysis of customer requirements plays a crucial role because the realization structure of a service should be constructed by starting with each customer requirement. For this reason, a tool for extracting customer requirements, which is called a requirement analysis template, is proposed in service engineering [3]. Using this tool, customer activity is analyzed by using a service

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 63–74.
DOI: 10.1007/978-3-642-30820-8_6

scenario that describes customer activity with natural language. On the basis of the service scenario, some keywords are extracted from the scenario, and then, customer requirements are identified based on each keyword.

However, the service scenario is described without any consideration of variable environmental factors, such as social changes and macroeconomic fluctuations, even though these factors influence customer requirements.

The purpose of this study is to propose a method of extracting customers' potential requirements. This study focuses on the Business to Business (B2B) industry. Hence, the term "customer" is meant to refer to a "client company" in this paper. To achieve this purpose, the requirement analysis template is integrated with the scenario planning methodology, which is a method of planning business strategies while considering external environmental factors.

2 Previous Studies and the Scope of This Study

2.1 Analysis of Customer Requirements for Service Design

The authors propose a requirement analysis template that extracts customer requirements via a series of templates. The first step of this method is to decide upon a fictitious target customer for the relevant service. Then, information that includes the customers' characteristics is added. On the basis of the information, a story about customer activity in a service delivery process is written in natural language. This story includes information that can be used for decision making in the service design phases. Then, considering the "phase of the service encounter" and "4W1H (what, what like, how, where, when)," keywords regarding the customer requirements are extracted. Finally, each keyword is associated with the required items/quality. Thus, the service designer is able to discover the customer's requirements (See [3] for more details).

This template is applicable to B2B services. The authors previously proposed a requirement analysis method for the strategic improvement of a B2B service and verified the effectiveness of the method by applying it to a real service [4].

2.2 Strategic Planning Method for Decision Making While Considering Uncertainty

Business strategy is significantly impacted by environmental factors, and a business manager faces the difficult task of making decisions while considering potential environmental factors. On the other hand, in the fields of management science, the scenario planning methodology, which is a method for planning business or management strategy while considering environmental factors, is widely applied. In scenario planning methodology, in order to improve the quality of decision making, the environmental factors are extracted, and a story about how the future might turn out is developed. Via this process, managers and employees increase their awareness of business vision. The scenario, in the context of scenario planning methodology, means some futuristic view of the business and a script regarding this futuristic view.

Preparing for future environmental factors is utilized not only in management strategy but also in business and national policy in the fields of global environmental conservation. Thus, scenario planning methodology is applied in various fields.

The concrete procedure of scenario planning varies widely among authors, but the outline is constructed mainly from the following steps. First, the purpose of constructing the scenario is identified (e.g., the goals of the company and the objective of decision making). Next, information related to the business's management is collected, and a driving force is selected: an external environmental factor that will influence future trends. Then, the selected driving force is evaluated in two aspects, namely impact and uncertainty. The impact refers to the significance of the influence, and the uncertainty refers to the difficulty of timing and result prediction. Finally, a scenario is constructed on the basis of the selected driving force.

2.3 Scope of This Study

By using the requirement analysis template, the service designer describes a story that includes a customer's activity in natural language and obtains a customer's requirements from the story. However, in this context, the focus is on a customer's activity regarding "as-is service". For this reason, using the existing framework, some difficulties remain in terms of analyzing customer requirements while considering external environmental factors.

The purpose of this study is to propose a new approach to extracting potential customer requirements related to environmental factors. In order to achieve this purpose, in this paper, requirement analysis methodology is integrated with a scenario construction methodology that is proposed in scenario planning. As mentioned in Section 2.2, scenario planning is a method of constructing a scenario that includes a vision of the future while considering environmental factors. By using scenario construction methodology, the service designer is able to analyze the activity of a client company and environmental factors. On the basis of results of this analysis, the service designer is able to extract a customer's potential requirements.

3 Service Scenario Planning

3.1 Overview of Service Scenario Planning

This chapter introduces an overview of and concrete procedures of a service scenario planning framework that can enable service designers to extract a customer's potential requirements. The service scenario planning framework uses the following five steps, as shown in Figure 1. First of all, the service designer analyzes a client company by using the requirement analysis template mentioned in Chapter 2.1 (STEP 1). In this step, a story about the customer's activity is constructed. In this paper, this story is called a service scenario, and the individual sentences that comprise the story are called the service script. On the basis of this story, a requirement structure is constructed that considers the "goals" of the company and its stakeholders. Next, the service designer collects information about the company, and then, external environmental factors are extracted from the information (STEP 2). Next, the service designer estimates the impact and uncertainty of the factors that influence customer requirements (STEP 3). The most crucial factor is selected as the driving force. Next, the service designer identifies the service script that is influenced by the driving force, and then, a script that contains an occurrence of the driving force is constructed (STEP 4). Finally, considering the driving force, the customer requirement is identified in the procedure of STEP 1 (STEP 5). The following chapter shows the detailed procedure of this framework.

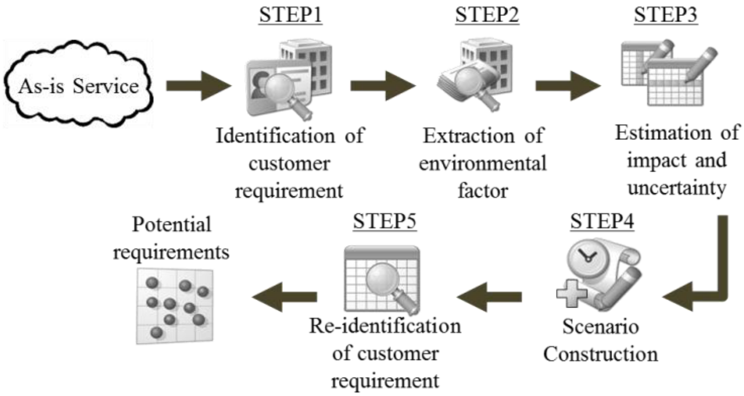


Fig. 1. Overview of Service Scenario Planning

3.2 The Procedures for Extracting Potential Customer Requirements

STEP1. Identification of Customer Requirements

To identify customer requirements, first of all the service designer analyzes the as-is service and constructs a requirement structure. In concrete terms, the "goals," which indicate objectives that should be achieved for each business task, are identified.

Goals

A goal is frequently used to extract requirements in the system design field; it indicates an objective that the system under consideration should achieve.

Based on the collected information, the corporate goals, which is the objective of the company, and the practical goals, which is the objective of the stakeholders, are identified. Furthermore, the practical goals are associated with the corporate goals through the decomposition of the corporate goals. The corporate goals are decomposed into sub-goals and then associated with the practical goals. Next, a service scenario, which is a story about a customer's activity, is written in natural language. From the script written for the service scenario, the service designers identify some "keywords" that can be considered important elements for the service.

Finally, each keyword is associated with the required items/qualities and quality elements. Here, required items refer to what customers want to do, and the required quality is a linguistic expression of customer needs. On the other hand, quality elements work as criteria for evaluating a given quality. In this way, the service designer obtains the requirement structure of the target client company. An example of a requirement structure is shown in Figure 2.

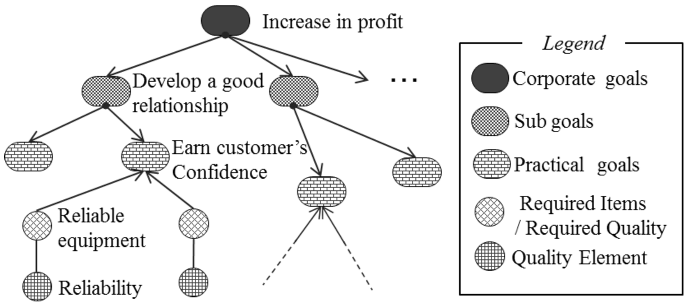


Fig. 2. Relationship among corporate goals and practical goals

STEP2. Extraction of Environmental Factors

In this step, the service designer extracts environmental factors using a "PESTEL (Politics, Economy, Society, Technology, Environment, and Legal)" framework, which is used for extracting external environmental factors. Concretely, first, the service designer collects information about the environmental factors affecting the client company (e.g., the trends of relevant industry segments, national politics, and regulations). Next, from the collected information, the key factors that seem to influence the client company are extracted and categorized using the PESTEL model. In this study, the definitions of the viewpoints are described as follows.

Political factors

These refer to national or regional government policy trends, such as a change in the ruling party, a change in public agency structure, and changes in political decisions such as financial assistance and business promotion. Political decisions can impact many vital areas of business.

Economic factors

These include factors that influence the exchequer and the service price of the client company; for example, interest rates, taxation changes, and the changing prices of materials and fuel. Economic factors mainly influence customer requirements-relevant cost reduction.

Social factors

These include external factors that refer to changes in social trends, such as demographics, fluctuations in demand, and the reputation of local residents. For example, the population's aging influences major fields of business.

Technological factors

Technological factors include the development of new technology and new products by competing companies, progress in science and technology, and the aging of facilities.

Environmental factors
Environmental factors include natural environmental changes, such as weather and climate. Furthermore, global environmental issues and the depletion of natural resources are also included in this category.

Legal factors
These refer to legal environment changes that affect an organization's action. Concretely, legal restrictions, shifts in regulation standards, and trends in judicial precedent are legal factors.

STEP3. Estimation of Impact and Uncertainty
The external environmental factors that include significant impacts and uncertainty can influence the requirement structure of the client company. In this step, the driving force is selected from the environmental factors extracted in Step 2. First, the goals of the customer and the environmental factors that influence those goals are associated with relevant environmental factors. Next, environmental factors are evaluated to determine the degree of impact and uncertainty. The definitions of impact and uncertainty and the estimation procedures used for them in this study are described as follows.

Impact
In this study, the significance of a given influence in terms of customer requirements and business is defined as "impact." The impact of environmental factors is estimated in relation to other factors that influence the same customer requirements.

Uncertainty
The service designer estimates the uncertainty of the environmental factors. Uncertainty is defined as the difficulty of predicting when a given environmental factor will occur. Namely, a factor for which the service designer can easily estimate the timing is estimated to have a lower uncertainty. In contrast, if a service designer cannot estimate the timing and predict the results of the factor, it is estimated as having a great deal of uncertainty. The degree of uncertainty is evaluated absolutely.

On the basis of the definition above, environmental factors are evaluated on a five-point scale. Then, the factor that receives the highest number of points is considered the driving force.

STEP4. Scenario Construction
In Step 3, the driving force and relevant goal are identified. In Step 4, the script in the case of the occurrence of the driving force is constructed. The procedure of Step 4 is shown in Figure 3. First, on the basis of the requirement structure, the required item that is related to the goal-relevant driving force is identified (Figure 3(a)). Next, the service script that is related to the required item is identified (Figure 3(b)). Finally, the service designer constructs a new script using the driving force (Figure 3(c)). Concretely, the service designer assumes the occurrence of the driving force, and possible customer activity is also written. In this way, the service designer reconstructs the service scenario.

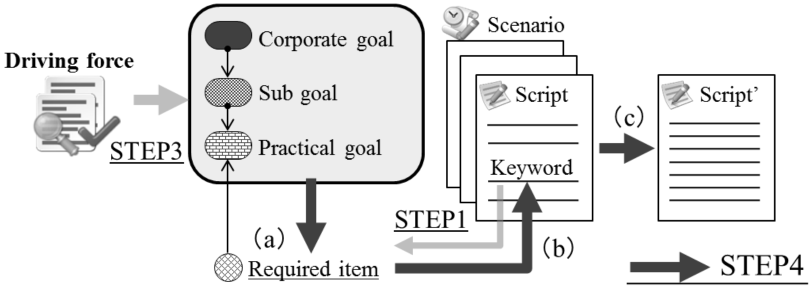


Fig. 3. Scenario restructuring process

STEP5. Identification of the Customer's Potential Requirement
Using the reconstructed service scenario, customer requirements are analyzed via the same procedure used in Step 1. Using the steps mentioned above, the service designer obtains the customer requirements while considering the driving force. Therefore, by designing a service by starting from an identified requirement, an enhanced service that can deal with a given environmental factor will be the result.

4 Application of an Example Case

This section discusses how the proposed method was applied to a B2B service, a facility construction and maintenance service, in which a utility company was the client company. In this example, the utility company offers a social infrastructure service and maintains lifelines for the public. Thus, the social responsibility of the utility company is important. On the other hand, a facility construction/maintenance company constructs and maintains the facilities of the utility company.

STEP1. Identification of Customer Requirements
First of all, a requirement structure is constructed for the as-is service. In this example, on the basis of an annual report released by the utility company which includes information about management and strategy, corporate goals were extracted (e.g., increase in profit, acceptance of social demands). Then, the corporate goals are decomposed into sub-goals; for example, the corporate goal "increase in profit" is decomposed into the sub-goals "cost reduction" and "business expansion."

Next, the practical goal, which is the objective of the stakeholders in the client company, is identified. In this example, the practical goal "cost reduction of utility work" is identified by focusing on stakeholder-relevant utility work, and this practical goal is associated with the sub-goal "cost reduction" (Figure 4 (A)).

Then, a service scenario, which is a story about a customer's activity to achieve this practical goal, is written (Figure 5). From the script written for the service scenario, the service designers identify the customer's requirements (Figure 4).

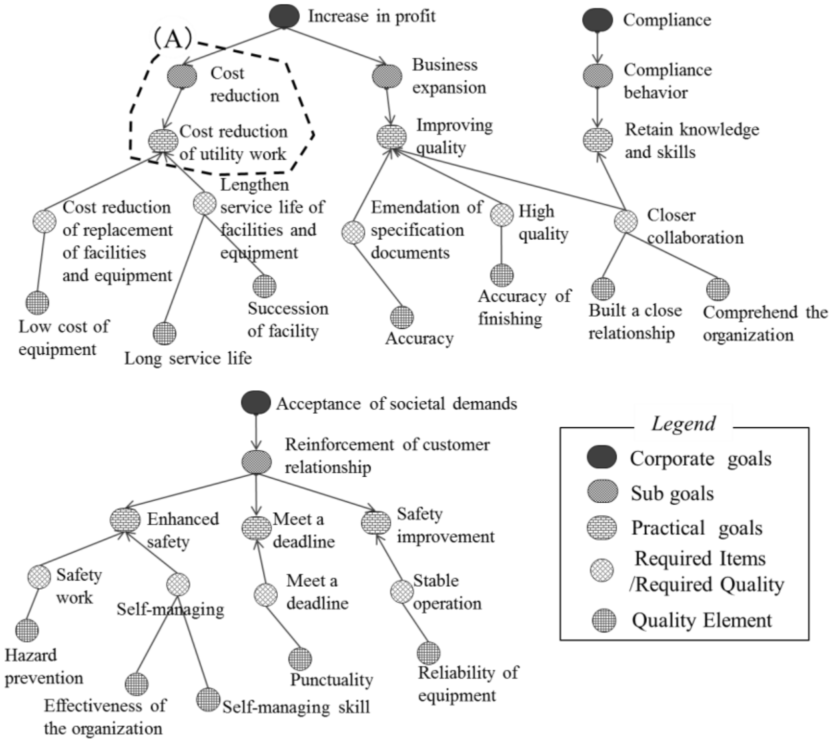


Fig. 4. Requirement structure of utility company

▸Activity: Construction/Safety plan

▸Practical goal:

－Cost reduction

▸ After a field explanation, we will request the estimation for the facility construction/maintenance company.

▸ The necessary equipment is ordered from the manufacturer by the supplies division. We want to avoid equipment modification in terms of cost, technique, environment, and system.

▸ We request the estimation of construction for the facility construction/maintenance company. We want to complete the construction work with low cost as possible.

▸ We create a specification sheet. In recent years, workers familiar with facility construction, have retired. Thus, the technical capabilities is decreasing. Hence, we worry that the specification sheet will be unmatched with a real construction field. We prefer suggestions and revisions about the specs from people in the field.

▸ When we make the construction plan, safety and quality are emphasized, then due dates and cost. Namely, we must not decay the safety and quality of the construction for cost reduction. Safety is the first priority.

▸ ……

Fig. 5. Script template (partial)

STEP2. Extraction of Environmental Factors

In this step, the first information about the environmental factors affecting the client company was collected based on an annual report that the client company released.

In this example, 31 kinds of information were collected, such as "cutting subsidies for wind power enterprise" and "demand of applying noise regulation low for the wind power plant." Then, this information was placed into six categories of the PESTEL framework. For example, "cutting subsidies for wind power enterprise" was placed into the political factors category, and "tightening environmental regulations" was placed with the legal factors. The result of classification is shown as Table 1.

Table 1. Environmental factors about the utility company

PESTEL framework	Extracted factors
Political factors	Government policy trends relevant to global warming, Deregulation of electric utilities, Cutting subsidies for wind power enterprise
Economic factors	Lack of space for construction of new facilities, Escalating fuel price, Economic down turn, interest rate fluctuation
Social factors	Increase demand for cooling and heating, Increase in broadband subscriptions, Demand for electric rate decrease, Decline in power demand, Mass retirement of skilled workers, Shortfall in young workers, Electricity-dependent society, Demand of utility work during nighttime hours, Low demand for applying noise regulation for the wind power plant, Occurring compliance violation
Technological factors	Decrease of construction and repair work for the plant, Coming of age of large-scale electrical power utilities, Extensive replacement of facility equipment, Deteriorating technology of utility company, Increase of large construction work, Leaking of personal/company information
Environmental factors	Recent low summer temperatures and high winter temperatures, Increase of natural disasters (e.g., earthquake, torrential downpour), Weather variance
Legal factors	Obligation of concern about energy and environmental issues, Fuel cost adjustment system, Tightening environmental regulations

STEP3. Estimation of Impact and Uncertainty

Environmental factors, extracted in Step 2, are associated with goals in the requirement structure, and then evaluated to determine the degree of impact and uncertainty. In this case, when service designers focused on the sub-goal "cost reduction," the environmental factor "escalating fuel price" is associated with the sub-goal. The environmental factors relevant to the sub-goal "cost reduction" are shown as Figure 6. Next, environmental factors are evaluated to determine the degree of impact and uncertainty, and then "extensive replacement of facility equipment" is identified as a driving force (Table 2).

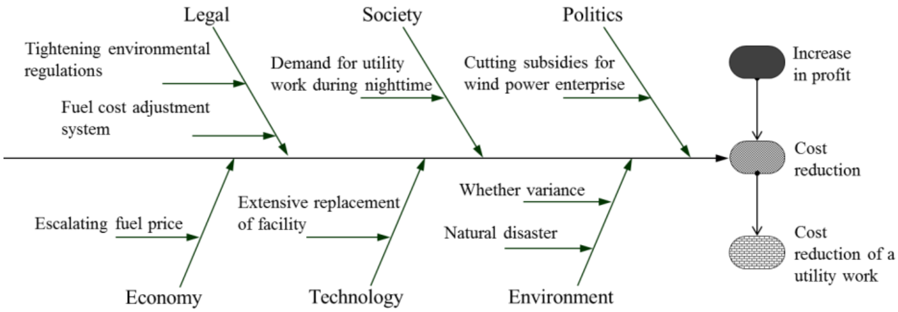


Fig. 6. Environmental factors relevant to the sub-goal "cost reduction"

Table 2. Results of impact/uncertainty estimation

Driving force	Impact	Uncertainty
Cutting subsidies for wind power enterprise	3	4
Escalating fuel price	4	3
Demand for utility work during nighttime	3	3
Extensive replacement of facility equipment	5	4
Increase of natural disasters	2	4
Weather variance	1	1
Fuel cost adjustment system	2	1
Tightening environmental regulations	4	2

STEP4. Scenario Construction

In this step, the script in the case of the occurrence of the driving force is constructed. In this case, on the basis of the requirement structure, the quality element "low cost of equipment" is identified as a relevant factor to the sub-goal "cost reduction." Then, the script that is related to the quality element is identified. Thus, the script related to the driving force is also identified. Concretely, first of all, the quality element "low cost of equipment" is identified by focusing on the keyword "low cost." Thus, the script underlined is identified as influenced by the driving force (Figure 7(a)).

Next, the scenario is reconstructed based on the driving force. In this case, the service designer assumes the occurrence of the driving force "extensive replacement of facility equipment," and possible customer activity is also written. Concretely, in the case of occurrence of the driving force, the skilled worker employed at the time of construction has already retired. Furthermore, the skills were not passed on to younger workers. For this reason, there is fear of a prolonged construction period and increased cost. The script mentioned above is incrementally written as a new script (Figure 7(b)).

▸Activity: Construction/Safety plan

▸Practical goal:
- Cost reduction

▸Driving force:
- Extensive replacement of facility equipment

▸ After a field explanation, we will request the estimation for the facility construction/maintenance company.

▸ The necessary equipment is ordered from the manufacturer by the supplies division. We want to avoid equipment modification in terms of cost, technique, environment, and system.

▸ (a) *We request the estimation of construction for the facility construction/maintenance company. We want to complete the construction work with low cost as possible.*

▸ (b) *On this occasion, it is necessary to replace the equipment. However, skilled worker, who worked in the time of constructing, is already retired. Furthermore, the skills were not inherited on to younger workers. Because of this reason, there is fear that the period of construction is prolonged and the cost increases.*

▸ We create a specification sheet. In recent years, workers familiar with facility construction, have retired. Thus, the technical capabilities is decreasing. Hence, we worry that the specification sheet will be unmatched with a real construction field. We prefer suggestions and revisions about the specs from people in the field.

▸ When we make the construction plan, safety and quality are emphasized, then due dates and cost. Namely, we must not decay the safety and quality of the construction for cost reduction. Safety is the first priority.

▸ ……

Fig. 7. Restructured service script

STEP5. Identification of the Customer's Potential Requirement

In this step, the keyword "Inherit technique" is extracted from the restructured service script (Table 3), and then a new required item, "inherit technique," and new quality element, "Technique inheritance," are identified. Furthermore, these items are associated with the practical goal "cost reduction of utility work" (Figure 8).

Table 3. Result of RSP identification template

Keyword	Required item/ Required quality	Quality element
Inherit technique	Inherit technique	Technique inheritance

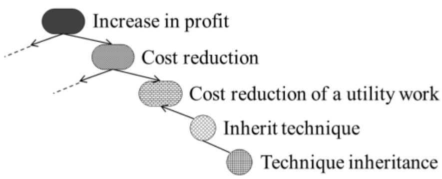


Fig. 8. Result of restructuring requirement structure (partial)

5 Discussion

In this paper, the facility construction and maintenance service is used as the example case. New requirements of the utility company were extracted. On the basis of the existing method, the requirements such as "lengthen service life of facilities and equipment" were identified to achieve "cost reduction." On the other hand, in this paper, the driving force influencing the requirement structure of the utility company is identified, and then the requirement "inherit technique" is additionally extracted. Thus, a concrete requirement item is identified while considering the future occurrence of cost escalation. On the basis of this requirement, the service designer can take variable environmental factors into consideration in the design.

By using service scenario planning, the service designer can analyze the business environment of a client company from the place of service provider. However, it is not easy to minutely analyze environmental factors in terms of costs and volume of information. Thus, an easily applicable supporting method will be required. Concretely, supporting an association between environmental factors and goals in Step 2, and the evaluation index of impact and uncertainty in Step 3, are required.

6 Conclusion

This paper proposes a supporting method that service designers can use when building their service strategies, to help consider environmental factors and grasp customers' potential requirements. To achieve this purpose, the requirement analysis template is integrated with the scenario planning methodology, which is a method used to consider environmental factors for business strategy planning. Future work includes identifying a method for validating the identified customer's requirements, and a supporting method to help the service designer easily apply the service scenario planning.

References

1. Shimomura, Y., Tomiyama, T.: Service Modeling for Service Engineering. In: Proceedings of the 5th International Conference on Design of Information Infrastructure Systems for Manufacturing 2002 - DIISM 2002, pp. 309–316 (2002)
2. Arai, T., Shimomura, Y.: Proposal of Service CAD System - A Tool for Service Engineering. Annals of the CIRP 53(1), 397 (2004)
3. Kimita, K., Akasaka, F., Ronnback, A., Sakao, T., Shimomura, Y.: Requirement Analysis for User-Oriented Service Design. In: Proceedings of the 42nd CIRP Conference on Manufacturing Systems. CIRP, CD-ROM (2009)
4. Akasaka, F., Hosono, S., Kimita, K., Nakajima, M., Shimomura, Y.: Requirement Analysis for Strategic Improvement of a B2B Service. In: Proceedings of CIRP, IPS2 Conference 2010, pp. 117–124. CIRP, Linkoeping (2010)
5. Schoemaker, P.J.H.: Scenario Planning: A Tool for Strategic Thinking. Sloan Management Review, 25–40 (Winter 1995)
6. Hashimoto, S., Osako, M., Abe, N., Inaba, R., Tasaki, T., Nansai, K., Fujii, M., Matsuhashi, K., Moriguchi, Y.: Scenarios planning on resource / waste flows and resource recycling / waste management system in the near future. Journal of the Japan Society of Civil Engineers G 65(1), 44–56 (2009)
7. Cooper, A.: The Inmates are Running the Asylum. SAMS/Macmillan, Indianapolis (1999)
8. Andrew, G.: Foundations of Economics Second Edition - Additional Chapter on Business Strategy. Oxford University Press (2011)

Analysis of Design by Customers: Customers Expectation as a Substitute for Design Knowledge

Satoshi Shimada[1], Kazuyoshi Aratani[1], Jun Ota[2], and Tatsunori Hara[2]

[1] Department of Precision Engineering, School of Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan

[2] Research into Artifacts, Center for Engineering, The University of Tokyo, Kashiwanoha 5-1-5, Kashiwa-shi, Chiba 277-8568, Japan

{shimada,aratani,ota,hara_tatsu}@race.u-tokyo.ac.jp

Abstract. In both, service and manufacturing industries, customer participation in design and formulation is promoted as a way to add value. Experts, providing services and products, construct the relationship between customer requirements and the function of services and products. Subsequently, they design their offerings based on this relationship. In case customers participate in the design process, they have to design products and services like experts though they have lesser knowledge. This study defines customer expectation as a substitute for the lack of design knowledge among customers and aims to encourage participatory design. For instance, this study examines customer expectation of the tourism service in Tokyo. Tourists were surveyed to gauge what they considered important when planning their travel. The difference between the results of analysis of Japanese and foreign tourists suggests that the relationship between the domains depends on customers' knowledge and experiences.

Keywords: expectation, design, knowledge.

1 Introduction

The attendance of customers during the manufacturing process of products and services is called customer involvement. Customer involvement in production and consumption has been discussed on simultaneity; one of the characteristics of the service [1]. Recently, customer involvement is used for adding value to products and services. In the previous research on customer involvement [1], Iven showed the effect of customer involvement on the design system. However, there are few studies on supporting customer involvement. In this study, we propose a methodology to support customers' designing services based on customers' interpretation in design.

The challenges towards building the methodology are as follows:

- Clarifying the features of design by customers
- Constructing the system to support design by customers based on the features

This paper adapts the design methodology proposed for experts to design by customers. In section 2, previous studies about design methodology are explained.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 75–84.
DOI: 10.1007/978-3-642-30820-8_7

In section 3, customers expectation is introduced to represent the difference between experts and customers on design and the importance of supporting design by customers based on expectation is described. With the case of tourism service, the design by customers is analyzed, in section 4. Section 5 concludes with the result of analysis and future works as the next step of this research.

2 Design by Customers

2.1 Previous Study: Methodology in Engineering Design

As shown in Fig.1, the design process is the operational concept to derive a design solution from design specifications [2]. In general design, design knowledge represents design objects and design processes.

Fig. 1. Representation of the design process [2]

In design methodology ([3], for example), customer requirements for products and services are mapped to the function of products and services that fulfill these requirements and their function is mapped to attributes that reveal the function. Fig.2 illustrates this methodology.

Mapping between the regions in Fig.2 is equivalent to the operation concept as shown in [2]. Mapping connects elements of different domains and depends on the designers' interpretation of the products and services they are trying to create.

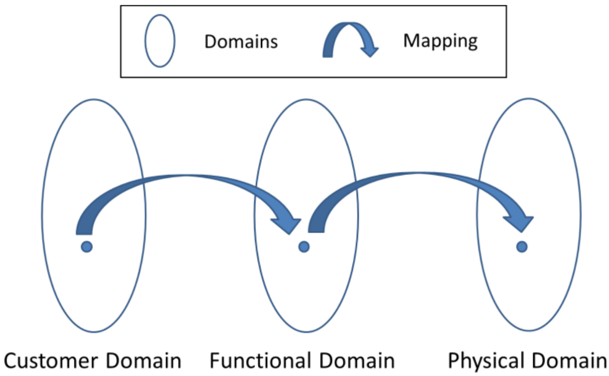


Fig. 2. Design as mapping among design domains [3]

2.2 Design by Customers on the Design Methodology

The designing process of experts is described in Section 2.1, which requires an understanding of the design process and design knowledge to comprehend. On the other hand, most customers do not have specialized knowledge and experience about products and services. As a result, those customers' own knowledge is not enough to interpret the relationship among design domains. The lack of knowledge has been important issue on customer involvement because it causes the increase of conflict in design[4]. However, even in case of customers with insufficient knowledge, as long as the design is completed, some mapping is determined with interpretation of products and services.

The characteristic of the design by customers appears as the factor that helps customers to interpret service instead of design knowledge. This study introduces customers expectation as this factor. In the next section, the reason for introducing expectations is described.

3 Customers Expectation

3.1 Expectation in Previous Research

Evaluation by customers is one of the most important issues in studies of service industries. Therefore customer satisfaction has become an important evaluation index. Customer expectations are asserted as a reference of customer satisfaction. For instance, the American Customer Satisfaction Index (ACSI) [5] cited customer expectation as one of the factors related to customer satisfaction among others such as perceived quality and customer loyalty.

In [6], customer expectations are classified into three types based on the differences in their characteristics:

- Desired service

  Desired service "reflects what customers want."

- Adequate service

  Adequate service is "the standard that customers are willing to accept."

- Predicted service

  Predicted service is "the level of service customers believe is likely to occur."

Desired service is the standard of relative advantage of the services perceived by customers, adequate service plays the role of indicating the validity of the service, and predicted service acts as the standard of customer satisfaction [6].

3.2 Expectation and Interpretation of Services

For experts of products and services, their design knowledge is the criterion for evaluating and determining the process of design. On the other hand, customers have insufficient design knowledge. As a result, the criteria for design depend on demand

and estimation for services; thus, design by customers is diverse. As mentioned in section 3.1, expectation is the standard of evaluation for consumption of services. This paper tries to extend the expectation as a criterion for evaluation of design by customers. Fig.3 shows this:

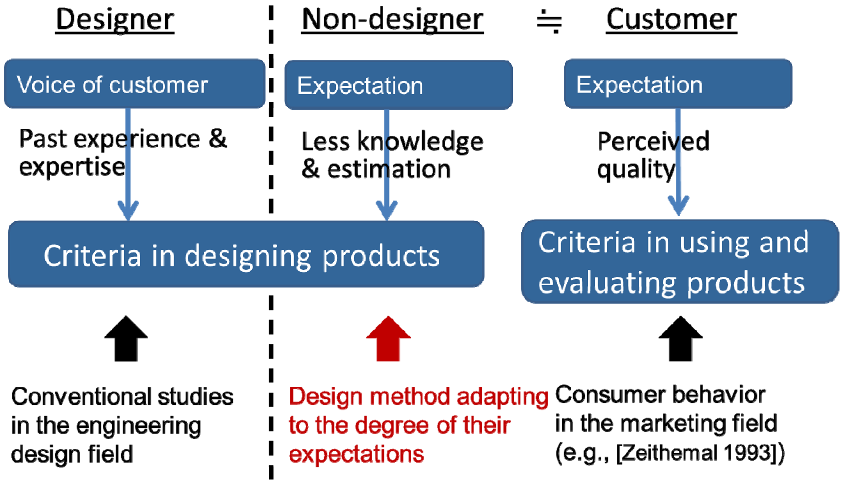


Fig. 3. Evaluation criteria for design by customers

In case of design by customers, design contents are determined as what customers desire. Therefore, in terms of classification [6], the evaluation criteria for design by customers are considered to have strong properties of desired service.

Diversity of customer requirements is discussed in several previous studies about services. Customer involvement is one of the ways to correspond the diversity of customer requirements. Customer involvement correspond the diversity through reflecting customer requirements by themselves. However, design by customers also includes diversity. It means that even though a customer's requirements are same as another customer's requirements, they will design different products and/or services. Therefore, in order to realize the high-value-added products and services, corresponding to the diversity of design is necessary.

As told above, this paper tries to extend customers expectation as a criterion for evaluation of design by customers. The difference of customers criteria for design cause the diversity of design. Thus, with the viewpoint of customers expectation, this research aims to build a methodology to support customers' designing service. The following results can be expected:

- Understanding the various ways of customers' interpretation
- Classifying and structuring function of services for design by customers
- Supporting design by customers with:
  - providing knowledge that customers lack
  - proposing appropriate design operation
  - recommending a candidate design solution

4 Analyzing Customers Expectation on the Design of Service

4.1 Contents of Analysis

This study investigated Free Individual Travelers (FIT) in the Japanese metropolitan area. Design by customers in the tourism service is the planning of travel by FIT, while design by experts is the creation of the package tour. Customer requirements, the process of design (planning), and the itinerary as the final result of design are easy to observe in tourism services. Tourism services are expected to contribute to economic growth and attracting tourists; not only domestic (Japanese, in this case) travelers but foreign travelers too, is the immediate challenge. Therefore, the methodology of this research has significance for the specific field of tourism. Addition to this, by generalize the case of tourism service, the result of analysis and the methodology can contribute to other services and PSS.

The questionnaire of investigation asked tourists about their objectives in three phases of tour; when they planned their travel, before departure from their residence and during their time in Japan. With the data from the investigation, the relationship between customer expectations and psychological distance was analyzed. "Psychological distance is a subjective experience that something is close or far away from the self, here, and now"[7]. The result of the analysis suggested that customer expectations vary with psychological distance.

Smith's tourism products [8] lists the essential elements of the tourism service. In [7], Smith defined tourism from the viewpoint of the providers who design tourism products. Table 1 shows the elements of the tourism service and their categories. The categories are subdivided to represent customers' recognition of the services. The numbers in Table 1 represent categories. Configuration of the elements and categories was carried out with the help of an expert at a travel agency in Japan.

Table 1. Categories and elements of tourism service

Categories	Elements
"1" Travel Experiences	Japanese way of life
	Communication/exchange with locals
"2" Sightseeing and Hospitality	Culture・Events
	Japanese hospitality
"3" Sightseeing/travel Services	Local guidance
	Local tours
"4" Transit, Accommodations, etc.	Public transit
	Lodgings
	Food
	Shopping
"5" Sightseeing Spots	Theme parks, Amusement parks, Zoos, Aquariums
	Museums, Industrial sightseeing
	Natural scenery, Appreciating the four seasons
	History, Traditional scenery, Temples/shrines
	Downtown areas, Cityscapes

Elements in Table 1 correspond to elements in the functional area (Fig.2) and represent the functions of tourism in the metropolitan area. Therefore, tourists responses to the questionnaire represent how tourists' requirements were mapped to the functional domain in participatory design. By a principal component analysis for the combination of emphasized elements, the structure of functional elements of tourists' design is analyzed. Based on principal component obtained by the analysis, tourists are classified and the patterns of tourists' expectation for tourism are extracted. From these patterns, the mapping between functional domain and customer domain is discussed.

Domestic (Japanese) tourists and foreign tourists were studied separately. 515 data samples were collected for domestic tourists using Macromill, an online research company. investigation on foreigners were conducted in two hotels in Tokyo and 117 data samples were collected.

4.2 The Principal Components of Function

One tourist's answer to the questionnaire is converted into one dataset. Principal component analysis was conducted separately on datasets of Japanese participants and those of foreign participants. Fig.4 shows an example of a main component. The elements are shown on the left of the vertical axis and the horizontal axis indicates the score of each element. Fig.4.(a) is the first principal component of domestic participants. [Museums, Industrial sightseeing], [Natural scenery, Appreciating the four seasons], [History, Traditional scenery, Temples/shrines] and [Downtown areas, Cityscapes] get the highest score among the components. Oh the other hand, Fig.4.(b) shows that the score of [Public transit], [Lodgings], [Food] and [Shopping] is highest in the first principal component of foreign participants.

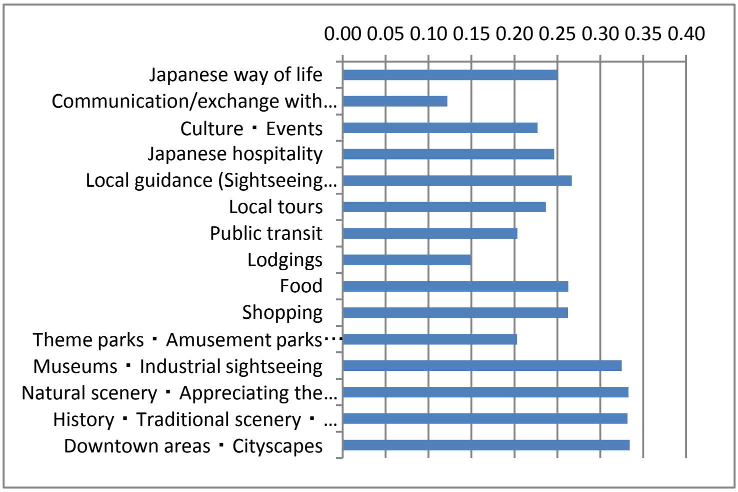


Fig. 4. (a) First principal component of domestic tourists

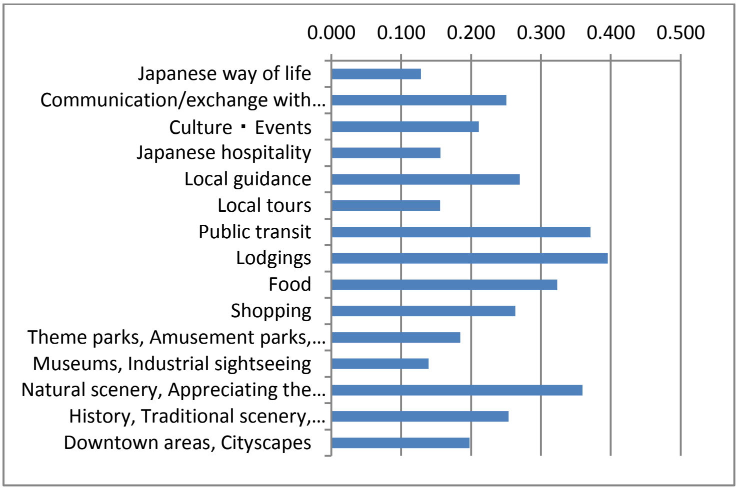


Fig. 4. (b) First principal component of foreign tourists

The elements which score high on the principal components are shown in Table 2. "P" means positive scores and "N" means negative scores in Table 2.

Table 2. Elements that score high on the principal components

	1st principal components	2nd principal components	3rd principal components
Domestic tourists	P : "5" [Museums, Industrial sightseeing], [Natural scenery, Appreciating the four seasons], [History, Traditional scenery, Temples/shrines], [Downtown areas, Cityscapes]	P : "4" [Public transit], [Lodgings], [Food], [Shopping]	P : "3" [Local guidance], [Local tours]
Foreign tourists	P : "4" [Public transit], [Lodgings], [Food] "5" [Natural scenery, Appreciating the four seasons]	P : "4" [Food], [Shopping] N : "1" [Japanese way of life] "2" [Culture・Events] "5" [Natural scenery, Appreciating the four seasons]	P : "3" [Local guidance], [Local tours] N : "5" [Museums, Industrial sightseeing], [Downtown areas, Cityscapes]

On the result of analyses of Japanese participants, elements that score higher in one principal component belong to one category. On the other hand, the principal components of foreign tourists include elements from multiple categories.

Based on these elements, the meaning of each principal component is interpreted as shown in Table 3. For the principal components of domestic tourists, each component corresponds to one category and thus the meaning can be the same as the category. The first principal component of foreign tourists includes basic elements of trip, and thus the word, "Travel", means the aspect of tour to be realized, in contrast, "Type of sightseeing" includes the enjoyable elements of tourism.

Table 3. The meaning of each principal component

	1st principal components	2nd principal components	3rd principal components
Domestic	"Sightseeing Spots"	"Transit, Accommodations, etc."	"Sightseeing/travel Services"
Foreign	Travel	Type of sightseeing	Support for sightseeing

4.3 Classification of Tourists Based on the Scores for Principal Components

Based on the scores for the principal components extracted in 4.2, the expectations of foreign tourists were classified. Classification was limited to the first five principal components based on the value of eigenvalue. Eigenvalue is one of the main index that indicates the importance of the principal component. K-means clustering methodology is chosen as the method of classification. K-means clustering is a non-hierarchical approach to classify data into a certain number of clusters. This paper divides the results of classification into 3 clusters. As shown in Table 2, the features of each cluster include the elements that are emphasized and the customer attributes

Table 4. Clusters of foreign tourists: classified based on the scores of principal component

	Features about the scores to the principal components	Features about the customers' attributes
Cluster 1	Negative : 2nd "Type of sightseeing"	Residence : Mainly from North America
Cluster 2	Positive : 2nd "Type of sightseeing" Negative : 3rd "Support for sightseeing"	Residence : Mainly from Asian areas
Cluster 3	Positive : 1st "Travel"	Experience on Travel : Much

Cluster 1 gets high negative scores on the second principal component and tends to focus on [Travel Experiences] and [Sightseeing and Hospitality]. This cluster has many travelers from North America.

In cluster 2, the second principal component scores positive and the third principal component scores negative. The tourists in cluster 2 focus on concrete sightseeing spots like [Museums・Industrial sightseeing] and [Downtown areas・Cityscapes] and not on elements like [Local guidance] and [Local tours] that assist in determining where to go. In this cluster, many travelers belong to neighboring areas, such as Hong Kong and Taiwan.

In cluster 3, the first principal component scores highly and tourists in cluster 3 focus on "Transit, Accommodation, etc." In this cluster, tourists have experience of international travel and this is their first visit to Japan. They planned only to realize the tour. They didn't take what to enjoy in planning into account and considered it after coming to Japan.

4.4 Discussions

On Principal Component Analysis: Categories are summarized as functions of tourism service from the perspective of professionals in this industry. Therefore, it is considered that the interpretation by Japanese tourists is close to that of experts, where the compatibility of one principal component with one category is concerned. On the other hand, in the results of the analyses of foreign participants, the correspondence between the category and the principal component is partial and the unity of elements, as a result of interpretation, is different from the experts'. Difference of the principal components is the difference of the structure of the functional elements for each party of Japanese and foreign tourists. Thus, if customers with the typical characteristics of each population were to design the tourism package on the basis of the same request, a different solution will appear.

On Clustering: Clusters are classified by principal component scores and are divided by the differences in their requirements and the mapping to function. Focusing on the attributes of each cluster, bias in country of residence and travel experience is observed, as described above. Consider the cluster that is skewed on customer attributes; those attributes are important to correspond with tourists based on the diversity in design of tourism. By further analyzing the differences in requirements and mapping them on design, more individualized correspondence can be achieved. For example, contents of the services can be changed based on attributes such as customer country of residence and information can be provided to compensate for the lack of travel experience and to assist in the formation of expectation.

For domestic tourists, because of similarity of function tree, the support for design should be similar to that for experts basically and, to support the mapping among domains, providing information about correspondence of requirements to functions will be the additional support. For the foreign tourists in cluster 1 and cluster 2, the support to their planning tour at their country is effective to correspond to their diversity. As mentioned in section 3, function of services will be classified and structured based on the components such as types of sightseeing and the support such as "providing knowledge that customers lack" is provided to customers. However, tourists in cluster 3 design their tour without reflecting their requirement at their country but reflect it after coming Japan. This suggests that another support to correspond to their diversity is necessary in Japan.

5 Conclusion

This paper aims to develop a methodology to support customers' participation in service design. In the case study of tourism service in the Japanese metropolitan area, a principal component analysis of the data of elements emphasized in planning tour is done, separately for Japanese tourists and foreign visitors. In addition, foreign tourists are classified based on the scores of principal component. The results suggest that to correspond to the diversity with the methodology, some attributes can be the index for develop the methodology. Especially, some suggestions can be adapted to other services directly, for example the diversity by experience of service and the phase of process when customers reflect their requirement to service. Further analysis is needed in the areas of customer requirements and actual tourist behavior to clarify and improve the methodology of incorporating customers' service design.

Acknowledgments. This research is supported by Service Science, Solutions and Foundation Integrated Research Program, Research Institute of Science and Technology for Society (RISTEX), Japan Science and Technology Agency (JST).

References

1. Iven, B., Olson, M.H.: User Involvement and MIS Success: A Review of Research. Management Science 30(5), 586–603 (1984)
2. Takeda, H., Veerkamp, P., Tomiyama, T., Yoshikawa, H.: Modeling Design Processes. AI Magazine 11(4), 37–48 (1990)
3. Suh, N.P.: The Principles of Design. Oxford University Press (1990)
4. Robey, D., Farrow, D.: User Involvement in Information System Development: A Conflict Model and Empirical Test. Management Science 28(1), 73–85 (1982)
5. Fornell, C., Jhonson, M.D., Anderson, E.W., Cha, J., Bryant, B.E.: The American Customer Satisfaction Index: Nature, Purpose, and Findings. Journal of Marketing 60, 7–18 (1994)
6. Zeithaml, V.A., Berry, L.L., Parasuraman, A.: The Nature and Determinants of Customer expectations of Service. Journal of the Academy of Marketing Science 21(1), 1–12 (1993)
7. Trope, Y., Liberman, N.: Temporal Construal. Psychological Review 117(2), 440–463 (2010)
8. Smith, S.L.J.: The Tourism Product. Annals of Tourism Research 21(3), 582–595 (1994)

Commercial Space Tourism – A Case of Applied Product-Service Systems Networks

Åsa Ericson[1], Johan Wenngren[1], and Karin Nilsdotter[2]

[1] Product Innovation, Luleå University of Technology, Luleå, 97187, Sweden
[2] Spaceport Sweden, Space Campus, Box 812, Kiruna, 98128, Sweden
{asaeri,johwen}@ltu.se, karin@spaceportsweden.com

Abstract. In the vision of Product-Service Systems (PSS) there is anticipation on stakeholders to develop sound networks to enable and support innovative product and service solutions. As such PSS business relationships could be viewed as innovation systems. The challenge to find appropriate and relevant stakeholders is commonly mentioned in manufacturing industry as a difficult task. This paper elaborates on such a challenge, but has put an emerging industry as a frame of interest in order to discuss the progress of a innovation system which has the purpose to inspire product and service development based on commercial human space flights. Some managerial implications for PSS innovation system development are made, for example it is suggested to implement a learning environment as a "demonstrator" from which an innovation system can evolve.

Keywords: innovation systems, collaboration, development processes, networks, space tourism.

1 Introduction

The change in industry from selling standalone goods to the delivery of a solution has in recent years proven interesting for many companies, yet such a change in organizational structure and individual capabilities imply a multitude of implications for implementing PSS [1]. Manufacturing industry has a long history and established routines of developing and selling physical goods, e.g. a transaction-based business idea. Services are seen as a means to keep the core goods operating, as for example maintenance to keep a machine running or training to know how to use it. Representatives from the manufacturing industry segment has already experienced and identified the number one challenge, namely that both an adjustment in organizational structure and in individual capabilities are depending on a change in mindset of all stakeholders [2].

Vargo and Lusch [3] have stressed that product development and service development are based on two totally different logics, and question if those can be managed simultaneously. Commonly, firms that develop and manufacture technical solutions regard services as after market activities [4]. Hence, services are developed after the goods have been produced and do not influence the technical design. While a common underpinning feature of PSS is an integration of the two different rationales,

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 85–94.
DOI: 10.1007/978-3-642-30820-8_8

product and service, as early as possible in the product development process. In particular, the contradictory rationales between product and service development indicate a necessary paradigm shift for manufacturing firms when turning towards PSS businesses. So far, this is a grand challenge for manufacturing industry where thinking, doing and processes are established and grounded in an engineering tradition. But, what about a new emerging, and thus immature, industry? What kind of challenges will it meet? Will there be different conditions for emerging innovation systems in comparison with the established ones?

In recent years, commercial human spaceflight has emerged as a growing industry. New technology and spacecrafts are being developed, primarily by private companies and entrepreneurs, aiming to increase access to space, for tourism, research, education, product demonstration and launch of small satellites, into low Earth orbit and beyond [5]. The opportunity for common people to travel into space was defined by the Ansari X PRIZE [6], a competition set in 2004 to incentivize and spur the development of the first non-government organization to launch a reusable manned spacecraft into space. This worked to demonstrate that spaceflight could be affordable and accessible to corporations and civilians, opening the door to commercial human spaceflight.

Since then the industry has seen a rapid development where a number of entrepreneurs and private companies, Virgin Galactic [7], XCOR [8], Armadillo Aerospace Sierra Nevada Corporation [9] to name but a few, are developing and testing new technology and space launch system aiming to increase access to space. On October 7, 2012, the first official commercial mission to resupply the International Space Station was launched by the private company SPACEX [10], founded by the entrepreneur Elon Musk [11].

In the early stages of commercial human spaceflights, the focus was on technical requirements, to prove that it was doable. However, it was soon realized that the project was not purely technical. Focusing on commercial manned spaceflight and space tourism, as a totally new industry, it has to encompass a wide range of different competences, e.g. from designing infrastructure, develop the space experience, and innovate appropriate outfits to understanding health issues. Thus, not only involve mechanical engineers, but all kinds of expert domains. In this evolving industry, a different mindset for how to combine product and service solutions is already established and applied.

Globally, space tourism is only the tip of an iceberg in this second space age. New companies are being established as well as new research and education. Governments and companies worldwide are currently mobilizing to capitalize on the opportunities that the second space age will bring in terms of economic growth, job creation and inspire young people to pursue careers in the field contributing to regional attraction enabling both regions and companies to grow and build for the future [12].

The Swedish organization Spaceport Sweden [12] is a pioneering initiative to establish commercial human spaceflight and space tourism in Sweden and is guided by a vision to become a world leading spaceport and Europe's first and foremost portal to space. Yet, a vision to provide space experiences in a more holistic way guides the work. In order to capitalize on the interest and potential of this new industry, Spaceport Sweden recognizes the need for new ideas and development of innovative experiences, services, and processes to create long-term economic growth. As such, Spaceport Sweden forms the core of an innovation cluster or innovation system, aiming to inspire people to start new companies and see the development of new innovative services and experiences. A key interest for this paper is to conceptualize what can be learnt from the advancement of a new industry to support evolving Product-Service System (PSS) organizations. More exactly, the purpose of this paper is to draw from the Spaceport Sweden case and reframe those lessons learned into innovation and collaboration aspects of PSS.

2 Methodology

At the heart of an emerging market is the fact that all stakeholders are not known, meaning that studies of that market is not readily done. This is one reason for this study to apply a conceptual approach, where data are qualitative and mainly acquired from theory. In particular, literature from the innovation and entrepreneurial knowledge domains are used. Spaceport Sweden is affiliated as a live case in the research project, from which lessons could be learnt on for instance how innovation systems can act as a platform for not only regional, but also national and international growth. Subsequently, inspires start up companies in all kinds of fields. Data are planned to be longitudinal, i.e. will be acquired over time. The study presented here will apply a more experimental and conceptual approach to elaborate on possible stakeholders and opportunities for a PSS rationale to govern new companies development processes.

First, Spaceport Sweden is shortly introduced and a number of key challenges are presented. Second, a presentation of the perspective of innovation systems and PSS will be done. Third, a stakeholder view is discussed before ending the paper with a concluding remark.

3 Spaceport Sweden – The Live Case

A live case is a new approach in the research project; a live case can be compared to an on-going real situation, which has the purpose to provide interaction and thus collaborative learning. A key interest for the whole project is innovation systems and different aspects in relation to this, this study focus on an emerging innovation system and its actors. Spaceport Sweden [12], situated in the north of Sweden in the city Kiruna, provides input acting as the live case.

The Swedish Minister for Enterprise and Energy inaugurated Spaceport Sweden [12] in 2007. Partners to the organization are a government initiated investment company [13], a tourist company [14], two mountain resort companies [15],[16], and a venture cap company [17]. Spaceport Sweden will supply launch infrastructure, R&D facilities and high-tech expertise to commercial space operators, services to companies and academia as well as unique world-class experiences to a global market. Spaceport Sweden's mission is to develop learning space experiences on the ground, in the air and, in time, in space. Currently, the organization is offering commercial flights into the northern lights, as its first space adventure.

The city Kiruna has a tradition in innovative aviation that started already in 1916, when the biplane model Albatross was tested in the area. Kiruna is Europe's premier space city since 1957, home to the Swedish Institute of Space Physics as well as Esrange Space Center, managed by SSC [18] and established as the European launch site for research rockets and stratospheric balloons. Sweden saw its first rocket launch in 1961 and has since developed world-renowned capability and experience, and a comprehensive infrastructure has been built up to support aerospace operations. Moreover, Kiruna is also host to Arena Arctica [19], as 5,000 square meters hangar which was inaugurated in 1990 at Kiruna Airport suitable for both space related research activities as well as serving as a proving ground in sub-arctic environment. Such testing activities also have a long tradition and for example the Swedish Air Force did the first test in the Kiruna region in 1924. Luleå University of Technology is also present in Kiruna, offering two space master programs and one upper secondary school for students wishing to combine their interest for science with skiing the winter resort of Kiruna.

Kiruna's geographical location up in the north of Sweden provides large unpopulated areas and offers unique possibilities. A main advantage is that Kiruna offers a free airspace and with minimal amount of commercial airline traffic over an area equivalent to about an eight of Sweden's total land area. Also, the unspoilt nature and sub-arctic climate offers unique possibilities to develop attractive tourism services, for example cross-country and alpine skiing, trekking and fishing. Moreover, tourism services also offer people to learn more about the world's largest iron ore mine, or the Sami, indigenous people of Lapland. The world famous hotel built from pure ice, the ICEHOTEL [14], is also situated here.

The city Kiruna was founded just over 100 years ago due to the rich findings of iron ore in the area where mining and related activities have been the main focus of the town. However, the ore goes underneath the city and will in a short future cause problems, so this has led to the necessity to actually move the central town from its current site to another site nearby. This is not only a unique and challenging task, but also seen as an opportunity to redesign a new city to fit contemporary industries and interests.

Guiding principles for the emerging innovation models should be to develop economical, environmental and social sustainable business models and products. As a pioneering initiative there are several challenges for this kind of emerging industry and businesses, one key challenge is that the structure and network of the innovation system has to emerge based on local capabilities but for an international viable business. Inherent in such a challenge is to identify, attract and assign relevant actors/stakeholder as co-developers of the innovation system. Another challenge for Spaceport Sweden is to drive the development of a creative space or a multicenter, i.e. a physical place where both space and the mining industry provide a platform for cross-industry innovation, research and education, but also for adventure and entertainment. Such physical site makes the experiences accessible for all kinds of actors and could become a hub for regional growth. Yet another challenge for Spaceport Sweden is related to the mission of being a catalyst for regional development. Initially, inspiration to startup companies within, tourism and creative industries, as fashion, events, music, and food, are in focus. That is, Spaceport Sweden, as an innovation system, seeks to encourage entrepreneurship among a vast segment of actors.

4 Innovation Systems

A common way to describe innovation systems is as a network of actors who has an aligned goal, for example to take a new idea to a market. Hence, as such it becomes an innovation system. For example, Lundvall [20] p.2, state that *"…a system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful knowledge* […] *and are either located within or rooted inside the borders of a nation state".* The mechanism of developing innovation systems or innovation networks can be intentional or unintentional, nonetheless the stakeholders that constitutes the system act in order to realize a solution that cannot be developed in solitude. By this need to bring in external knowledge, innovation systems are based on an open innovation approach [21].

Product-service systems (PSS) are suggested to be defined as the result of an "innovation strategy" [22], since the core is a shift from only developing and selling physical products to also designing and provide services, which integration are capable to fulfill specific customer requirements. A PSS vision is suggested to rely on this innovation perspective, and also to rests upon two main pillars [1]. First, PSS development should always take the standpoint to develop functionally or fulfillment of the user's/customer's goal, this should be in opposite to starting from a solution based on a sole physical artifact. Second, the focus on sustainable solutions should permeate all business relationships, meaning that the existing structures and/or the companies' position within those structures should not be taken for granted. Instead, these should be continuously negotiated. Basically, PSS aligns with innovation systems, or competitive business networks that should co-produce added value to its customers [23] Also, the idea of distributed property rights is part of the PSS vision [24] and means that PSS stakeholders have to create channels in the network to share information and build a joint knowledge base of core innovation capabilities, in opposite to monitor, control and prevent collaboration. Typically, in innovation systems the stakeholders are obliged to both cooperate and compete, i.e. the work can be described as coopetition [25]. This is in contradiction to a traditional value chain structure, where the actors take responsibilities to develop one "part" each and the main stakeholder assembly all pieces to a final product. In value chain collaboration, the main stakeholder provides the leading channel to customers. Customers, users, end-users etcetera can be part of an innovation system, and this could explain some of the focus on such collaboration in PSS development.

An innovation system depends on an adequate critical mass of stakeholders for the system to survive and prosper. The geographical distribution is commonly of importance and the system is often referred to as regional or national [26]. Further, the distribution depends on the homogeneous set-up that a region gives, while this is not the case for larger areas, e.g., national innovation systems. An investigation has shown that stakeholders within a community, or innovation system, develop specific forms of capital, e.g. social relations, norms, values and interactions [26]. Such capital is then used to reinforce capabilities related to innovation and competitiveness [26]. Recently, a shift in research focus has occurred, now not only the stakeholders in a network are of interest but also how the links between them perform [27]. Within this perspective the notion of a “learning environment” is of utmost importance for overall performance, thus the innovation system could also be referred to as networks of learning [28].

The use of Internet and Information and Communication Technologies (ICT) are an important vehicle for building and maintaining innovation systems, and such they “remove” regional borders and summon new actors. Also, they are predicted to play a key role in the development of new services and products, for example Gartner Inc. [29] predicts that by 2014 as many as 25 percent of new business applications will be built by ‘citizen developers’ [29].

The innovation processes as such differs from how they are conducted in mature industries, from this point of view innovation often follows, or at least is described as, an established gated process. Commonly, ordinary day-to-day product development is not separated from an innovation process. On the same token, the direction towards a strictly technical innovation process might occur. In other innovation systems more entrepreneurial ventures are conducted within the processes. Thereby, the process is less defined, but more flexible. A key concern in such entrepreneurial innovation systems is that it is seldom obvious where the idea comes from [30]. On an overarching macro level, the innovation process starts with an identified need [31] or an idea and the whole innovation system is leveraging their knowledge and capabilities to bring out commercial products and services. Typically several individual stakeholders have contributed to the development of different products and services, or to the same product or service. Further, stakeholders that do not contribute to the actual development processes are instead supporting other stakeholders in the innovation system, e.g. banks and venture capitalists.

5 A Stakeholder View

To increase the implementation of innovations and encourage startup companies, the government investments are commonly done to support an innovative and entrepreneurial industry sector. Typically, to create regional growth the approach is to inspire new actors by, for example funding their production in the region or to create industry specific clusters to support transfer of know-how and experiences. Thus, homogeneous and specific networks of stakeholders emerge. If problematizing such an approach it can be, on one hand, argued that it might be difficult for heterogeneous businesses, like PSS, to enter or to work in such innovation systems. On the other hand, a vast array of different stakeholders might not be able to contribute to the innovation system and its purpose. An identified key question is to identify what conditions that must thus be in place for various stakeholders to actively contribute in the innovation system.

In Figure 1, stereotype examples of stakeholders are described as well as it is indicated that they might have different motivations to contribute in the system. For example the initiator locates a need, an idea or a problem situation and initiates the innovation activities. A typical initiator stakeholder could be an inventor that has an

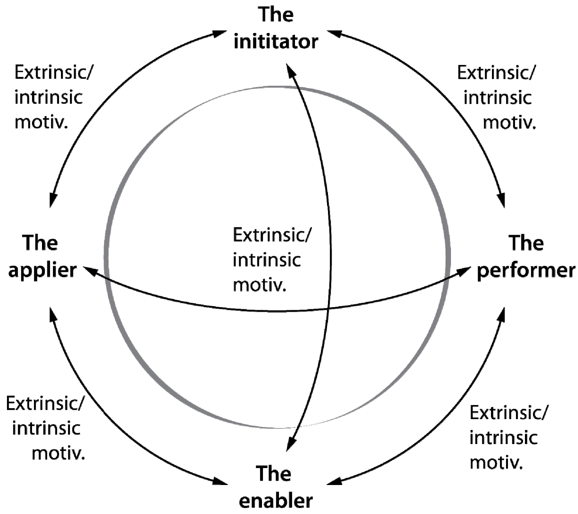


Fig. 1. Examples of stereotypes in an innovation system

idea has or invented a new technology. The performer, which could typically be an entrepreneur or a company, ensures that the idea will find a market and that the product will be directed toward an appropriate segment of that market. The enabler could be a funding agency or a partner company, which possesses necessary resources to realize/commercialize the solution. Finally, the applier, that is a business-to-business partner, customer or an end-user, applies the product or service to fulfill their objective when using the solution. In some cases the same person takes on the different roles, for example Spaceport Sweden could for example be an initiator, i.e. has identified the need for space related tourism in the region, but also an applier, i.e. using the infrastructure for flight take off and landing. Thus, the stakeholders can be part of many different innovation systems and have different roles in each of them. As suggested in PSS literature [1] the position in the system has to be continuously negotiated, but also the motivation for taking part of it must be made clear. As some innovation systems, and thus maybe also PSS networks, evolve unintentionally it cannot be expected that all types of business relationships are regulated in contracts. The dynamic behavior of such an innovation system is also a possibility to find new combination of products and services. That is, new combinations arise from the actors' negotiation and renegotiation of their positions in the system. Signing contracts before doing business is, on the contrary, important in value chain collaborations, where the contract regulates the position in the constellation.

Further, in contrast to clusters of similar firms, a heterogeneous innovation system include stakeholders possessing different areas of expertise, as for example in the Spaceport Sweden case, private space companies, venture capitalist, payload integrators, industrial partners, lawyers, tourism agencies, safety, regulatory and insurance experts. But also, as wished for the future, the innovation system would be enhanced with small firms based on, e.g. creative art and handcrafted products.

On a macro level, the different stakeholders benefit from regional and national growth, but on a micro level a primary focus might be on what motivates them to contribute in the innovation system. In comparison, a PSS structure could also be seen from a macro level where extended enterprises and new practices of collaboration are formed. In general, the macro level focus on benefits like win-win and gaining additional competences, while a micro level focus could highlight hinders and barriers for the individual stakeholders. In particular for heterogeneous innovation systems, not only as in the Spaceport Sweden case but also as in PSS, there seem to be a need to visualize the motivational aspects for each type of stakeholder. This can make not only extrinsic motivation visible, but also the intrinsic motivation for contribution in the innovation system can be clarified.

6 Concluding Remark

This paper is based on an empirical case where an emerging industry has served as inspiration to discuss innovation systems within the conceptual framework of PSS collaboration. In particular, the discussion was aimed to draw some lessons learned useful for PSS organizations. We have found that heterogeneous innovation systems, or PSS collaborations, might be a sound platform for product and service integration. However, a main concern is to further elaborate on each stakeholder's motivation, extrinsic as well as intrinsic, for contributing in the innovation system. In successful systems, all stakeholders benefit from the interchange and the vision of PSS collaboration as being based on win-win is already established [32]. However, it would be a good effort to implement demonstrators of innovation systems to learn from, as for example the live case reported on in this paper.

In general, our research within the PSS field indicates that taking the first step towards PSS collaboration is not straightforwardly done. The case company presented in this paper is not "biased" in terms of having an established background in manufacturing industry, though commercial human spaceflights include space shuttles that are high-tech and highly complex products, which mean that manufacturing industry will be part of this kind of innovation system. Hence, the Spaceport case will be followed in future studies. Also research on implicit and explicit PSS development [33] seems relevant and interesting.

Acknowledgments. We would like to acknowledge CiiR (Centre for inter-organizational innovation research, an excellence center funded from VINNOVA) and the VINNMER national qualification program. The contribution in terms of invaluable discussions with Vinit Parida, Håkan Ylinenpää and Daniel Örtqvist, colleagues in the research project, are also gratefully acknowledged.

References

1. Tukker, A., van den Berg, C., Tischner, U.: Product-services: a specific value proposition. In: Tukker, A., Tischner, U. (eds.) New Business for Old Europe: Product-Service Development, Competitiveness and Sustainability, pp. 22–34. Greenleaf Publishing, UK (2006)
2. Workshop at a Swedish manufacturing company, May 8-9 (2012)

3. Vargo, S.L., Lusch, R.F.: Evolving to a new dominant logic for marketing. Journal of Marketing 68, 1–17 (2004)
4. Normann, R., Ramirez, R.: Designing interactive strategy: from value chain to value constellation. John Wiley & Sons Ltd., UK (1998)
5. The Tauri Group. The space report – the guide to Global space activity (2006), http://www.taurigroup.com/st_space_report.htm (accessed October 16, 2012)
6. XPrize Foundation, http://www.xprize.org (accessed October 16, 2012)
7. Virgin Galactic, http://www.virgingalactic.com (accessed October 16, 2012)
8. XCOR, http://www.xcor.com (accessed October 16, 2012)
9. Armadillo Aerospace, http://www.armadilloaerospace.com (accessed October 16, 2012)
10. SPACEX, http://www.spacex.com (accessed October 16, 2012)
11. The New York Times. SpaceX's Falcon 9 Rocket Makes History with NASA, http://topics.nytimes.com/top/reference/timestopics/people/m/elon_musk/index.html (accessed October 16, 2012)
12. Spaceport Sweden, http://www.spaceportsweden.com (accessed October 16, 2012)
13. Inlandsinnovation, http://www.inlandsinnovation.se (accessed October 16, 2012)
14. Icehotel, http://www.icehotel.com (accessed October 16, 2012)
15. Björkliden Fjällby, http://winter.bjorkliden.com (accessed October 16, 2012)
16. Riksgränsen, http://en.riksgransen.se (accessed October 16, 2012)
17. Norrskenet, http://www.norrskenet.se (accessed October 16, 2012)
18. Esrange Space Center, http://www.sscspace.com/esrange-space-center-3 (accessed October 16, 2012)
19. Arena Arctica, http://www.arenaarctica.com (accessed October 16, 2012)
20. Lundvall, B.-Å.: Product innovation and user-producer interaction, industrial development. Research Series 31. Aalborg University Press, Aalborg (1985)
21. Chesbrough, H.: Open Innovation: The New Imperative for Creating and Profiting from Technology. Harvard Business School Press, Boston (2003)
22. Manzini, E., Vezzoli, C.: Product-Service Systems and Sustainability: Opportunities for sustainable solutions. Report UNEP (2001)
23. Mont, O.: Drivers and barriers for shifting towards more service-oriented businesses: Analysis of the PSS field and contributions from Sweden. The Journal of Sustainable Product Design 2, 89–103 (2002)
24. Hockerts, K., Weaver, N.: Towards a theory of sustainable product service systems—what are the dependent and independent variables of S-PSS? In: INSEAD-CMER Research Workshop on Sustainable Product Service Systems—Key Definitions and Concepts (2002)
25. Bengtsson, M., Kock, S.: "Coopetition" in Business Networks – to Cooperate and Compete Simultaneously. Industrial Marketing Management 29(5), 411–426 (2000)
26. Parida, V., Ylinenpää, H., Örtqvist, D.: Research report: Rural Innovation and Business Systems (RIBS): A glimpse into theory and a model for work in practice. Luleå University of Technology, Sweden (2011)
27. Arnold, E., Kuhlman, S., Van der Meulen, B.: A singular Council: evaluation of the Research Council of Norway. Research Council of Norway, Oslo (2001)
28. Powell, W.W., Koput, K.W., Smith-Doerr, L.: Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. Administrative Science Quarterly 41, 116–145 (1996)

29. Gartner Inc. Press release. Gartner Says Citizen Developers Will Build at Least 25 Percent of New Business Applications by 2014, http://www.gartner.com/it/page.jsp?id=1744514 (accessed September 12, 2012)
30. Branscomb, R.L.: Where do high tech commercial innovations come from? Working Paper, Duke University Law School (2004)
31. Fey, V., Rivin, E.: Innovation on demand: new product development using TRIZ. Cambridge University Press, Cambridge (2005)
32. Alonso-Rasgado, T., Thompson, G., Elfström, B.-O.: The design of a functional (total care) product. Journal of Engineering Design 15(6), 515–540 (2004)
33. Müller, P., Stark, R.: Opportunities for enhanced Project Management in PSS Development. In: Hesselbach, J., Herrmann, C. (eds.) Functional Thinking for Value Creation: Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, Technische Universität Braunschweig, Braunschweig, Germany, May 5-6. Springer, Heidelberg (2011)

Towards Establishing Production Patterns to Manage Service Co-creation

Shigeru Hosono[1] and Yoshiki Shimomura[2]

[1] Knowledge Discovery Research Labs, NEC Corp.,
1753 Shimonumabe, Kawasaki, Japan
[2] Department of System Design, Tokyo Metropolitan University,
6-6 Asahigaoka, Hino, Japan
s-hosono@bu.jp.nec.com, yoshiki-shimomura@center.tmu.ac.jp

Abstract. This paper proposes production patterns for web services to provide a standard procedure to assess and optimize the production processes. The patterns consist of design models in each of design, implementation, test and operation phase, and models of practitioners' tasks and activities through a service lifecycle. These two models are linked together and stored into a repository, and they form patterns of service production. The patterns can give a frame of co-creating services, and it will be used as a template for service production as well as a yardstick to keep track of production progress. A conceptual verification shows that the progress of practitioners' activities can be assessed and the total lifecycle cost of the service can also be estimated, enabling administrators to perform better production management and decision making.

Keywords: production patterns, agile development, critical chain for services, lifecycle cost, PSS for cloud-compliant web services.

1 Introduction

Service oriented architecture (SOA) [1] has introduced flexibility to web services, adapting to changes in business environment quickly. The SOA will be attained through a series of web service technologies [2] - standardized design interfaces and development methods for waterfall-based development. However, all the clients' requirements for web services cannot be determined at the early phase of development as the pace of change has accelerated these years. These changes require an adjustment for the integration of web services from traditional waterfall-based ways to a rather agile style, which develops prototypes of web service continuously while acquiring surfaced requirements. This new paradigm entails service integrators to change their development mindset from product-oriented to service-oriented one; the value of clients' services arises not from the scale or quality of systems' functions but from immediate improvements in their business. Therefore, the involvements of practitioners' activities have become more significant, and the integrators are required to co-create clients' services through a number of hypothetical prototyping continuously. To deal with such environments, activities and their deliverables in each development phase should be managed comprehensively.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 95–106.
DOI: 10.1007/978-3-642-30820-8_9

2 Design and Operation Patterns

To assist continuous prototyping with hypothetical verifications, the authors have proposed service model chains [3], which is developed under the service design and operation framework [Appendix: *Service Lambda for Cloud Computing*]. A service model chain consists of a set of deliverables in a development process. It can be developed by the continuous design and operation tools of the framework: *service objectives, value chain, goal prioritization, service system design, quality-function insight, application use case, resource combination design, application prototyping,* and *application execution*. While a major concern for a service production, such as design-centered development, implementation-centered development, or lifecycle-centered management, have taken into definite forms, the *service domain* can be determined, and an appropriate tool set is specified from the tool chain. Then, a service model chain, which represents a pattern of design and operation for the domain, is established with the selected tool chain. The service design and operation patterns are stored into the shared service repository - *public service portfolio*, and service integrators are encouraged to reuse and customize these assets for another service production by importing them as templates to each project's repository - *private service portfolio*. With these mechanisms, the service model chains can bring a solution of *mass customization* to productions of cloud-compliant web services.

However, this service model chain is not sufficient to administrate service productions, as it lacks the interactions between stakeholders, i.e. practitioners and users, through a service lifecycle. The traditional development can be regarded as product-oriented, and service model chains are enough to improve service productions as the development is bound to software/hardware products' specifications and behavior. However, the development of cloud-compliant web service has characteristics of services, as negotiations between practitioners account for a higher proportion than composing software and hardware functions of cloud platforms. These practitioners' interactions would rise and fall, while the clients' requirements have developed. Then, tasks will become varied and it will be hard to administrate. To clarify management of such practitioners' tasks in product and service developments, the next section discusses project management approaches, which give a form of practitioners' activities.

3 Task Management in Production Process

Project management methods are approaches to explicitly handle practitioners' activities in product and/or service productions. This section contemplates two notable approaches - Critical Path and Critical Chain, and discusses how these methods can apply to production processes and how they should be extended to exploit characteristics in service productions.

3.1 Critical Path

Critical path [4] is a project management approach to identify one or more sequences of tasks, which will lead a project delay when a task in the sequence delays, and to manage the tasks to keep them on track. A critical path consists of a group of tasks, which have subordinate relationships - for example, task A should start after task B. All work in a production process is broken down to a collection of tasks - WBS (work breakdown structures). All tasks in a production process are depicted in a PERT (program evaluation and review technique) chart, and then the shortest route between the beginning and ending tasks can be identified in the figure. This route is the critical path in this production process. For instance, the shortest route in Figure 1 is the sequence of nodes (tasks) whose floating time are zero; A, B, D and F. With this chart, the total amount of production time and lead time are determined.

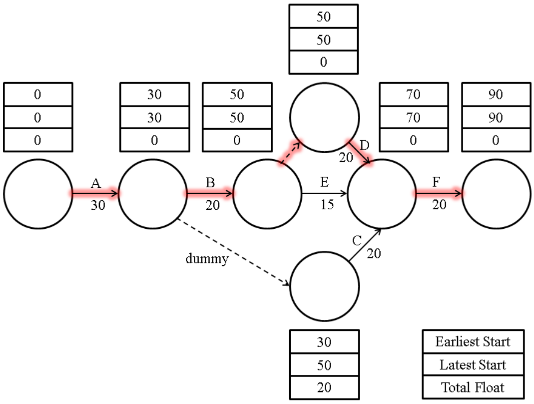


Fig. 1. Critical path

The critical path has been applied to a large scale project and it is aimed at optimizing complex schedules. A task delay in the critical path causes a delay of total schedule, and accelerating tasks to shorten the critical path reduces the total production time. Accordingly, managing the critical path will be pursued in product productions. However, this approach is unfitted to consider undetermined tasks, such as workers' psychology, behavior and social/organizational obstacles in a project.

3.2 Critical Chain

Projects with undetermined tasks can be managed through a critical chain [5] (Figure 2). A critical chain considers how the total development period should be kept or shortened. It contemplates workers' psychology, behavior, and social/organizational problems and enables to optimize project management comprehensively, such as scheduling, task execution and progress management.

The traditional project management based on the critical path assumes that each task should be completed as scheduled. Then, practitioners should try to secure buffering time not to extend the planned schedule with delays of their tasks. However, this redundant schedule may cause a *student syndrome* leading to further delay or phenomena of Parkinson's Law [7] preventing poorly synchronized integration.

To exclude such obstacles, the critical chain introduces *project buffers* and *joint buffers*. These buffers are controlled not by practitioners but by project managers.

Project buffers are defined at the position right after the end of critical path in a PERT chart, and joint buffers are placed at the position where a non-critical path joins the critical path, allowing latitude in project management. Critical chain also takes account of resource contentions, which are frequently observed in delayed projects. For instance, a task cannot be started while the required resources are used by another task. Whenever these tasks are not prioritized, it will cause further delays, requiring resource negotiation.

The critical chain approach considers resource contentions at the early stage of scheduling. When a resource contention occurs, it will become a bottleneck in a project. As this approach is based on the theory of constraints (TOC) [9] aimed at maximizing the ability of bottlenecked tasks, the tasks competing for same resource will be prioritized to avoid overlapping these tasks for the best scheduling.

In these ways, the critical chain approach differs from plans by the critical path management. The critical chain seems appropriate for managing service production. However, the undetermined tasks are not unique features to service production, and the next section discusses how critical chain for services differs from that for products.

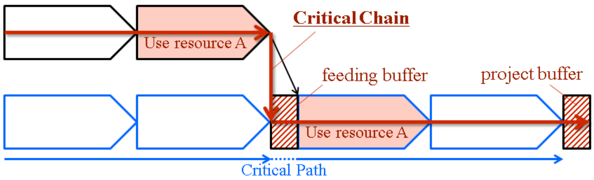


Fig. 2. Critical chain

3.3 Critical Chain for Products and Services

Critical chain for products (CCp) relies on physical resources and it depends on internal constraints. Meanwhile, users' involvement and interactions are mainly engaged in service development. Hence, the critical chain for services (CCs) has dependency on such external constraints. Furthermore, the characteristics of CCs are noteworthy from different perspectives. CCs allows more projects to be completed without increasing staff. Buffer penetration for CCs provides an ambiguous indicator of whether the project is on schedule. Eliminating bad multitasking in CCs makes individuals more productive and less prone to burnout [8].

Similarly to CCp, CCs also addresses resource contention. To put these principles of CCs into practice, it is required to quantify the amount of each task and the relationships between tasks. However, quantifying tasks in service productions includes a wider range of practitioners' activities, and each of activities has been managed by projects administrators and managers manually.

To establish a standardized method to quantify and formally address these practitioners' activities, the next section discusses how task chains can represent activities in conjunction with the service model chains. These two model chains will give a structure to production processes for services and become templates for another service production where agile development [9] has been adopted.

4 Production Patterns to Manage Service Co-creation

4.1 Task Chain

Service is defined as an activity between a service provider and a service receiver to change the state of the receiver [10][11]. Service is composed of 'content' and 'channel'. Service content directly changes the state of receivers. Service channel is the device which indirectly contributes to the change of state of receivers, e.g. communication, supply and amplification.

The service content is to be divided further into a set of functions, and the channel is to be denoted as a flow of the functions. The services, such as consulting, system planning, implementation, or monitoring IT platforms have functions. The channels are in the form of meetings, e-mail, networks, etc. From a lifecycle perspective, these functions and function flows exist not only in the operational phase of the service but also in the phases of ahead or behind: plan, design, implementation, and improvement. Development deliverables, such as requirement definition, system modeling and interface definition, will work as functions, and deliverables between stakeholders in production process will be flows of functions, i.e. 'channel'.

In this way, the whole production process can be regarded as a system in which stakeholders in development processes deliver functions to others. These relationships can reflect a sequence of tasks between practitioners, and a structure of task chain is established (Figure 3). Each task has task names as well as attributes, such as 'man-hour' to complete it.

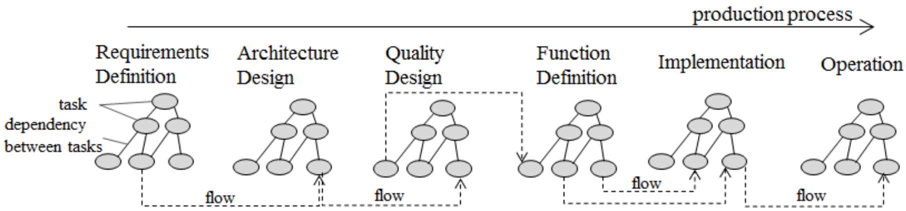


Fig. 3. Task chain

This task chain can be regarded as an abstraction form of CCs, as it is not only a set of each task. The CCs also abstracts feeding buffer, resource buffer, and project buffer. The data linkage represents a sequence of tasks with resource contention, as they reflect optimized sequences of real tasks.

4.2 Production Pattern Development and Reuse

By defining task chains in line with model chains, a complete production patterns can be established with the following steps.

Step 1. Development of Model Chains.
Each service model is developed with corresponding design and operation tools [3]. The developed service model forms structured data in an XML (eXtensive Markup Language) form. The XML data are concatenated along the lifetime phases. Furthermore, each tag data in an XML is linked to a tag in the next phase on the basis of reference relationships. As a result, a service model chain is formulated (Figure 4).

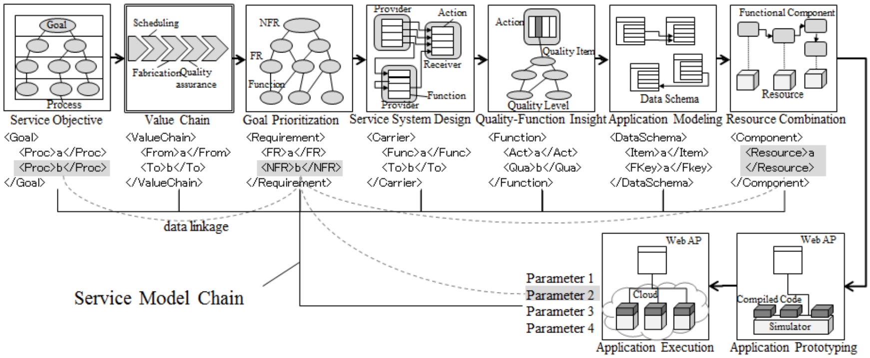


Fig. 4. Service model chain

Step 2. Development of Task Chains.
While developing service model chains, corresponding tasks to produce each deliverable, such as reviewing documents and implementing application software, are identified. These tasks are structured and linked to corresponding parts in the service model chain. Task sets in each development phase are also linked along with the production process (Figure 5). The man-hour attributes in the task chain will be translated to costs of practitioners' resources in the next step.

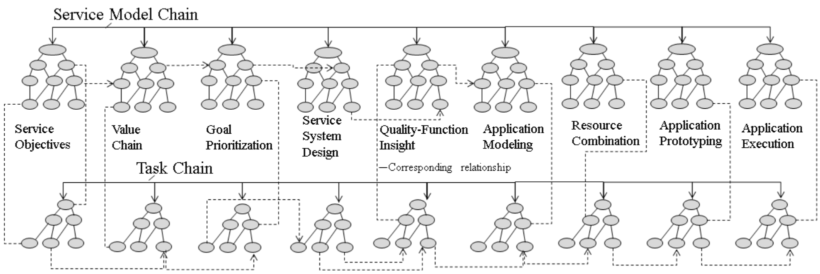


Fig. 5. Association between service model chain and task chain

Besides, this man-hour value can be brought from project management tools, which issue task tickets with planned value and actual performance records of human resources. These practitioners' resource data are integrated to the task chains. Then, a pair of model chain and task chain is stored into repositories as a production pattern for later use (Figure 6).

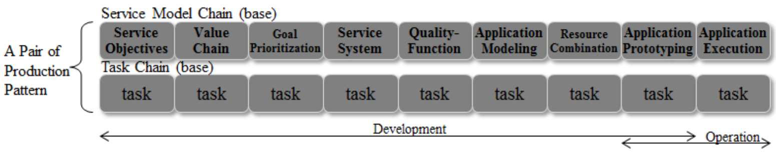


Fig. 6. Production patterns

Step 3. Reuse of Production Patterns.
Service portfolio will be the key to manage these production patterns efficiently. The service portfolio should consist of repositories for managing requirements, design, implementation, operational data and tasks for deliverables. The portfolio should also manage the common and service-specific data separately. Then, two extended portfolios are introduced; the *public service portfolio* is shared by any development project and the *private service portfolio* is owned by each application provider (Figure 7).

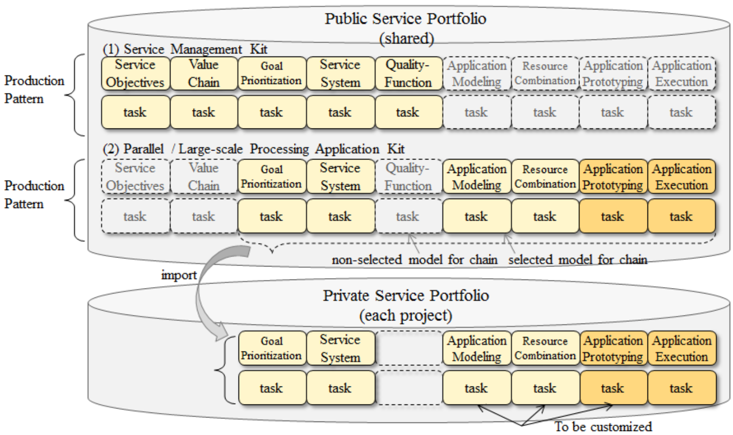


Fig. 7. Public and private service portfolios

When a production pattern is developed, it is exported to the *public service portfolio* after pruning off confidential data, minimizing anticipation that the core asset may have clients' specific data. Then, production pattern can be used for another service development. With this mechanism, a new project of service development can be started by importing it. Service developers can start the web service production from the beginning, and they just customize the interfaces and attain the target web services. In the same way, the second or after cycle in iterative/agile development can be started by importing a partial chain, which corresponds to the spectrum of the original pattern. Therefore, the system integrators can achieve clients' requirements easily and quickly. Furthermore, when the development cycle ends and it returns to the earlier phase for the next development cycle, the man-hour attribute in the partial chain can indicate the lifetime cost of the new development cycle.

4.3 Implementation

To evaluate the feasibility of the steps in the previous section, a production process framework is implemented by enhancing the *Service Lambda for Cloud Computing* framework [Appendix]. This framework consists of service design editors, task management tools, repositories, and analytic tools, which identify similar production patterns from the repositories and identify the influenced part in the patterns (Figure 8).

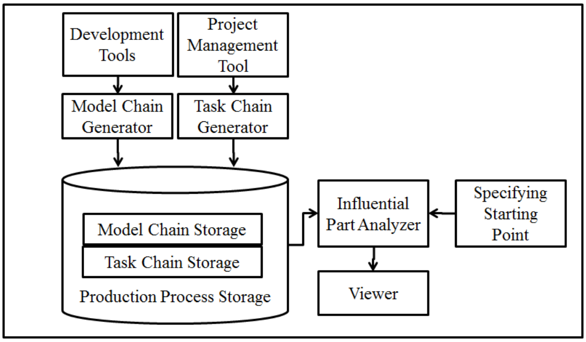


Fig. 8. Overview of production process framework

This framework is applied to a cloud service infrastructure and environment - PaaS (platform as a service), and the productivity and manageability are evaluated by developing a typical cloud-compliant web service.

5 Case Study

The feasibility of our approach is examined through developing a web service, which shows trends of newly-released web contents, such as new product information, from RSS feeds on websites. The crawling module of the web service collects RSS feeds from websites. The service runs alternatively, multi-threads or multi-nodes, based on its configuration rules. While developing this web service, the production pattern is stored into the *public service portfolio*. Then, a similar web service for other clients is developed in an agile development way as follows.

Reuse of Production Patterns.
The model chain and task chain are used as a standard process for web service development. When developers specify a target service to develop, the framework (Figure 8) finds a model chain and the corresponding task chain, which is similar to the target function from the *public service portfolio*, and imports them into a *private service portfolio* and uses them as a base of web service development.

After developing a prototype of web service, the development cycle circulates and returns to the earlier development phase, as the requirements for non-functional requirements are updated. For example, the requirement of its performance is updated to a higher level. To follow this requirement change, the similar nodes/trees, which correspond to the change is identified from the *public service portfolio*. The identified whole/partial chains with task chains are used as a reference for a baseline of the next round development. Using the man-hour attributes in the identified chains, the project owners can estimate the production cost of this development round and also evaluate the progress of development (Figure 9).

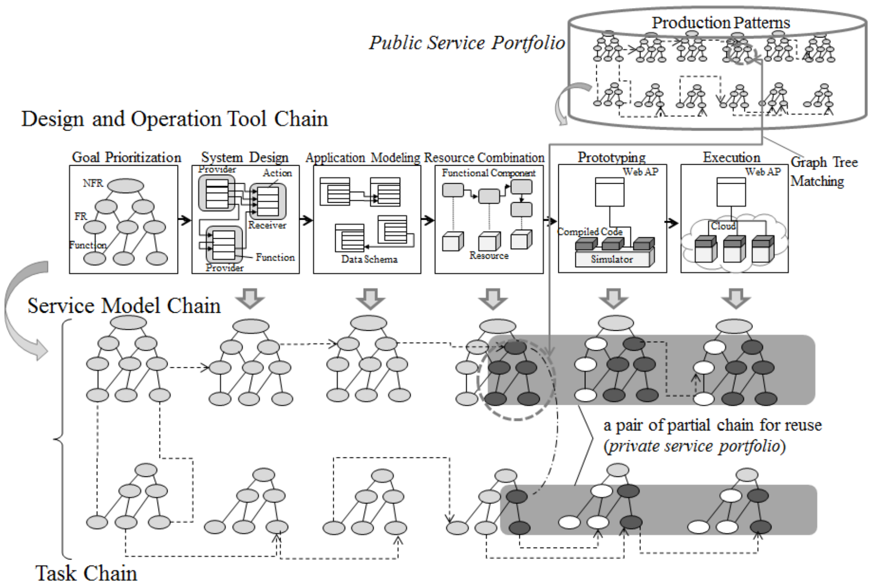


Fig. 9. Reuse of partial production pattern

Assessment of Production Progress.

The reuse of production patterns can be extended for the entire development phases. While developing web services in this agile way, the frequent interactions between practitioners make assessing progress obscure. Earned-value analysis [12] is a good way to assess production progress at the time of evaluation. Through the earned-value analysis, planned value (PV) is defined as the budget given at the evaluated date. Actual cost (AC) is given as the cost that they actually used. Earned value (EV) is determined by the date of measurement. The value of PV, AC and EV can be deemed with the following equations:

$$\text{PV (planned value)} = \Sigma \text{ (planned man-hours} \times \text{a unit price)} \quad (1)$$

$$\text{AC (actual cost)} = \Sigma \text{ (actual man-hours} \times \text{a unit price)} \quad (2)$$

$$\text{EV (earned value)} = \Sigma \text{ (planned man-hours} \times \text{a unit price} \times \text{progress rate)} \quad (3)$$

The values of PV, AC and EV are obtained through the initially determined data in the framework (Figure 8), such as project start date, estimated end date, the number of iteration time, and the estimated date to complete the cycle. The value of EV at the time of assessment can be generated at any time during the service development as the data stored in the *public service portfolio* and the *private service portfolio* is always available. With PV, AC, and EV, the production progress at the time of assessment and the expected completion date of each iteration development are visualized (Figure 10). In this use case, the production patterns give standard data for 'estimated ending date' and 'required man-hour for the next development cycle', as the partial chain corresponding to the next cycle will provide past actual records of the production period and man-hours.

As illustrated above, the model chain and task chain can be used for estimating lifetime and for decision making of investing to the service development. The models retain a complete production process from the design to operation phases. Therefore, the assets of web service development can be reused and development on customization will become easier.

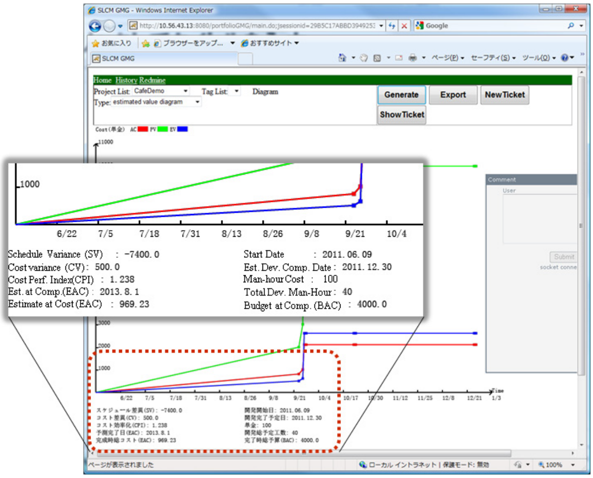


Fig. 10. Assessment of Production Progress

6 Discussion

The case study shows that the model chains have increased productivity and manageability of service production. As exemplified in the agile development, a reusable process is easily specified as the beginning of the spectrum is the start point of reusable models, and the spectrum can be easily imported to a *private service portfolio* for reuse. Similar structures are identified through a graph tree matching algorithm, and appropriate chains stored in the repository are selected when a new service project starts. In addition, the selected parts of chains are used to determine the influenced activities and estimate lifetime costs.

On the other hand, the case study of earned value analysis shows that the progress of service production as of time is visualized. The task model structures practitioners' activities and they are used for a standard for assessing the progress of cloud-compliant web services. Hence, the presented approach gives another solutions to lifecycle cost modeling and estimation in the researches on product-service systems (PSS) [13][14][15][16].

7 Conclusion and Future Work

This paper proposes production patterns providing development principles for web services. The patterns consist of design models and task models through a service lifecycle. The task chains give a structure to sequences of tasks and resource coordination between the tasks. This data structure can be stored in a repository. Then, they are reused as a template for service production as well as a yardstick to keep track of production progress. A conceptual verification shows that the progress of practitioners' activities can be assessed and the total lifecycle cost of the service can also be estimated enabling administrators to perform better production management and decision making.

However, the adequacy of each task model chain has been left for future work. As production procedures depend on each organizational culture, the future study extends consideration of such cultural background and identifies an appropriate buffer size for such environment. The customization interfaces for task chains can be identified by introducing roles representing organization to task chains. This mechanism will increase the accuracy of the CCs, and better co-creating services will be depicted clearly. In addition, task chains in this paper focused on practitioners' tasks mainly as hardware and software resources are affluent from the cloud, and they are excluded from the attributes of task chains. To apply this approach to general service developments, the presented approach should be extended to handle resources explicitly.

References

1. Erl, T.: Service-Oriented Architecture: Concepts, Technology and Design. Prentice Hall (2005)
2. Zhang, L.J., Zhang, J., Cai, H.: Service Computing. Springer (2007)
3. Hosono, S., Shimomura, Y.: Towards Establishing Mass Customization Methods for Cloud-compliant Services. In: Proc. of the 4th CIRP Int'l Conf. on IPS^2, pp. 447–452 (2012)
4. Fuller, R.B.: Critical Path. St. Martin's Griffin (1982)
5. Goldratt, E.: Critical Chain. North River Press (1997)
6. Goldratt, E.: The Goal: Beating the Competition. Gower Pub. Co. (1996)
7. Parkinson, C.N.: Parkinson's Law. Buccaneer Books (1996)
8. Ricketts, J.A.: Reaching The Goal: How Managers Improve a Services Business Using Goldratt's Theory of Constraints. IBM Press (2007)
9. Anderson, D.: Agile Management for Software Engineering: Applying the Theory of Constraints for Business Results. Prentice Hall (2003)
10. Arai, T., Shimomura, Y.: Proposal of Service CAD system - A tool for Service/Product Engineering. Annals of the CIRP, 397–400 (2004)
11. Arai, T., Shimomura, Y.: Service CAD system - Evaluation and Quantification. Annals of the CIRP, 463–466 (2005)
12. Fleming, Q., Koppelman, J.: Earned Value Project Management, Project Management Institute (2000)
13. Abramovici, M., Jin, F.: A New Approach to Executive Information Management as Part of IPS^2 Lifecycle Management. In: Proc. of the 2nd CIRP Int'l Conf. on IPS^2, pp. 543–547 (2010)

14. Roy, R., Erkoyuncu, J.A.: Service Cost Estimation Challenges in Product-Service Systems. In: Proc. of the 3rd CIRP Int'l Conf. on IPS^2, pp. 1–10 (2011)
15. Fernandes, P., Roy, R., Mehnen, J., Harrison, A.: An Overview on Degradation Modeling for Service Cost Estimation. In: Proc. of the 3rd CIRP Int'l Conf. on IPS^2, pp. 309–314 (2011)
16. Komoto, H., Tomiyama, T.: Life Cycle Cost Estimation using a Modeling Tool for the Design of Control Systems. In: Proc. of the 18th CIRP Int'l Conf. on Life Cycle Engineering, pp. 663–668 (2011)

Appendix: Service Lambda for Cloud Computing

The authors have proposed the design and operation framework, *Service Lambda for Cloud Computing* to provide comprehensive platforms for developing and operating cloud-compliant web services [3] (Figure 11, 12). This platform is a client-server system. The client-side tools cover system design and implementation phases, providing development tools as well as collaborative development environments for practitioners. The server/cloud-side tools manage the applications' lifecycle and also provide an execution environment for them.

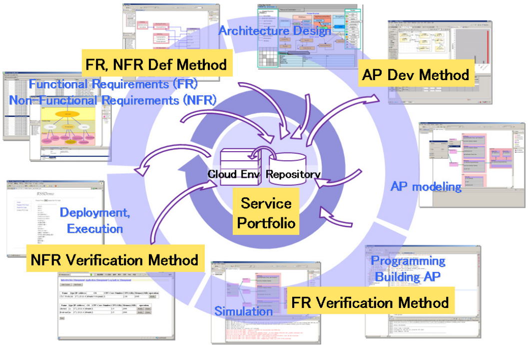


Fig. 11. Overview of Service Lambda for Cloud Computing [3]

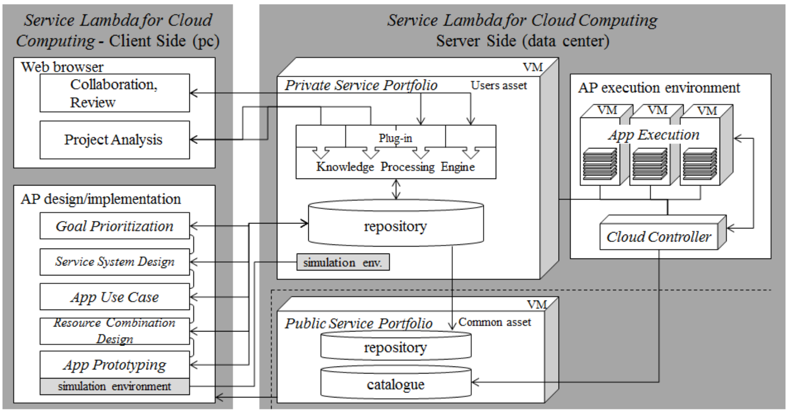


Fig. 12. Architecture of Service Lambda for Cloud Computing [3]

Towards a Reference Model of Information Exchange and Coordination in Facility Management Networks

Anna-Karina Averbeck[1], Torben Bernhold[1], Sebastian Bräuer[2], Ralf Knackstedt[3], and Martin Matzner[2]

[1] Home Economics and Nutritional Sciences – Facility Management, University of Applied Sciences Münster, Johann-Krane-Weg 25, Münster, 48149, Germany
{anna.averbeck,bernhold}@fh-muenster.de

[2] Department of Information Systems, University of Münster – ERCIS, Leonardo Campus 3, Münster, 48149, Germany
{braeuer,matzner}@ercis.uni-muenster.de

[3] Institute for Business Economics and Information Systems, University of Hildesheim, Samelsonplatz 1, Hildesheim, 31141, Germany
ralf.knackstedt@uni-hildesheim.de

Abstract. An efficient and effective management of facilities requires considering all the product and services related to a building's entire life at an early stage. The interdisciplinary Facility Management (FM) approach advocates accordant concepts and techniques with the intention to reduce the total costs of facilities. A successful FM needs to bring together several actors involved in planning and operating a facility in a network organization. The specification of information flows and coordination mechanisms between these actors is complex, and in this paper we argue that reference models can speed-up this process. We elaborated more than 50 process models that uncover the interaction in FM service networks through interviews and workshops with practitioners. This research-in-progress develops a reference model of the interactions between conventional construction enterprises and specific FM service providers based on this empirical data following an iterative research process.

Keywords: Facility Management, Consulting, Service Networks, Reference Model, Information Flow Models.

1 Introduction

Facilities are more and more seen as strategic resources and as also the costs for their planning, construction, operation and maintaining increased dramatically in the recent years enterprises require for a more active management of facilities [1-2]. The Facility Management (FM) discipline offers a holistic approach for all the commercial, technical, and infrastructural tasks related to the management of facilities [2]. FM Consulting (FMC) is a service that wants to improve FM in two dimensions: economic efficiency and usability. First, FMC aims at increasing the run-time economic efficiency of a facility as it suggests methods for assessing, analyzing, and balancing any related costs at an early stage. FMC takes a long-term perspective that includes a

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 107–120.
DOI: 10.1007/978-3-642-30820-8_10

building's conception, construction, maintaining, revitalization, and conversion or demolition [3-4]. In a FM project, the service-related costs in the operation phase account for a multiple of the construction costs. Most of these costs are fixed in the conception phase already, and it's hard to modify them at later project stages. Second, each FM project is unique as facilities differ in terms of their required types of use, flexibility, materials, energetic and room-functional requirements. Different actors need to co-operate so that a facility with the desired properties can be achieved. The actors include the general planner, specialized construction consultants (e.g., for logistics and energy), the constructor, the architect, and the building company. All the involved together constitute a service network [5] with the intention to deliver the use of a facility as a service to a customer. In service networks, information exchange needs to be established between actors so that the individual actors' tasks can be coordinated and joint decisions can be made efficiently [6]. Consequently, each time a FMC project is initiated, every actor needs to analyze which information it requires from others to fulfill his activities and which information about his own activities could or should be provided to other actors so that they can efficiently and effectively do their tasks. Establishing this information exchange is time consuming and thus expensive [7]. Observations from practice indicate that required information is often not exchanged or that information is not provided in the right form or quality [8-10].

At this juncture, reference information models ("reference models" in brief) are a means for describing a class of relevant real-world phenomena on an abstract level [11], and they are designed for reuse to guide the design of other information models. For instance, the IT Infrastructure Library (ITIL) is a well-known reference model for IT service management [12]. Reference models often describe "best-practice" conceptual knowledge that is identified from the analysis of specific models such as a "reference business processes" that are identified from the study of several business processes as they are implemented in practice.

In this paper we present the status-quo of a reference model for the information exchange in FM projects that strives to assist the formation of FMC service networks. We have documented more than 50 processes of enterprises that are engaged in traditional construction projects or FMC service networks using the conceptual modeling software tool FlexNet Architect [13-14]. Based on an analysis of these processes, we identify a corpus of well-established information exchanges that is the evidence we build our reference model upon. The reference model is intended to be of immediate utility for the practice of FM and FMC.

The remainder of this paper is structured as follows: Section 2 discusses the research background on information flow modeling and Information Logistics as well as related industry standards and guidelines. Section 3 presents the IT artifact conglomerate FlexNet Architect. Section 4 depicts the reference model development process. Section 5 outlines the status-quo of the reference model. Finally, section 6 discusses implications and limitations and gives a brief summary and outlook.

2 Research Background and Related Work

Information models have been used in previous literature to assist the identification and documentation of information flows; for instance when analyzing the requirements for an integrated information processing for the technical and operational tasks in manufacturing (Y-CIM) [15], for illustrating the information flows between different areas of operation in the retail business (e.g., between purchasing and warehouse) (Retail-H) [16], for creating a framework and reference processes that describe the daily operations of a consulting company (Consulting C) [17], or for optimizing practices along industry supply chains (SCOR-model) [18]. However, in the context of construction projects that include facility services no such approach can be identified.

Another strand of literature that analyzes inter-organizational information flows is subsumed under the term Information Logistics (IL). According to Winter et al. IL comprises the planning, execution, controlling, and monitoring of data flows as a whole between business areas or organizations as well as the storage and processing of data for decision support [19]. Whereas this definition emphasizes the importance of inter-organizational data flows in cross-company cooperation [20-21], it excludes further activities such as the data processing required for the automated execution of operational business processes [19]. Consequently, IL aims at providing relevant information in sufficient quality to a decision maker [19].

Recommendations for organizing information exchange and coordination in FMC are also given by various regulations and industry standards. The Official Scale of Fees for Services by Architects and Engineers (HOAI) is an official German regulation for the fees of architects and construction engineers that includes guidelines for dividing construction projects into certain phases. The German Facility Management Association (GEFMA) has released several drafts of guidelines that define the general role of FM, its scope with regard to services [22] and general instructions for a stronger integration of the documentation as a part of the life cycle oriented planning and maintaining of facilities [23].

The Service Science literature and Service Management practice give further advices. For instance, in the context of service integration, a specification of IT system interfaces has been suggested [24] in order to facilitate information exchange between manufacturers and service providers in service networks: The industry standard DIN PAS 1091 gives detailed descriptions of such interfaces and the needed information flows between the participants of a service networks in the collaborative design, development and offering of services.

3 Methodology

3.1 A Modeling Language for Information Flows in Service Networks

We used a modeling language that particularly supports the documentation of processes, information flows, information objects, and coordination in service network constellations [14] to represent and successively further develop our reference model. Fig. 1 illustrates the main constructs of this modeling language by representing its meta-model in form of an Extended Entity Relationship Model (EERM).

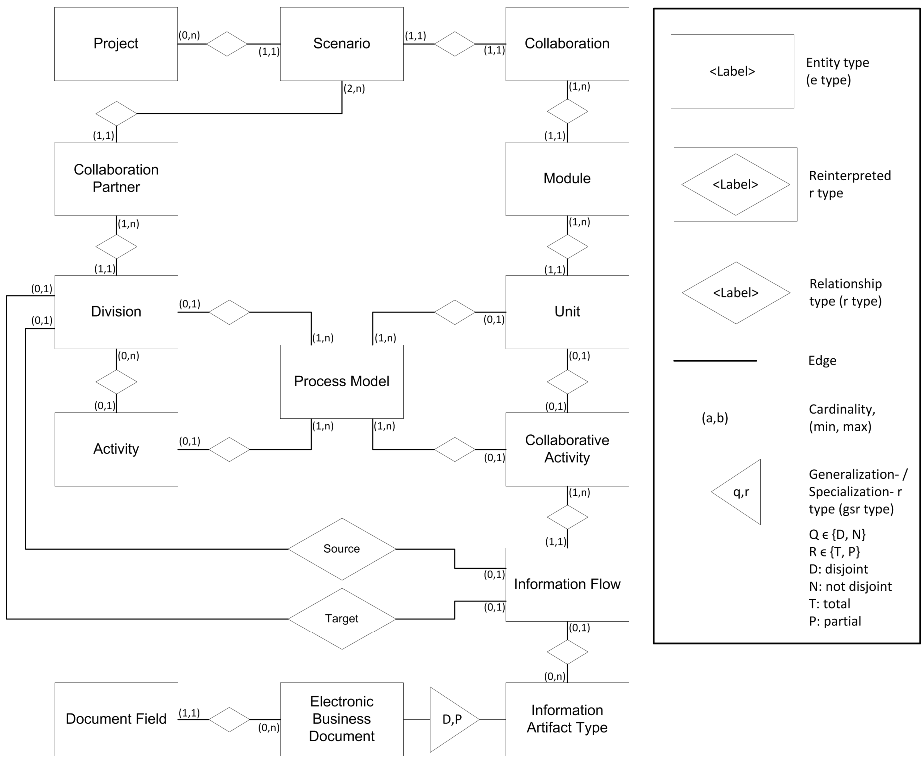


Fig. 1. Meta-model of the applied modeling language

A *project* delimits the scope of analysis. *Scenarios* allow to represent different development stages of a reference model and to conceptualize variants of a model, for instance if considering different network structures for a construction project such as a network with a general contractor or a full service contractor, respectively.

A *collaboration partner* (actor) represents one of the producers and service providers that collaborate along the facility's life cycle. The customer is also represented as an actor. Actors can be further detailed into divisions. A *division* is a logical unit that delimits an actor's functional areas. Divisions can lend themselves to functional areas as they are prescribed in well-established industry frameworks such as the Y-CIM-Model, the Retail-H-Model or the Consulting-C. Divisions subsume several *activities* that are associated to them. *Process models* can be used to describe the relations between activities.

Collaborative activities connect activities of different actors, and they describe measures for aligning and coordinating these activities. Examples for collaborative activities range from redirections of information to the more complex aggregation of data and prescribing recommended procedures. *Units* allow bundling several collaborative activities. *Process models*, again, can be used for describing the relations between several collaborative activities that are associated to a common unit. In this context, a unit's interface represents the information requirements of the included activities (input) and the information that is provided to other activities (output).

Modules encapsulate units with respect to their contents. Modules also can lend themselves to established frameworks from industry (like the divisions can do).

Finally, *information flows* allow for capturing the interaction between the divisions of different actors. An information flow represents information that is either provided by a division for further processing through collaborative activities or information that is received by the particular division. An information flow is used to exchange *information artifact types*. In general, two types of information artifacts can be distinguished: a *general information artifact type* and an *electronic business document*. Whereas the general information artifact type can be interpreted as a proxy for a not further specified information object, an electronic business document allows the specification of the document's structure by the definition and hierarchical organization of *document fields*, each of which is described by name, type and cardinality. Electronic business documents allow describing information objects that are exchanged between activities more precisely, and they define standards for the information exchange.

3.2 Reference Model Development

We developed our reference model based on empirical data that was obtained in a series of interviews and workshops with practitioners. The development process orients on the iterative procedure model that was suggested by Carroll and Swatman [25] and Walsham [26] for the design of interpretative case studies (Fig. 2). Following this approach, an initial model (scenario) reflects the research group's ex-ante state of knowledge. At the end of each research cycle, the model is questioned critically and new knowledge obtained about the research area is integrated into the model [25]. Consequently, the model serves two purposes. First, the reference model is the research result that encapsulates the elaborated domain knowledge and that is permanently evaluated and questioned throughout the different research cycles. It is developed with the intention to finally help overcoming observed problems in practice. Second, the intermediate models documents the research progress of the researchers as they illustrate how the data collection process and the researchers' understanding of the research domain evolved over time.

This research yet traversed twice through the Carroll and Swatman model: in an exploratory and in a deepening phase. Further phases will follow. The main activities undertaken are listed below:

1. Exploratory phase: Desktop research; development of a framework for the life cycle-oriented planning; definition and description of possible actors and their areas of operation; first steps towards the design of suitable collaborative activities and their realization with the FlexNet Architect, an internet platform that implements the previously described modeling language and thus supports the reference modeling process[1]

[1] The FlexNet Architect is publicly available: `http://www.flexnet-architect.ercis.de.`

2. Deepening phase: Capturing of the actor-specific processes for the accordant areas of operation on the basis of event-driven process chains (EPC) [27]; deriving and illustration of collaborative activities being relevant for a life cycle oriented planning; further description of the exchanged business documents and their structures

Within each of these phases, a spiraled process guides the stepwise development and refinement of the reference model (Fig. 2):

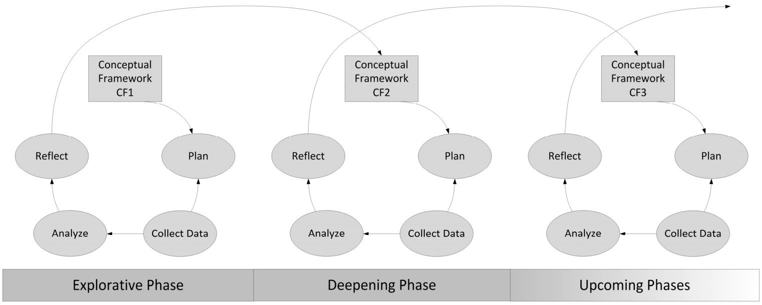


Fig. 2. Spiraled process of comprehension [25]

- Each iteration starts with the identification of interview partners, addressing contact persons and agreeing upon the methods used for the collection, recording and analysis of the data (Plan).
- Subsequently, the data is collected (in interviews) and processed according to the agreed rules (Collect Data).
- During the analysis, the raw data (in form of conversation records and documented adaptations of the model) are structured. Additionally, the data is reduced by consolidating the results in the FlexNet model as a new scenario (Analysis).
- Finally, the resulting model is critically reflected. This review includes the decision if a further iteration is required and an agreement on a specific model area that should be further improved.

In the context of our research the modeling tool FlexNet Architect is used for three purposes: First of all, since the tool forms one possible implementation of the modeling language, it directly supports the research process by providing means of structuring and processing the collected actor-specific information, as well as the identified information flows and exchanged information objects with regard to the aspired reference model. Second, by the usage of scenarios it is not only possible to fully document the development path, but also to create branches for considering model variants. Finally, another focus of the research lies on the development of standardized templates for model components and standardized specifications of electronic business documents which is supported by the FlexNet Architect. These templates not only serve as “best practices” but also accelerate the later adaptation of the reference model for specific business cases. Details concerning the so far performed iterations and their results are presented in the subsequent chapters.

4 Results of the Research Process

4.1 Results of the Exploratory Phase

We stepped into the development of our model by first identifying the relevant participants of FM projects as they are described by extant literature. We could identify three classes of commonly accepted actors: the general planner (including technical planners and the architect), the building constructor, and the building owner (who consolidates the interests of owners, project developers and occupants). For each of these actors, we tapped into existent and widely-accepted frameworks in order to achieve a first conceptualization of their individual divisions and activities. Table 1 lists the specific frameworks and guidelines that we used.

Table 1. Applied frameworks and guidelines [5, 28-33]

Actor	Framework	Integrated Aspects	Relevant Aspects for Project
Building Owner	AHO (2004), AHO (2009)	Scope of Services, Project Management	Modeling of actor-specific divisions as well as fundamental activities
General Planner	HOAI (2001), Scholtissek (2010)	Description of service phases for planning as well as phase-specific activities	Modeling of general planner's divisions along the nomenclature, modeling of collaborative activities in chronological order
Building Constructor	Girmscheid (2005)	Basic description of actor and illustration of processes for service provision	Modeling of actor-specific divisions, integration of core competencies, modeling of the phase-specific processes for service provision
FM Consultant	Bernhold et al. (2008), AHO (2010)	Framework for FM-oriented planning, FM Consultant's scope of services	Description of the actor-specific divisions, relevant activities and interfaces between actors, usage as basis for identification of relevant collaborative activities

Table 2. Extract of questions for deepening phase's problem-centric interviews

Actor	Focus	Exemplary Central Question
Building Owner	Organization	Are organigrams used for representing the relations between the project participants?
	Quality/Quantity	Are the checks performed in collaboration with other project participants?
	Costs/Funding	Which data is required from which participant to perform the cost / funding calculations?
	Appointments/Capacities/Logistic	Who performs the capacity planning and with which inputs?
	Contracts/Insurances	Who is part of the determination of contracts / insurances?
General Planner	Establishing of the Project Basis	Does the FMC partake in this phase? When and with which service is the FMC integrated in these phases?
	Preliminary Design	When are first results discussed with the building owner and who is involved?
	Final Design	How can the FMC be involved in this phase?
	Building Permission Application	How are possible requirements for change from the public construction authority taken into account?
	Execution Drawings	When are the drawings from the expert planners required?
	Preparation of Contract Award	Which documents are required for the technical specifications?
Building Constructor	Invitation of Tenders	Are the draft contracts part of the tender documents?
	Tendering	Are additional documents required in this phase? Which documents and who provides them?
	Negotiation of Contracts	At which point of time is the schedule determined?
	Work Scheduling	What is the typical procedure after the contract award in the context of the work scheduling?
	Construction	How much collaboration with the other actors is present during this phase?
	Commissioning	Who partakes in the acceptance procedure?
FMC	Project Management	How do the optimal organizational preconditions for the project look like?
	HOAI 1+2	Which information are relevant for the definition of the planning requirements?
	HOAI 3	Which information are relevant for the creation of the planning requirements? Who contributes them?
	HOAI 4-8	Which information are relevant for the creation of the job profiles in the context of the operating concept?
	HOAI 9	Which facility services are part of your duties?

Although these frameworks and guidelines constituted a profound basis for our purpose, i.e. to develop a reference model for information flows in FMC, they do not address the network of actors and the required coordination and information exchange between the actors, accordingly.

Subsequently, all the collected information has been composed in an actor-specific way and it was used for providing a problem-centric discussion basis for the interviews in the second phase of the research process [34-35]. Structured in a corresponding catalogue of central questions (Table 2), the interviews aimed at the extraction of deeper insights into the individual actor's structures and processes, but also at the identification of actor-comprehensive cooperatively performed activities [36].

4.2 Results of the Deepening Phase

As a starting point for the problem-centered interviews and workshops with partners from practice (Table 3), we further included eight modules into our draft reference model that capture collaborative activities required between the four actors. These modules lend themselves to the chronological phases as defined in the Official Scale of Fees for Services by Architects and Engineers (HOAI) [30].

Table 3. Overview of conducted interviews

Phase	Actor	Number of Interviews	Total Number of Interviewees
1	S/FMC	2	3
1	BO/PM	1	2
1	BC	1	1
1	FMC	2	2
1	GP	2	2
2	BO/PM	5	4
2	BC	4	4
2	FMC	4	5
2	GP	4	4

S = Sciences; FMC = Facility Management Consulting; BO = Building Owner; GP = General Planner; BC = Building Constructor; PM = Project Management

Then every actor from the exploratory phase and the FM Consultant were subject to a detailed investigation in order to further develop the existing model. Actor- and division-individual processes were documented by event-driven process chains (EPC) that were iteratively refined during the problem-centered interviews and through several workshops. On the basis of 40 interviews we created more than 50 process models that cover the current state of interaction in FMC service networks. The interviews were analyzed following the summarized qualitative content approach as proposed by Mayring [34]. For the further specification of the information flows and document structures, cross-actor EPCs have been derived from the actor-specific process models. Finally, all results have been integrated into a new intermediate version of the reference model using the FlexNet Architect software tool.

4.3 Current State of the Reference Model

Fig. 3 displays an extract of the current state of the reference model. As shown in this screenshot from the FlexNet Architect software tool, the actors and their divisions as well as the structures for covering the collaborative activities are yet described on a detailed level. The model further includes actor-specific processes, which are however not exhibited in the figure, but which are assigned to their particular divisions. Moreover, a huge amount of information flows between the collaborative activities as well as the actors' individual activities have been identified. However, especially with regard to the collaboration between the actors, the information flows and associated information objects still require a fundamental revision. Particularly the identification of commonly exchanged business documents and their structures has still to be addressed in a further research phase with accordingly focused interviews and workshops.

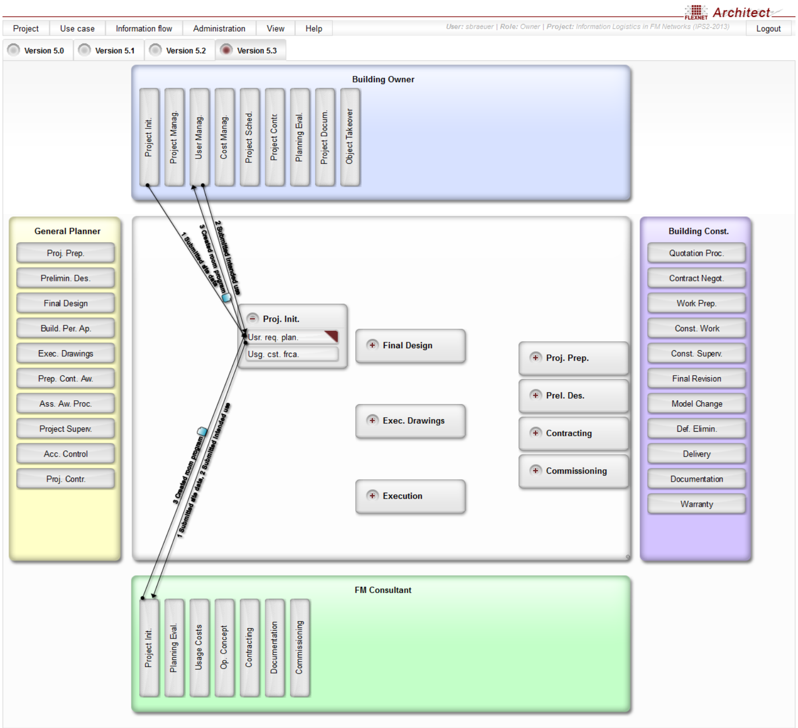


Fig. 3. Application of the modeling language on the web platform

At this current state, the project highlights the importance of documenting the collaboration between the different actors already. The model emphasized the documentation of accordant information flows and exchanged information objects using a consistent modeling language. In the following, the information exchange and associated activities surrounding one of the central documents for a life cycle oriented planning will be further described by using the structures of the presented modeling language.

The industry standard DIN 18205 addresses the requirements planning in the construction industry, and it highlights the importance of identifying user needs [37]. The standard suggests defining a room program which documents the expressions type and number of required rooms from the perspective of the building owner respectively the later occupant. This document can be further detailed through a room book. A room book bundles various detailed information that are relevant for the whole life cycle of building sections and consequently for the entire building in one single document. Typically it comprises information such as the room sizes, room numbers, and occupancies or to be cleaned surfaces, as well as details about room-specific ventilation and air-conditioning technologies or further electrical installations. For capturing these information in an often digitally maintained room book, successive contributions and thus a systematic collaboration of the different actors partaking in the network is required.

At the beginning of the construction planning, the building owner respectively occupant has to define the room program, which provides a first detailed overview of the construction works. Since most individuals lack the necessary knowledge for properly creating an accordant document, the room program is often defined in collaboration between an expert, such as the architect (whose role is summarized in the general planner), and the building owner respectively occupant. During the final design (HOAI phase 3), the architect uses the room program as a first orientation for the creation of the building's conceptual design. In the context of the execution drawings (HOAI phase 5), the information from the room program can be used as an input for further specifying the later accomplished rooms in the room book. Although the creation of the room book, according to the HOAI, does not belong to the basic but special services provided by the architect, it provides highly relevant information for the purchasing of the furniture and embedding of the technical infrastructure (construction) and especially for the planning, preparation and execution of later cleaning, maintenance, refurbishment or rebuilding tasks along the life cycle of the building. Additionally, the FM Consultant analyzes the room book with a life cycle-oriented perspective for discovering further potentials for optimizing the total costs associated with the to-be utilized materials or the to-be installed technical infrastructure and provides the building owner with recommendations that form the basis of potential further adaptations of the room book. Finally, further adaptations of the room book during the construction process (execution) and even in the later operation of the building are possible and need to be thoroughly documented.

On the basis of this example and against the background of the previously introduced modeling language Table 4 exhibits an extract of the activities that are required for the creation and adaptation of the room program and the room book.

Table 4. Exemplified collaboration for creation and adaption of a room book

Module	Unit	Collaborative Activity	Information Flow	Information Artifact Type	Source [1] (Actor – Division)	Target [1] (Actor – Division)
Project initiation	User requ. planning	Submit site data	Submitted site data	Site data	Building owner – Project init.	FM Consultant – Project init.
		Submit intended use	Submitted intended use	Building and usage description	Building owner – User management	FM Consultant – Project init.
		Create room program	Created room program	Room program	FM Consultant – Project init.	Building owner – User management
Fin. de.	Co. de.	Create conceptual design	Created conceptual design	Conceptual design	General planner – Final Design	Building owner – Planning evaluation
Execution drawings	Development of execution drawings	Create room book	Created room book	Room book	General planner – Execution drawings	Building owner – User management
		Submit room book	Submitted room book	Room book	Building owner – User management	FM Consultant – Planning evaluation
		Optimize room book	Optimized room book	Room book	FM Consultant – Planning evaluation	Building owner – User management
Execution	Building shell	Submit room book	Submitted room book	Room book	General planner – Project supervision	Building constructor – Construction work
		Adapt room book	Adapted room book	Room book	Building constructor – Construction work	General planner – Project supervision
	Interior work	Submit room book	Submitted room book	Room book	General planner – Project supervision	Building constructor – Construction work
		Adapt room book	Adapted room book	Room book	Building constructor – Construction work	General planner – Project supervision

1 Underscore marks main responsibility for execution of collaborative activity.

This example illustrates that the role of the FM Consultant in the network is not yet fixed in terms of employed structures, procedures and precise definitions and still requires for clarification and extension. Actually the applied tools and methods strongly differ in many cases within the examined units. However, the project's current results point out that the main aim of the FM Consultant is the integration of technical, infrastructural and commercial expertise on sustainable facility-related planning over the whole life cycle of the object and thus to reduce the accordant duties of other actors, especially the general planner, in the network. Moreover, our research shows that the role of FM Consultant with his interdisciplinary knowledge indeed resembles that of an intermediary, who especially supports tasks of the early phases, such as the project initiation, preparation and the preliminary design, but who also inherits duties in the commissioning phase, e.g. the documentation tasks. Nevertheless, the complexity and heterogeneity of this service complicates a unique and generic phase orientation and definition of the FMC's specific scope. Especially the information flows and coordinative actions between the general contractor and the FM Consultant are yet to be further distinguished.

5 Limitations, Outlook and Conclusion

This research-in-progress paper presents and discusses an intermediate version of a reference information model. From a careful review of the extant FM literature and industry standards we identified four actors that typically constitute any FMC service network: the general planer, the building constructor, the FM consultant and the building owner. The model describes activities to be accounted by each of the actors as we could identify it from the literature. Based on the analysis of more than 50 processes as observed in practice, the model further suggests and prescribes a corpus of well-established interaction and information exchange between the actors with the intention to speed-up the formation of FMC service networks and to improve the quality of FMC service network organizations.

However, at this stage this work is subject to several limitations. In practice a FMC service network involves further actors than the discussed such as the governmental authorities. Some actors could be replaced if distinguishing more fine-granular roles; for instance the general planner could be substituted by specialist engineers such as the land and soil surveyor, the structural engineer or the building physicist. It is further possible to differentiate between the building owner and the occupant of a facility and. The occupant and his individual activities then could be represented as an additional actor. Concerning a life cycle oriented planning and maintenance of the facility, it might be helpful to integrate the service-specific know-how of the individual service providers during the operating and utilization phases. Some of these central services are already covered, at least on an aggregated level, by the FM Consultant.

These observations from the status-quo reference model will be addressed in future research. Two further research phases are yet planned. Phase 1 will focus on refining and further justifying the collaborative processes and required information flows in the FMC network and on consolidating the set of information objects. Through further interviews and especially by introducing and establishing additional modeling guidelines, which are to be designed on the basis of our gained domain-specific knowledge, we aim at the unification of the used terminology as well as the elimination of redundancies. In a yet further development phase we will contact general standard committees such as the German standards association (DIN) or the association of German engineers (VDI) or alternatively FM-specific associations such as the German Facility Management Association (GEFMA) or the International Facility Management Association (IFMA) for a further discussion and refinement of the reference model.

The presented research-in-progress, however, yet offers contributions to research and to practice. Researchers from Management and Information Systems disciplines might be inspired by seeing the iterative application of empirical studies in order to gradually refine an information reference model and to see that this iterative procedure is smoothly supported by the used modeling language. FM researchers can directly tap into the "best practice" conceptualization of information exchange and coordination in FMC networks as we elaborated it from a careful study of the literature and our empirical data.

Domain experts from the FMC area instead might directly tap into the reference model and might take the prescribed information exchanges and coordination activities as a basis when establishing new FMC service networks or when trying to improve the organization of existing ones. At this, the presented reference model already provides an overview of the required services of the involved actors and it contains first recommendations for common document types and points of time for their exchange. Thereby the reference model is expected to increase the level of standardization, an issue that can however only be evaluated in long-term projects; and we are confident that it will help to establish a common terminology and understanding of the central processes and informational duties in service networks, which will already help overcoming many coordination problems observed in today's FMC service networks.

References

1. May, M.: Motivation. In: May, M. (ed.) IT im Facility Management Erfolgreich Einsetzen: Das CAFM-Handbuch, 2nd edn., pp. 1–3. Springer, Berlin (2006)
2. Pfnür, A.: Modernes Immobilienmanagement. Immobilieninvestment, Immobiliennutzung, Immobilienentwicklung und –betrieb, 3rd edn. Springer, Berlin (2011)
3. Marchionini, M., Hohmann, J., Prischl, P.: Zum Verhältnis von Facility Management und CAFM. In: May, M. (ed.) IT im Facility Management Erfolgreich Einsetzen: Das CAFM-Handbuch, 2nd edn., pp. 5–18. Springer, Berlin (2006)
4. Bernhold, T., Nitzsche, F., Rosenkranz, C.: Ein Ordnungsrahmen für lebenszyklusorientierte Planung im Facility Management. In: Bichler, M., Hess, T., Krcmar, H., Lechner, U., Matthes, F., Picot, A., Speitkamp, B., Wolf, P. (eds.) Multikonferenz Wirtschaftsinformatik 2008, pp. 1625–1636. Gito-Verlag, Berlin (2008)
5. Basole, R.C., Rouse, W.B.: Complexity of service value networks: Conceptualization and empirical investigation. IBM Systems Journal 47(1), 53–70 (2008)

6. Durugbo, C., Tiwari, A., Alcock, J.R.: A review of information flow diagrammatic models for product–service systems. The International Journal of Advanced Manufacturing Technology 52(9), 1193–1208 (2011)
7. Becker, J., Beverungen, D., Knackstedt, R., Matzner, M., Müller, O.: Information Needs in Service Systems. In: Proceedings of the 44th Hawai'i International Conference of System Sciences (HICSS-44), Koloa, Hawai'i, USA (2011)
8. Schäfermeyer, M., Rosenkranz, C.: Inhibiting factors for adopting enterprise systems in networks of small and medium-sized enterprises – an exploratory case study. In: Proceedings of the 14th Americas Conference on Information Systems, Toronto, Canada (2008)
9. Wang, Y., Yang, J., Shen, Q.: The application of electronic commerce and information integration in the construction industry. International Journal of Project Management 25(2), 158–163 (2007)
10. Sun, M., Aouad, G.: Integration Technologies to Support Organisational Changes in the Construction Industry. In: Proceedings of the 7th ISPE International Conference on Concurrent Engineering, Lyon, France, pp. 596–604 (2000)
11. Becker, J., Delfmann, P., et al.: Reference Modeling. Efficient Information Systems Design Through Reuse of Information Models. Physica, Berlin (2007)
12. Official ITIL® Website, `http://www.itil-officialsite.com`
13. Becker, J., Beverungen, D., Knackstedt, R., Matzner, M., Müller, O., Pöppelbuß, J.: Flexible Informationssystem-Architekturen für hybride Wertschöpfungsnetzwerke (FlexNet). In: Becker, J., Grob, H.L., Hellingrath, B., Klein, S., Kuchen, H., Müller-Funk, U., Vossen, G. (eds.) Arbeitsberichte des Instituts für Wirtschaftsinformatik (130). Institut für Wirtschaftsinformatik der Universität Münster, Münster (2011)
14. Becker, J., Beverungen, D., Knackstedt, R., Matzner, M., Müller, O., Pöppelbuß, J.: Designing Interaction Routines in Service Networks: A Modularity and Social Construction-Based Approach. Scandinavian Journal of IS (forthcoming)
15. Scheer, A.-W.: CIM. Towards the Factory of the Future, 2nd edn. Springer, Berlin (1994)
16. Becker, J., Schütte, R.: Handelsinformationssysteme. Moderne Industrie, Frankfurt / Main (2004)
17. Nissen, V., Seifert, M.: Das Consulting C - Grundzüge eines Prozessreferenzmodells für Beratungsunternehmen. In: Bichler, M., Hess, T., Krcmar, H., Lechner, U., Matthes, F., Picot, A., Speitkamp, B., Wolf, P. (eds.) Multikonferenz Wirtschaftsinformatik, pp. 1661–1674. Gito-Verlag, Berlin (2008)
18. Supply Chain Council. SCOR 10.0 Model Reference, `http://www.supply-chain.org`
19. Winter, R., Schmaltz, M., Dinter, B., Bucher, T.: Das St. Galler Konzept der Informationslogistik. In: Dinter, B., Winter, R. (eds.) Integrierte Informationslogik, pp. 1–16. Springer, Heidelberg (2008)
20. Picot, A., Reichwald, R., Wigand, R.: Die grenzenlose Unternehmung: Information, Organisation und Management, vol. 5. Gabler, Wiesbaden (2003)
21. Kagermann, H., Österle, H.: Geschäftsmodelle 2010: Wie CEOs Unternehmen transformieren. F.A.Z.-Institut für Management- Markt- und Medieninformationen, Frankfurt (2006)
22. GEFMA 100-1-2: Facility Management. Teile 1 und 2. GEFMA e.V. Entwürfe (2004-07)
23. GEFMA 198-1-2: FM-Dokumentation. Begriffsabgrenzung, Vorgehensweise, Gliederung und Instrumente. Teile 1 und 2. Entwürfe (2012-08)

24. Becker, J., Beverungen, D., Knackstedt, R., Matzner, M., Müller, O., Pöppelbuß, J.: PAS 1091. Schnittstellenspezifikationen zur Integration von Sach- und Dienstleistung. In: Deutsches Institut für Normung e.V. (eds.) Beuth Verlag, Berlin (2010)
25. Carroll, J., Swatman, P.: Structured-case: a methodological framework for building theory in information systems research. European Journal of Information Systems 9(4), 235–242 (2000)
26. Walsham, G.: Interpretive case studies in IS research: nature and method. European Journal of Information Systems 4(2), 74–81 (1995)
27. Keller, G., Nüttgens, M., Scheer, A.-W.: Semantische Prozeßmodellierung auf der Grundlage Ereignisgesteuerter Prozeßketten (EPK). In: Scheer, A.-W. (ed.) Veröffentlichungen des Instituts für Wirtschaftsinformatik, Saarbrücken, vol. 89 (1992)
28. AHO: Neue Leistungsbilder zum Projektmanagement in der Bau- und Immobilienwirtschaft. Ausschuss der Verbände und Kammern der Ingenieure und Architekten für die Honorarordnung e.V., Berlin, vol. 19 (2004)
29. AHO: Untersuchungen zum Leistungsbild, zur Honorierung und zur Beauftragung von Projektmanagementleistungen in der Bau- und Immobilienwirtschaft, 3rd edn., vol. 9 (March 2009)
30. HOAI: Verordnung über die Honorare und Leistungen der Architekten und der Ingenieure (Honorarordnung für Architekten und Ingenieure). From 17th of October 1976 (BGB1. I p. 2805, 3616) as amended by the fifth amending Official Scale of Fees for Services by Architects and Engineers from 21th of September 1995 (BGB1. I p. 1174, 1996 p. 51) (2001)
31. Scholtissek, F.-K.: Honorarordnung für Architekten und Ingenieure, Kommentar, Beck'sche Gesetzestexte: Kommentar. Beck, München (2009) (established 2010)
32. Girmscheid, G.: Angebots- und Ausführungsmanagement – Leitfaden für Bauunternehmen: erfolgsorientierte Unternehmensführung vom Angebot bis zur Ausführung. Springer vdf-Hochschulverlag, Berlin (2005)
33. AHO: Untersuchungen zum Leistungsbild und zur Honorierung für das Facility Management Consulting, 4th edn. Ausschuss der Verbände und Kammern der Ingenieure und Architekten für die Honorarordnung e.V., Berlin (2010)
34. Mayring, P.: Einführung in die qualitative Sozialforschung – eine Anleitung zu qualitativem Denken, 5th edn. Beltz, Weinheim (2002)
35. Lamnek, S.: Qualitative Sozialforschung: Lehrbuch, 4th edn. Psychologie-Verlags-Union, Weinheim (2005)
36. Becker, J., Beverungen, D., Knackstedt, R., Matzner, M., Müller, O., Pöppelbuß, J.: Bridging the Gap Between Manufacturing and Service Through IT-Based Boundary Objects. IEEE Transactions on Engineering Management (forthcoming)
37. DIN 18205: Bedarfsplanung im Bauwesen. Normenausschuss Bauwesen (NABau) im DIN Deutsches Institut für Normung e.V. Beuth Verlag, Berlin (1996)

Systematic Approach to Formulate PSS Development Project Proposals in the Fuzzy Front End

Ana Paula B. Barquet[1], Daniela C.A. Pigosso[2], and Henrique Rozenfeld[1]

[1] Department of Production Engineering, University of São Paulo,
Av. Trabalhador São-Carlense, 400 - São Carlos, SP 13566-590, Brazil
[2] Institute of Mechanical Engineering, Technical University of Denmark,
Produktionstorvet Bygning 426, 2800 Lyngby, Denmark
{anabarquet,daniela.pigosso}@gmail.com, roz@sc.usp.br

Abstract. Product-service systems (PSS) adoption has increased over the last years due to its potential for innovative value creation. However, the identification of ideas and opportunities in the innovation planning and the structuring of PSS projects are still incipient in organizations, following the same patterns adopted for product development. Currently, there is not a systematic approach that can be followed for the formulation of PSS proposals in the fuzzy front end. Therefore, the aim of this research is to develop a method for defining PSS project proposals based on attributes that should be considered by companies during this definition. The systematization of PSS attributes may help increase the knowledge about different PSS projects that can emerge in the front end, thus leading to the discovery of opportunities that are not apparent in the existing business models and give rise to new ideas that can be translated into successful projects.

Keywords: Product-Service System, Fuzzy front end, Proposal, Attributes.

1 Introduction

Growing competitiveness and market demands drive companies to seek new ways to create and deliver value to their customers. In this regard, the Product-Service System – PSS approach has been suggested as an alternative for companies seeking to consider these aspects in their business.

The PSS can be considered an alternative for companies seeking innovation in their business, since its development requires changes or the creation of new business. In PSS, the paradigm of developing solutions only in the form of physical products to be sold must be broken, because value is not necessarily provided through the sale of the physical product, but instead, by means of the functionality or result it can generate. This form of offering value differs from the way in which the traditional business model of companies is structured, which involves only the development and sale of physical products [1].

Thus, one of the major changes involves the context in which PSS is developed, which goes beyond product development to also encompass the strategy and

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 121–130.
DOI: 10.1007/978-3-642-30820-8_11

development of the business [1]. However, manufacturing companies aiming to adopt PSS already develop products and should also include product project dimensions in their PSS proposals. Innovation, which may involve products [2], technology [3] or knowledge about a product and a customer base [4], can be considered a dimension of the product project.

Each of these dimensions also encompasses characteristics, which, in turn, comprise attributes with different values. For instance, innovation (dimension) may involve a product (characteristic). Product innovation may be market-focused (attribute) or customer-focused (attribute) [5]. Figure 1 illustrates the hierarchy of the aforementioned items.

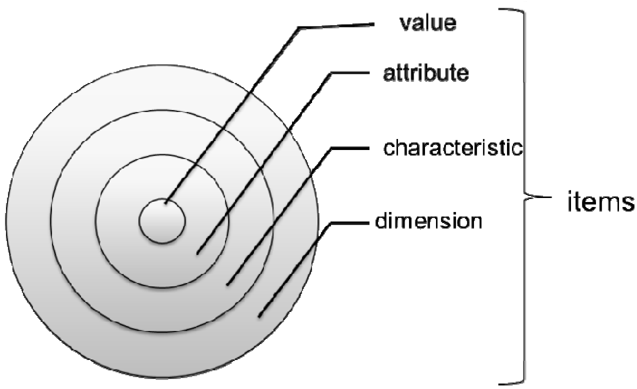


Fig. 1. Hierarchy among the items

Table 1 describes the hierarchy among the items: dimension, characteristics, attributes and values for the example given above.

Table 1. Hierarchy between items of the product project

Dimension	Characteristic	Attribute	Values		
Innovation	Product innovation	Market-focused product innovation	low	intermediate	high
		Customer-focused product innovation	low	intermediate	high

In addition to differentiating PSS offerings, these items can be used for the preparation of PSS proposals, since they can serve to characterize these proposals and facilitate the determination of the scope and efforts required to develop the PSS. To this end, some of the items (dimension, characteristics, attributes and values) must be known before starting to develop a PSS at the front end. However, the literature does not provide sufficient information about how to prepare PSS proposals, which hinders its adoption and may be one of the reasons for its limited implementation by companies [6, 7].

PSS development requires the holistic and multifunctional vision indicated by Jetter [8]. Structuring PSS proposals based on their characteristics and attributes can make it easier to understand them from the business standpoint, as suggested in the literature [9, 10, 1, 11, 12]. Within this context, the aim of this research is to develop a tool for defining PSS project proposals that considers items of the product project and of PSS.

2 Literature Review

2.1 Characteristics of the Fuzzy Front End

The front end encompasses the activities performed prior to the development of technologies, products and/or services or new business [13], starting from the identification of an idea or opportunity and ending when the company approves the development of the project [14].

A strong characteristic of the front end is uncertainty, according to Jetter [8] and Koen et al. [15]. The uncertainties and dynamism of the information required and generated during the front end make it difficult to adopt a structured approach to manage this process [16]. Therefore, the process-oriented approach to study complex processes, which is the case of the front end, is not always considered the most suitable one. Some authors suggest an information processing approach, also known as the uncertainty reduction approach [17], to be used in the front end. In this approach, the focus is on the analysis of information that is processed throughout the front end. This information therefore assumes a primary role, while the activities assume a secondary role. Therefore, the information processing approach assumes that at the beginning of the process there is zero knowledge about this information and that, at the end of the process, there will be complete knowledge about the information [18].

It should also be noted that, despite the extreme importance of the front end to the performance and success of the product and service innovation process [19, 14], this process usually involves a small team or only one person [15]. This fact may influence decisions made during the front end, because of the possible lack of knowledge about given functional areas to underpin the most suitable decision. In this regard, Moenaert et al. [17] mention the importance of creating innovation teams composed of people from different functional areas, who know where to look for information or who possess information from different sources and areas of knowledge, thereby reducing the uncertainties. Information about the newness of the market, the technology and the product would be known and used during the front end, which would help in creating more robust and complete project proposals and would thus increase the chances of assertiveness in the approval of development proposals.

2.2 PSS Perspectives

Tan [1] defines PSS as a new approach that integrates activities and competences of an organization, and intensifies its relationship with clients and partners in the value chain. Like Manzini and Vezzoli [20], Tan [1] believes that the development of PSS represents an expansion of the scope of the product development process (PDP). PSS involves different areas of expertise, each of which addresses PSS from a different perspective [1]. Thus, this paper addresses PSS according to three perspectives adapted from those suggested by Tan [1], all of them from the point of view of PSS providers. These perspectives are:

- PSS Proposals: are created in the front end, based on new ideas and strategies.
- PSS Development: begins when a PSS proposal is approved for development. At the product project level, it encompasses the activities of planning, design, detailing, product manufacturing and service offering, as well as the activities that occur during the product's life cycle. However, PSS development o should be treated as an expansion of the scope of the product development process by also considering the development of the business. Thus, the development of the business, the design of the PSS, and the execution of the PSS project are addressed within the ambit of PSS development. The result of PSS development is PSS offerings.
- PSS Offerings: are the combined service and product options that are offered and supplied to clients.

Figure 2 illustrates the three PSS perspectives addressed in this paper.

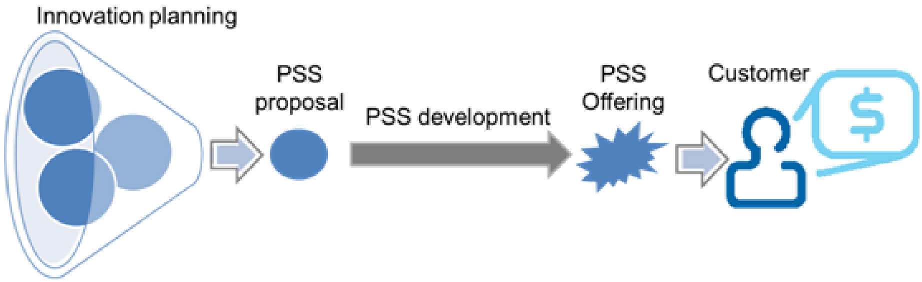


Fig. 2. PSS perspectives

3 Methodology

The steps defined for the construction of the tool are: identification of items, systematization of items, and definition of the relationship between the attributes.

3.1 Identification of the Items

To identify the items, two Systematic Literature Reviews (SLR) were performed, one involving product project literature and the other PSS-related literature. SLR is a technique used for mapping published papers about a particular theme, to assist in the preparation of summaries about existing knowledge of the subject [21].

3.2 Systematization of the Items

To compile and organize the product project and PSS items identified in the SLR involves several tasks: arrange the characteristics and attributes of the product project and of PSS and define the hierarchy among the items after making this arrangement. The result of the systematization of the items is a conceptual framework of PSS, with defined dimensions, characteristics and attributes.

3.3 Definition of the Relationships between Attributes

This activity involves defining the relationships of dependence between attributes, using the Design Structure Matrix (DSM) method, which focuses on the representation of information flow rather than of workflow [22]. Thus, the DSM method is according consistent with the information processing approach. The first step in the method is to enter the elements in a binary matrix with identical rows and columns. An analysis of the rows indicates to which elements that element provides something. An analysis of the columns, in turn, indicates which other elements in that column depend on a given element. Thus, the columns indicate input sources and the rows indicate outputs [23].

In the first step, the attributes of the PSS conceptual framework are used as elements. In the second step, the attributes are entered in a square matrix and relationships between them are defined, thus generating the relationship matrix. Following the steps of the method, the partitioning procedure is performed by means of the topological sorting algorithm, which determines the sequence of the attributes. Knowing the sequence of the attributes is essential to indicate the order of their selection by the PSS Proposal Configuration tool. This sequencing can be used to guide the selection of attributes and their values during the front end, assisting in the preparation of PSS proposals.

4 PSS Proposal Configuration Tool

The tool proposed in this work is called a PSS Proposal Configuration Tool. The items (dimensions, characteristics, attributes and values) that comprise the tool are identified below.

4.1 Identification of the Items

Items of Product Development Projects. The characteristics and attributes found in the literature on product project were classified according to the following dimensions: Projects, Knowledge and competence, External actors, Innovation, Complexity, and Environmental aspect. Table 2 exemplifies the attributes of the characteristic "project management," which refers to the dimension "Projects."

Table 2. Example of product project items

Dimension	Characteristic	Attribute	Values				Authors
Project	Project management	**Project management style**	Client-oriented	Process-oriented	Contract-oriented		[24]
		Project size	Low	intermediate	high		[25]
		Type of project manager	Project coordinator	Supervised project coordinator	Autonomous project manager	Supervised functional project manager	[26]

In all, the items of product project comprise 6 dimensions, 30 characteristics and 110 attributes. Thus, these are the 146 items that were found in the SLR on product project items.

PSS Items. Unlike the findings on product project, the characteristics found in the PSS typologies are at the business level. This fact is consistent with several works in the literature [1, 10] and led to the need to classify the PSS characteristics and attributes according to dimensions of business models, which are: value proposition, partnerships, relationship with the client, cost structure, revenue model, distribution channel, market segment, processes and activities and resources [27]. Table 3 lists the attributes of the characteristic "product ownership," which refers to the dimension "Relationship with the client."

Table 3. Example of PSS items

Dimension	Characteristic	Attribute	Values			Authors
Relationship with the client	Product ownership	**PSS ownership**	Transferred to the buyer/ client	Retained by the provider		[28]
		Transfer of product ownership	After delivery/ purchase	Returns to the company at the end of life	Is never transferred – ownership belongs to the company	[10]

In all, 9 dimensions were identified, encompassing 19 characteristics and 52 attributes. The 80 PSS items were identified in the SLR about PSS items. At this point, some comments are pertinent regarding the items found in the literature on product project and PSS. It was found that the product project items are not studied within the ambit of PSS and vice-versa. While most of the characteristics of the product project are at the product level, most of the PSS characteristics are at the business level. Nevertheless, both points of view should be considered in PSS proposals.

4.2 Systematization of the Items

The items of the product project and PSS were integrated in two steps: Analysis and search for a relationship between items of the product project and PSS, and preparation of a PSS conceptual framework, which is presented in Figure 3.

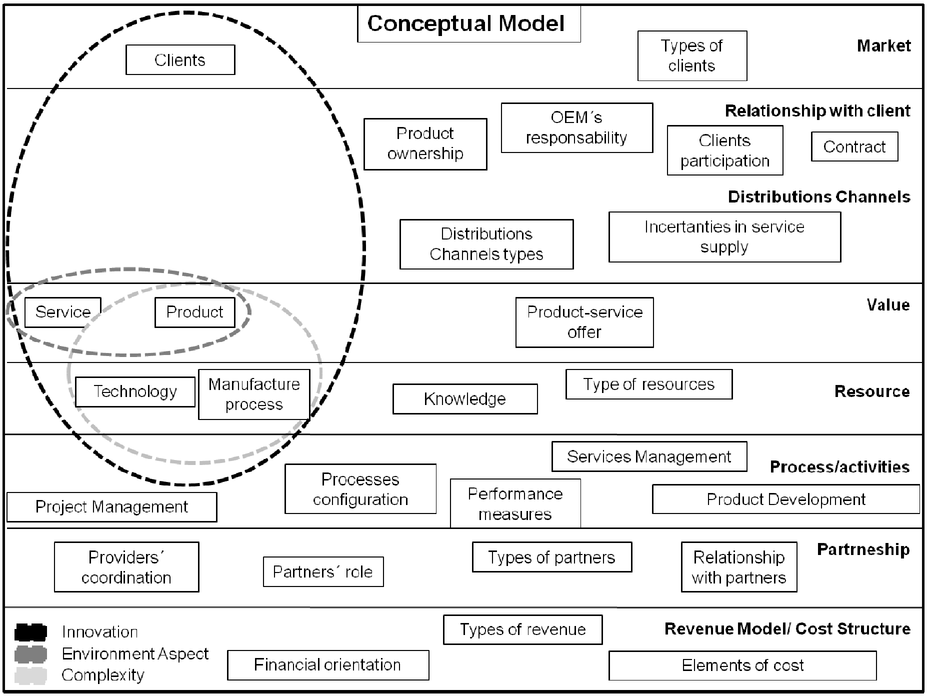


Fig. 3. PSS conceptual framework

The analysis of relationships between items led to the relocation of some attributes and changes in characteristics. This analysis supported the creation of the PSS conceptual framework.

The PSS conceptual framework has 9 dimensions, 32 characteristics and 134 attributes. Part of the PSS conceptual framework is illustrated in Figure 3 and shows only the dimensions and characteristics. The dimensions are represented on the right side of the figure and they are: Market, Relationship with client, Distribution channels, Value, Resources, Process/ activities, Partnership, Revenue Model and Cost

Structure. Each of these dimensions cover at least two characteristics. For example, the characteristics of the Market dimension are: Types of clients and Innovation on Client Segment.

The three circles inside the framework indicate aspects that encompass more than one characteristic. These aspects are innovation, environmental aspect and complexity. Therefore, the framework embraces the following characteristics for complexity aspect: Product Complexity, Technology Complexity and Manufacture Process Complexity. Regarding environmental aspect, the characteristics generated are: Environmental Aspect of Service and Environmental Aspect of Product. Lastly, innovation aspect resulted in some characteristics, such as: Product Innovation, Service Innovation, Technology Innovation, Manufacture Process Innovation and Innovation on Client Segment.

4.3 Definition of the Relationship between Attributes

Construction of the DSM. The next step in the construction of the PSS Proposal Configuration Tool consisted of the analysis of the relationships between the attributes, in order to define the flow of attribute selection. These relationships were defined using the Design Structure Matrix (DSM) method, which allows for the creation and analysis of relationship matrices [23]. The first step of the DSM method is the identification of attributes. This was possible by means of the previous steps: identification and systematization of the items. The 134 identified attributes were entered in the first column and the first row of the matrix. Then, the relationships of each row with each column were analyzed, in order to identify the relationship between the attributes, as mentioned in section 2 – Methodology.

Sequencing between Attributes. The relationship matrix was analyzed using the Excel Macros for Partitioning and Simulation tool [29]. This tool consists of an Excel spreadsheet that contains a specific macro for entering the attributes and relationships and for analysis of the matrix. First, to determine the sequence of the attributes, the Partitioning analysis was performed, whose objective is to resequence the attributes of the matrix so as to maximize the availability of the required information [30]. The partitioning analysis indicates the sequencing of attributes that will be used to define the flow of attribute selection and then to conclude the creation of the method.

4.4 Comments about the Method

The PSS Proposal Configuration Tool proposed here aims to support organizations in the creation of PSS proposals. Based on a list of attributes with different values, innovation teams can reflect about the creation of a PSS proposal during the front end. In addition, the attributes of the configuration tool originate from different areas of knowledge, taking into account the systemic vision to be considered in the front end. Thus, it is suggested that the innovation team be composed of people from different functional areas. Based on the information processing approach, the values of the attributes are selected as the information and knowledge of the innovation team increase. The more values that are selected the greater the knowledge of the team and the closer they will be to completing the front end and defining the PSS proposal.

5 Conclusions

This paper discusses the development of a tool to support the creation of PSS proposals. The information of both product and business project give the content of the tool a holistic character. Moreover, the tool's content considers a multifunctional vision. In this regard, the creation of front end innovation teams is proposed, since the use of the tool requires knowledge of different functional areas, which increases the wealth of information used in the definition of PSS proposals.

The use of the DSM method was considered a systematic way to seek the relationships and organize the attributes according to the information processing approach. The next steps in this work include consultations with experts to evaluate the sequencing of the attributes defined by the DSM method, as well as the development of a software program to automate the tool and apply it at companies, aiming to evaluate its practical use.

Acknowledgments. The authors would like to extend sincere thanks to CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) for supporting this research.

References

1. Tan, A.R.: Service-oriented product development strategies. Technical University of Denmark, DTU (2010)
2. Wheelwright, S.C., Clark, K.B.: Revolutionizing product development quantum leaps in speed, efficiency, and quality. Macmillan, New York (1992)
3. Tatikonda, M.V., Rosenthal, S.R.: Successful execution of product development projects: Balancing firmness and flexibility in the innovation process. Journal of Operations Management 18, 401–425 (2000)
4. Danneels, E.: The Dynamics of Product Innovation and Firm Competences. Strategic Management Journal 23(12), 1095–1121 (2002)
5. Booz, A & H: New Products Management for the 1980s. Booz, Allen & Hamilton, New York (1982)
6. Sakao, T., Sandström, G.Ö., Matzen, D.: Framing research for service orientation of manufacturers through PSS approaches. Journal of Manufacturing Technology Management 20(5), 754–778 (2009)
7. Kuo, T.C., Ma, H.-Y., Huang, S.H., Hu, A.H., Huang, C.S.: Barrier analysis for product service system using interpretive structural model. The International Journal of Advanced Manufacturing Technology 49(1-4), 407–417 (2010)
8. Jetter, A.J.M.: Educating the guess: strategies, concepts and tools for the fuzzy front end of product development. In: Proceedings of Portland International Conference on Management of Engineering and Technology Technology Management for Reshaping the World, pp. 261–273. Portland State Univ. (2003)
9. Meier, H., Massberg, W.: Life Cycle-Based Service Design for Innovative Business Models. CIRP Annals - Manufacturing Technology 53(1), 393–396 (2004)

10. Tan, A.R., McAloone, T.C.: Characteristics of Strategies in Product-Service-System Development. In: Proceedings of the 8th International Design Conference, Dubrovnik, Croatia, pp. 1–8 (2006)
11. Tischner, U., Verkuijl, M., Tukker, A.: Product Service Systems: best practice document, p. 133 (2002)
12. Mont, O.: Clarifying the concept of product – service system. Journal of Cleaner Production 10, 237–245 (2002)
13. Koen, P., Ajamian, G., Burkart, R., et al.: Providing clarity and a common language to the fuzzy front end. Research-Technology Management 44(2), 46–55 (2001)
14. Cooper, R.G.: Winning at New Products: Accelerating the Process from Idea to Launch, 3rd edn. Perseus, Cambridge (2001)
15. Koen, P.A., Ajamian, G.M., Boyce, S., Clamen, A., Fisher, E., Fountoulakis, S., Johnson, A., Puri, P., Seibert, R.: Fuzzy Front End: Effective Methods, Tools and Techniques. In: Belliveau, P., Griffin, A., Somermeyer, S. (eds.) The PDMA ToolBook for New Product Development 1, p. 480 (2002)
16. Murphy, S.A., Kumar, V.: The front end of new product development: a Canadian survey. R&D Management 27(1), 5–15 (1997)
17. Moenaert, R.K., De Meyer, A., Souder, W.E., Deschoolmeester, D.: R&D/marketing communication during the fuzzy front-end. IEEE Transactions on Engineering Management 42(3), 243–258 (1995)
18. Oliveira, M.G., Phaal, R., Probert, D., Cunha, V.P., Rozenfeld, H.: Int. J. Technology Intelligence and Planning 7(4), 309–326 (2011)
19. Griffin, A.: Research on New Product Development Practices: Updating Trends and Benchmarking Best Practices. Journal of Product Innovation Management 14, 429–458 (1997)
20. Manzini, E., Vezzoli, C.: A strategic design approach to develop sustainable product service systems: examples taken from the "environmentally friendly innovation" Italian prize. Journal of Cleaner Production 11, 851–857 (2003)
21. Biolchini, J., Mian, P.G., Natali, A.C.C., Travassos, G.H.: Systematic review in software engineering, p. 31 (2005)
22. Yassine, A.A.: An Introduction to Modeling and Analyzing Complex Product Development Processes Using the Design Structure Matrix (DSM) Method (2004)
23. Browning, T.R.: Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions. IEEE Transactions on Engineering Management 48(3), 292–306 (2001)
24. Twigg, D.: Managing product development within a design chain. International Journal of Operations & Production Management 18(5), 508–524 (1998)
25. Lakemond, N., Van Echtelt, F., Wynstra, F.: A configuration typology for involving purchasing specialists in product development. Journal of Supply Chain Management 37(4), 11–20 (2001)
26. Lechler, T.G., Dvir, D.: An Alternative Taxonomy of Project Management Structures: Linking Project Management Structures and Project Success. IEEE Transactions on Engineering Management 57(2), 198–210 (2010)
27. Osterwalder, A., Pigneur, Y.: Business Model Generation, p. 278 (2009)
28. Gao, J., Yao, Y., Zhu, V.C.Y., Sun, L., Lin, L.: Service-oriented manufacturing: a new product pattern and manufacturing paradigm. Journal of Intelligent Manufacturing 22, 435–446 (2011)
29. DSM. Design Structure Matrix. DSMweb.org (2012) (accessed August 4, 2012)
30. Gebala, D.A., Eppinger, S.D.: Methods for analyzing design procedures. Design Theory and Metodology 31, 227–233 (1991)

Timing and Targeting of PSS Methods and Tools: An Empirical Study amongst Academic Contributors

Hector Nøhr Hinz, Niki Bey, and Tim C. McAloone

Department of Mechanical Engineering, Technical University of Denmark,
Kgs. Lyngby, Denmark
{niki,tmca}@dtu.dk

Abstract. The emergence of product/service-systems has meant that development methods for such systems have emerged from academia. This paper investigates existing methods that are aimed at developing product/service-systems. Two aspects are determined for each examined method. The first aspect that has been surveyed is *when* a given method is meant to be used in the development of a product/service-system. This aspect has been determined through a qualitative assessment of each method. The second aspect surveyed is *which persons* in an organisation who are seen as the main drivers in the use of the methods. To gain this insight a questionnaire for each method has been conducted with the authors of the methods as participants. The main finding indicates that current PSS methods cannot thoroughly support the development of product/service-systems as their specificity is too low and that the methods need strong intra-organisational collaboration or even roles that do not yet exist.

Keywords: product/service-systems, methods, design, organisation.

1 Introduction

Product/service-systems (PSS) are integrated offerings of products together with services such as repair, maintenance, training or even operation of products. Furthermore the company can have the responsibility of disposing of the product, when it is no longer useable for the customer. In a world with increased competition and scarce resources product/service-systems have come to be seen as a possible way to counter these challenges, if done well. Such integrated offerings mean that a company and its customer will have a transactional relationship that lasts beyond mere product sale. Companies that successfully embrace PSS can have a stable source of revenue and tight ties with their customers, while also having an incentive to make their products as efficient as possible. At the same time, the customer can have stable access to the utility that the products bring, without having to deal with the inconveniences associated with owning a product [1].

When a company wants to offer PSS to its customers it will need to be able to coordinate the features of its products with the services it can provide. Therefore PSS calls for the collaboration between organisational units that concentrate on research and development of products with those units in an organisation that develop and

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 131–139.
DOI: 10.1007/978-3-642-30820-8_12

provide services. Also, PSS requires a company to coordinate with its suppliers, because its ability to provide products, maintenance and other services is also very often dependent on its suppliers [2]. In other words the design of PSS represents an extension of the design activities, when compared to product design [3]. As a research field PSS is still relatively immature, when comparing to traditional product development; there is still a lack of understanding of how PSS should be designed. Based on this insight, the aim of this paper is twofold: First to show where a number of PSS development methods are to be used within a generic PSS development process and use this to analyse the state of existing PSS methods in general; Secondly to investigate who the intended users of the methods are, who are seen as the main drivers of PSS development and what this says about the usability of the methods.

In the following section the methodology of the paper is explained, a definition of what constitutes a method is presented and a general framework for PSS development is established. The analysis gives a short summary of the methods that have been investigated, shows which part of the general PSS development framework each of the methods is suited to and shows who the intended users of the methods are, along with a brief explanation of the authors' view on who should drive PSS development. The discussion comments on the characteristics of PSS development methods and on what the intended users of the methods says about PSS development in general. Finally the conclusion picks up on the work that has been carried out and the results that have been presented.

2 Methodology

In this paper seven development methods are examined with regards to when in a PSS development process they are used and which persons who are going to use them. In order to select development methods for further analysis a definition of what constitutes a PSS method was defined. To be able to assess when the methods are used in a development process, a general framework of PSS development was established, so each method could be compared with it. Thus the goal of the PSS development framework is not prescriptive, but descriptive.

2.1 Definition of a Method

The definition of a method that has been used in this paper is the following: A method is a collection of connected activities that have a finite span in time. By a collection of connected activities is meant that a method consists of a sequence of activities, either in parallel or serial that gives output to another activity until the end activity. For example investigating customer needs is an activity but not a method. The same could be said about formulating requirements for a system. Furthermore investigating customer needs and formulating requirements is not part of a method as long as they are not connected. It is a method only if the output of an investigation of customer needs is used as a basis for formulating system requirements. The span in time is understood such that sequence of activities end at some defined point. When product in use data is collected as means for informing a design process that ends up with a new PSS that is regarded as a method, but when product-in-use data is continuously used to adjust maintenance schedules it is not regarded as a method, but as a running process.

The definition of what constitutes a method has meant that the analysis has included a number of works that have not specifically been labelled as 'methods' by their authors. Furthermore the definition does not in itself deal with the specificity of methods. That is, methods can have a broad scope, such as creating an operational strategy for a PSS or have a more narrow focus as for example a detailed method for the investigating user needs. The specificity of the methods is analysed by comparing them to the general framework of PSS development.

2.2 A General Framework of PSS Development

The framework of PSS development has been created on the notion that since PSS is not a one-time delivery, but a continuous interaction with the customer expanded in the time domain [3]. As such it is possible for a company to keep on altering both products and services even after the customer has begun to receive the offering. The framework is based on the phases found in [4]. It unites some of the phases that are similar and adds a phase called 'tactical considerations' in order to catch the activities that lie between the strategic decision to work with PSS and design of a PSS. The framework is shown in figure 1.

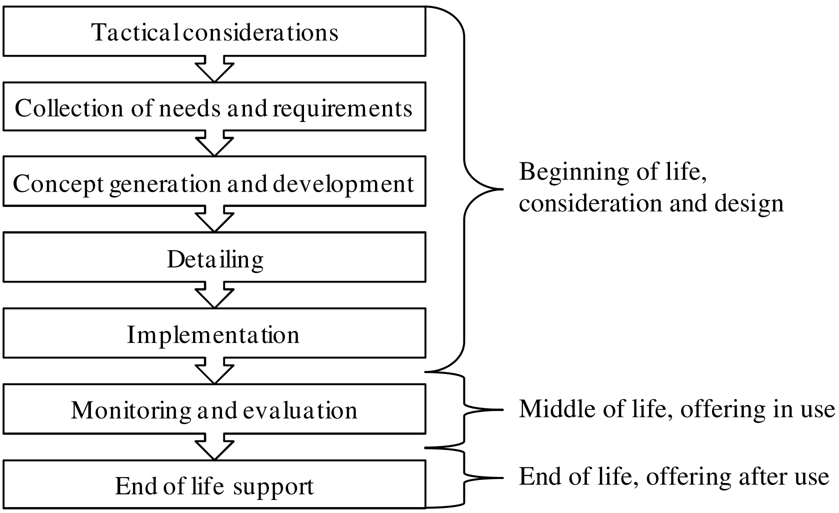


Fig. 1. General framework for PSS development, based on [4]

2.3 The Selected Methods

The methods that have been surveyed have been chosen on the basis of earlier work conducted that has analysed the research of PSS research clusters. The selected methods are either built on existing methods for product development, like Müller and

Stark, Ericson et al. and Matzen and McAloone [5-7], new methods focused on conceptualising PSS in the case of Hussain et al. and Vasantha et al. [8-9], or methods that deal with data collected in a PSS solution, which is the case for Seliger et al. and Sakao and Shimomura [10-11].

The assessment of where each of the methods fit into the general development framework has been achieved by analysing the content of each of the papers that describe the method. The mapping of the intended users of each of the methods has been achieved by conducting a survey with the authors of the papers. The survey consisted of the following three questions:

1. Which persons or departments in an organisation did you wish to target when you developed the method?
2. Did you get input from any persons in companies that are not mentioned in the paper? If so from whom?
3. Which persons or departments in an organisation do you see as the most important drivers for the development of PSS?

Where possible the first authors have been used as main contacts and sources for the survey, otherwise other authors have been contacted and surveyed. The authors have either replied in writing or through telephone interviews.

3 Analysis

3.1 Placement of Methods in Time

In the following each of the investigated methods are analysed with regards to which phases in the general framework for PSS development they follow. This is done by going through each of the methods and justifying how different parts of them fit into one or more of the general activities of the general framework. Even though none of the methods cover all of the activities in the general framework it is not the same as the existence of these activities is deemed unimportant or unnecessary in the methods. It rather demonstrates the specific focus of the methods. In addition to the assessment of the activities covered it is also explained whether an existing system is a requirement for the use of the methods.

The Activity Cycle Model of Matzen and McAloone is a method that makes its users analyse a market situation in order to generate a number of so called views that shows the needs of a customer along with the activities that supports these requirements and the actors that are involved with fulfilling the requirements. Thus the method guides its users to do some early tactical considerations about the actor-network that surrounds the customer without considering the users and their company's own role. Furthermore the identification of needs can be seen as part of collecting requirements. Later on the views are used as input for developing offerings and suggesting network collaborations, which can be considered concept generation and development.

The method for PSS design demonstrated by Ericsson et al. presents a model with five steps for developing PSS where four of the steps are related to modules that are used in the product development system, TRIZ. The first two steps are to identify needs and identify product characteristics, which corresponds to collection of needs and requirements. The last three steps are all concerned with concept generation and development. The method does not take any input from an existing system.

The model from Hussain et al. is generally applicable to systems where performance needs to be improved. It looks upon an existing system where gaps between customer requirements and the systems capability is first identified by using service blueprints as a mapping method. Thus the method deals with collection of needs and requirements. Then a proposals matrix is used to present and analyse solutions which can service to close the gap between the customer requirements and the PSS capabilities, which in turn represents concept generation and development.

The method of Vasantha et al. presents a number of activities needed to do development of PSS. It is stressed that even though the activities are presented in a serial sequence this is only done for simplicity. In reality all of the activities are interconnected and therefore give output to each other, except for the signing of a contract, which is the final activity that only receives inputs. Two of the activities are concerned with identifying the customer's needs and what is required to meet these needs, which is collecting requirements. Other activities are to identify which tasks are needed to fulfil the customer's needs at both the company that mainly delivers to the customers, as well as at the suppliers, and these are in turn concept generation and development. Finally some of the activities are concerned with developing business models, relegating responsibilities and evaluating solutions, which are regarded as detailing.

Sakao & Shimomura's method starts out by establishing a model that shows the interactions among high-level actors (e.g. companies) based on an existing system. Thus this method actually starts out with what can be regarded as concept generation and development before establishing a number of customer preferences that are equivalent to collection of needs and requirements. In the end the interactions between high level actors is elaborated on further by generating a so called realisation structure which corresponds to detailing, before finally modifying the high-level model to reflect any changes that have been made.

The approach presented by Müller & Stark, which according to the authors should be seen as work in progress, consists of a method based on a product development model. It consists of a number of activities from the initial project planning to the delivery of the PSS, with some parallel activities in the method, where development of services, products and systems take place concurrently. Together all of the activities in the method deal with the collection of needs and requirements, generation and development, detailing and implementation.

The methods that Seliger et al. show are built upon an already existing PSS, where the product has been fitted with equipment used for measuring the behaviour and the performance of the product. The data that are generated are then treated though a number of activities that prepare the data for being used for developing the PSS further. Together these activities constitute monitoring and evaluation.

As it can be seen from the above, a number of activities are covered in the general development framework. A summary of the distribution of covered activities can be seen in Table 1.

Table 1. Activities covered by the seven methods

	Tactical considerations	Collection of requirements	Concept generation and development	Detailing	Implementation	Monitoring and evaluation	End-of-life support	Uses existing system
Matzen and McAloone	•	•	•					
Ericsson et al.		•	•					
Hussain et al.		•	•					†
Vasantha et al.		•	•	•				
Sakao and Shimomura		•	•	•				†
Müller & Stark		•	•	•	•			
Seliger et al.						•		†

3.2 Users of the Methods

In order to provide an understanding not only of the characteristics of the methods but also of their users it was investigated, who were the intended users of the methods, by conducting brief interviews with the authors of the papers, describing each of the methods. For each of the methods a description of the intended users has been received. Along with information of the users the authors have provided information about who have given input to their work in addition to those mentioned in their papers. Thus it is possible to understand the background of the methods. Finally an appraisal of who should be the drivers of PSS development in general was given, which provided a view of the general understanding of the PSS development process in academia. The information that has been gathered is collected in Table 2.

When it comes to the intended users of the methods most of the authors point to a either people or teams with trans-disciplinary competencies or towards a group of people that together form a collection of competencies. With regards to the Systems Engineer and the PSS Architect the authors specifically pointed out, that these roles hardly exist in any companies. As for the sources used for inputs for the methods the answers also shows a lot of different roles have been utilised. With regards to the drivers of PSS the authors mostly point to the managers especially in the beginning of development. In the cases where management is only seen as the initial driver, the authors point to some kind of trans-disciplinary role to take over.

Table 2. Overview of intended users, sources for method and main drivers of PSS development

	Intended users of the method	Sources used for method	Main drivers of PSS development
Matzen and McAloone	Marketing Transdisciplinary teams	Student course Bachelor project Later tried in a number of companies	Initially management, later an independent organisation
Ericsson et al.	R&D Engineers Innovation teams in Advance Engineering or NPD	none	The whole company as PSS is holistic
Hussain et al.	Any stakeholder in any department or industry	Five senior managers in a manufacturer of aero engine components and aero engines Fifteen maintenance experts in various companies	The issues that the customer has in creating their own system Managers
Vasantha et al.	Ideally Systems Engineers working across departments But the framework is meant to be generic	Maintenance Engineers, Maintenance Managers, Maintenance Technicians, Business Managers, Process Developers and Sales People	Business Developers Sales Engineers Contract Promoters
Sakao and Shimomura	Manager of Product Development, Manager of Business Strategy Development, Product Developer, Service Developer, Management Executive in SME	Ministry workers who are working for business cultivation for SMEs and local industries Two company cases	Manager of Business Strategy Development
Müller and Stark	Ideally a 'PSS Architect', but the framework is meant to be generic	Interviews in 13 German companies with various roles. Later experiences have supported the results	Initially management Later ideally a 'PSS Architect'
Seliger et al.	A design team mainly with engineers - knowledge of service is needed in the team	*No answer obtained and no input described in paper*	Initially management but later the design team

4 Discussion

As it can be seen from the analysis of the placement of methods in time, all but one of the methods deal with collection of needs and requirements and concept generation and development, while detailing is touched upon by three of the methods. Contrary to this is the remainder of the activities that are either only treated by one method or not treated at all, as is the case with end-of-life support. This indicates that the existing methods for PSS development are still not able to support the development process in all of the phases. This does not mean that the quality of the methods is insufficient though. They might do what they are supposed to do very well and a discussion of the quality of the methods is out of scope of this paper. Rather, the lack of support for some of the activities could indicate that there is a lack of detailed knowledge within PSS research about how these activities should be properly supported and that the specificities of the existing methods are generally low. Furthermore the methods are generic in relation to the characteristics of the PSS solution that has to be developed. In other words, while being generic is certainly part of the point of using a method, it is still noticeable that none of the methods relate to different types of PSS, as for instance found in [12].

A general theme throughout the interviews with the authors is that of trans-disciplinary collaboration. It is a recurring theme within PSS research that the development requires collaboration across different functions in a company. Furthermore some of the authors point towards the need for somebody with a role that spans all involved departments, to use the methods or drive the PSS development. As it has been pointed out this role is rarely found in the companies that work with PSS. This means that there is a risk that some of the advantages of using these methods might be deteriorated by the companies' structures that makes them unable to use the methods in the best possible way.

5 Conclusion

Seven methods have been investigated by comparing them to a general framework of PSS development and by interviewing their authors about the intended users of the methods. The knowledge this has generated has been used as a basis for an evaluation of the state of PSS development methods. The results indicate that most PSS methods have a low amount of specificity, are highly generic and mostly concentrate of formulating needs and requirements as well as conceptualisation. There is a lack of methods that can support the development of PSS throughout the development process. The methods investigated are mostly meant to be used across a number of disciplines, which either calls for strong collaboration across departments or the introduction of new roles in the companies that use them.

References

1. Tan, A.: Service-oriented product development strategies. Technical University of Denmark, Kgs. Lyngby (2010)
2. Bastl, M., Johnson, M., Lightfoot, H., Evans, S.: Buyer-supplier relationships in a servitized environment: An examination with Cannon and Perreault's framework. International Journal of Operations & Production Management 32, 650–675 (2012)

3. Matzen, D., Tan, A., Andreasen, M.M.: Product/Service-Systems: Proposal for Models and Terminology. In: Design for X: Beiträge zum 16. Symposium, pp. 27–38. Lehrstuhl für Konstruktionstechnik, Neukirchen (2005)
4. Cavalieri, S., Pezzotta, G.: Product–Service Systems Engineering: State of the Art and Research Challenges. Computers in Industry 63, 278–288 (2012)
5. Müller, P., Stark, R.: A Generic PSS Development Process Model Based on Theory and Emprirical Study. In: Proceedings of the 11th International Design Conference, DESIGN 2010, pp. 361–370. University of Zagreb, Dubrovnik (2010)
6. Ericson, Å., Bertoni, M., Larsson, T.: Needs and Requirements – How TRIZ may be Applied in Product-Service Development. In: Proceedings of the 2nd Nordic Conference on Product Lifecycle Management – NordPLM 2009. Chalmers University of Technology, Göteborg (2009)
7. Matzen, D., McAloone, T.: A Tool for Conceptualising in PSS development. In: Design for X: Beiträge zum 17. Symposium, pp. 131–140. Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen (2006)
8. Hussain, R., Lockett, H., Vasantha, G.: A framework to inform PSS Conceptual Design by using system-in-use data. Computers in Industry 63, 319–327 (2012)
9. Vasantha, G.V.A., Hussain, R., Roy, R., Tiwari, A., Evans, S.: A Framework for Designing Product/service-systems. In: Proceedings of the 18th International Conference on Engineering Design, ICED 2011, pp. 67–76. Technical University of Denmark, Copenhagen (2011)
10. Seliger, G., Gegusch, R., Müller, P., Blessing, L.: Knowledge Generation as a Means to Improve Development Processes of Industrial Product/service-systems. In: Manufacturing Systems and Technologies for the New Frontier the 41st CIRP Conference on Manufacturing Systems, pp. 519–524. Springer, London (2008)
11. Sakao, T., Shimomura, Y.: Service Engineering: a novel engineering discipline for producers to increase value combining service and product. Journal of Cleaner Production 15, 590–604 (2007)
12. Tukker, A.: Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. Business Strategy and the Environment 13, 246–260 (2004)

Increased Raw Material Efficiency through Product-Service Systems in Resource-Intensive Production Processes? Barriers, Chances and an Assessment Approach

Katharina Mattes, Esther Bollhöfer, and Michael Miller

Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Strasse 48, 76139 Karlsruhe, Germany
{k.mattes,e.bollhoefer}@isi.fhg.de

Abstract. Product service systems (PSS) are a strategic option to increase raw material efficiency by intensifying product use or decoupling volume from profitability. To increase their market share in resource-intensive industries, this paper discusses an assessment approach based on the multi-criteria method PROMETHEE, which considers the benefits and perceived risks in a transparent way. The necessary criteria covering all aspects of the decision to introduce a PSS focusing on raw material efficiency are identified and determined by expert interviews and a comprehensive literature research.

Keywords: PSS, raw material efficiency, multi-criteria decision making, PROMETHEE.

1 Introduction

Raw material efficiency is turning into a crucial topic for the German manufacturing industry, because Germany is a country with limited natural resources and because there is a growing global demand for certain scarce resources as well as increasingly volatile and rising material costs [1]. Thus, it is particularly important for German industries to use raw materials and resources more efficiently. Especially resource-intensive industries which have a large demand for raw materials such as, e. g. the chemical, non-ferrous metal and steel making industries, have to employ technologies, concepts and strategies which focus on raw material efficiency in order to remain competitive [2].

Besides technological developments, implementing product-service systems (PSS) is a strategic option to achieve this objective, e. g. by intensifying product use, or by applying the specific expertise of a provider to use the product more efficiently.

PSS create conditions which can improve the profitability situation of the companies involved, not only through the products as such, but largely, or even entirely, through certain services or functions performed by the provider. Among others, the benefit of using PSS in the industrial sector is revealed in an increased productivity

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 141–152.
DOI: 10.1007/978-3-642-30820-8_13

and customer loyalty as well as competitive differentiation. This benefit is valid for both suppliers and customers [3]. Moreover, PSS enable the decoupling of volume (producing lots of goods) from profitability and – as a consequence – focus on the functionality, not on the material content. By this means they can reduce the environmental impact of production systems [4] [5].

A representative large-scale survey of German manufacturing industries conducted in 2009 [6] with a sample of 1,484 companies indicates the relevance of different motivational factors for offering and using PSS. Besides the ever-present aspect of cost-effectiveness, ecological aspects of sustainability are also crucial, e. g. in the case of energy-contracting [7]. The current use of different PSS concepts aiming to reduce material and energy consumption is plotted in Figure 1. Especially concepts such as chemical leasing (58 %), contracts for continuous optimization (36 %), pay on production and guaranteed life cycle costs (31 % each) seem to have an impact on the reduction of energy and material consumption. However, when considering the diffusion of PSS in resource-intensive industries[1], only 24 % of the companies use at least one of these five PSS [8].

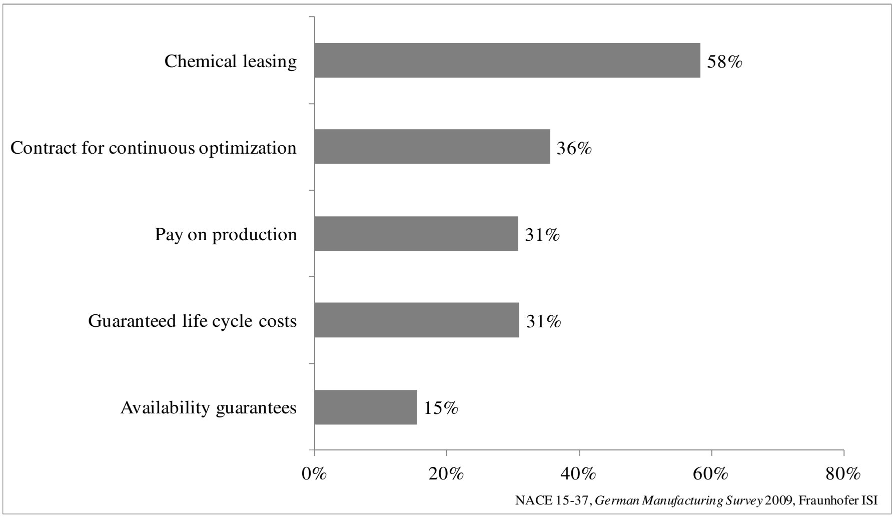


Fig. 1. Usage of different PSS concepts to reduce energy and material consumption

Quantitative (cf. Figure 1) as well as qualitative results [9] have shown the potential of PSS to reduce resource consumption in raw material-intensive production systems. And yet the market share of PSS is still relatively low. In order to enhance the awareness of the benefits of PSS regarding their potential to increase material efficiency and to overcome existing barriers which impede the usage of such PSS, this paper describes a decision support model. Decisions for implementing PSS are strategic and complex due to the scope of their impacts such as changes in the ownership structure and property rights as well as the level of customer involvement. Hence,

[1] Resource-intensive industries: NACE 17, 19, 20, 21, 23, 24, 26, 27.

various objectives should be considered: Besides the competitiveness of the PSS, they have to comply with ecological and technical requirements. The influencing criteria can be qualitative or quantitative in nature. Additionally, conflicting target parameters should be taken into account. Consequently, a multi-criteria decision support model is developed in this paper, which helps companies decide in favor of PSS focusing on material efficiency, if the value creation architecture is economically and ecologically attractive.

The paper is structured as follows. Section 2 gives an overview of the methodology applied. Section 3 focuses on a literature review regarding PSS and material efficiency and describes the barriers impeding the usage of PSS and their potential to increase material efficiency. Section 4 develops a multi-criteria approach for evaluating PSS. Different criteria are identified based on the literature review and expert interviews which cover the different aspects of PSS such as material efficiency as well as the economic and organizational perspectives. The last section concludes the paper.

2 Methodology

The aim of this paper is to develop an assessment approach for PSS which compares different PSS in a transparent way, assesses their benefits and barriers and, as a consequence, facilitates the decision to introduce them and/or increase their utilization. A multi-criteria decision approach seems to be suitable for selecting appropriate PSS which fit the corporate strategy as it considers the different objectives and preferences of decision-makers using e. g. economic, ecological and technical criteria. Where there are competing objectives, the attributes of the criteria might even be contradictory [10]. Moreover, applying a multi-criteria decision approach should make the potentials of certain PSS, the perceived risks and benefits of implementing PSS to improve material efficiency, as well as economic savings on the company level more transparent for decision-makers. Such an approach structures and simplifies the process of finding the most appropriate PSS [11] [12].

To fulfill the aforementioned requirements of assessing the different PSS in an objective and transparent way, the outranking method PROMETHEE was chosen. This ranks the different alternatives according to the criteria and preferences of the decision-maker. One of the advantages of PROMETHEE is the simultaneous consideration of quantitative and qualitative criteria. Moreover, PROMETHEE allows the decision-maker to take vague, incomplete, incomparable or even contradictory information and thus preferences into consideration due to the possibility to define threshold values, strict preferences, indefinite preferences and indifferences. This is especially useful if the decision-maker does not possess exact information about the alternatives. Another benefit of applying PROMETHEE is the avoidance of compensation effects. Accordingly, the advantages of one item do not compensate the disadvantages of another, and important information remains visible. This may result in different alternatives being incomparable and – as a consequence – lead to only a partial ranking of the alternatives. However, the aim of PROMETHEE is not to identify the optimal alternative, but rather any suitable alternative which matches the decision criteria and preferences of the decision-makers. Thus, the method delivers a transparently described ranking of the alternatives based on a well-structured decision process.

PROMETHEE is a multi-criteria decision aid method, one of the so-called outranking methods, and is one of the multi attribute decision making tools (MADM). Hence, each of the finite number of alternatives is evaluated regarding the different decision criteria and preferences of the decision-maker. Based on this assessment, the different alternatives – in this case of PSS – are (partially) ranked to choose the most appropriate alternative [13] [14]. This is achieved by a pair-wise comparison of the alternatives concerning the different criteria [15] [16].

Figure 2 shows the conceptual approach of a decision support tool for PSS based on PROMETHEE. The development and definition of decision criteria is the first and one of the most crucial steps in constructing the assessment tool, as the quality of the final decision is significantly influenced by the determination of the decision criteria. Thus, it is essential to have carefully elaborated criteria that cover all the aspects of the decision to introduce a PSS [17]. The following requirements need to be met: The decision criteria need to be easily understandable, measurable, free of redundancies, and contribute significantly to the decision. Furthermore, the criteria need to be balanced regarding completeness and conciseness as well as simplicity and complexity [18] [19].

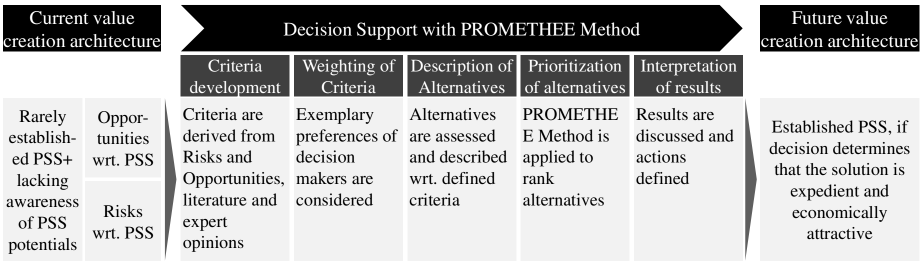


Fig. 2. Conceptual Approach of a Decision Support Tool based on PROMETHEE

Once the decision criteria have been selected, PROMETHEE allows the decision-makers to indicate their individual preferences by weighting them. Weights are assigned to each criterion, such that the overall sum is one or 100 percent.

This step is followed by the description and evaluation of the different PSS alternatives with respect to the defined criteria. The logic of the outranking method PROMETHEE then ranks the assessed alternatives according to the determined values and the weighting of the decision criteria.

PROMETHEE compares different alternatives with respect to the identified criteria. As this ranking does not yield an optimal solution, the results have to be discussed. A sensitivity analysis should be applied to test the stability of the results according to the weighting of the criteria and to demonstrate the consequences of any change in weighting.

To sum up, the structured approach simplifies the decision-making process of choosing an expedient PSS, which is economically and ecologically attractive.

In Section 4, the decision criteria are derived, which are a crucial prerequisite for applying this decision support tool based on PROMETHEE.

3 PSS and Raw Material Efficiency

3.1 PSS and Their Impact on Raw Material Efficiency

Raw materials are the basis for value creation in Germany's industrial society. Currently, there is an annual demand for 1.4 bn tons of abiotic raw materials in Germany[2] [20]. For a long time, this was not a major problem, but is now receiving more interest because of the international competition in purchasing raw materials [21]. Resource and especially raw material efficiency are therefore the object of multiple scientific projects focusing on resource-efficient production systems in the manufacturing industry. Implementing service-based business models is one strategic option to tackle the challenge of improving raw material efficiency.

The research into service-oriented business models is characterized by many different terms, e. g. servitization [22], functional sales [23] or performance-based contracting [24]. The business concepts underlying these terms describe a stand-alone solution which contains the combination of a minimum of one product and one service, is ready for the market and aims to fulfill specific customer needs [25] [26]. Within the research area dedicated to sustainability issues, these service-business relations between suppliers and their customers are predominantly referred to as PSS.

PSS concepts can be structured and designed in multiple ways [27]. Their key objective is to support customers in the daily use of the products (e. g. plant and machinery) by offering complementary services or – one step further – by assuming the risk for the production process (e. g. build-own-operate-model) and being paid for the production results. This frees the customer from tasks which are not related to the core business. The business model itself changes from a transaction-based concept to a relationship-based [28]. Unlike traditional business concepts, their added value consists of "providing functionality rather than products" [29]. Hockerts [30] claims that PSS are superior market solutions compared to the traditional selling of products.

The literature review showed that PSS reduce environmental impacts and positively influence sustainable development through the induced shift in incentives in the direction of dematerialization [31]. In traditional business concepts, the supplier wants to increase the volume of materials sold, whereas the customer wants to decrease the volume of materials used. In contrast, PSS offer the possibility to increase the value of the service for both parties involved. The supplier is remunerated for the service provided and not for the volume delivered [5]. Reiskin et al. [5] call this phenomenon "decoupling volume from profitability". Other advantages of PSS are that the provider possesses a more specialized knowledge, e. g. special engineering competencies, which lead to a more efficient use of the product, or an intensified usage of the products.

---

[2] Data of 2008.

3.2 Barriers to and Opportunities of PSS

Despite the benefits of PSS in increasing raw material efficiency, the usage of PSS in resource-intensive industries is still low. In the literature, various barriers and risks which hamper the diffusion of PSS are described, such as the difficulties new suppliers of PSS face when entering the market due to a lack of information about life cycle costs and other parameters of the equipment's operational phase. This is especially the case for customized solutions [32] [33]. Moreover, the transfer of experiences and information from customers to PSS providers is rather hesitant, because customers fear the loss of technological core competencies – and as a consequence – a threat to their competitive edge. This is particularly true for PSS which focus on harnessing the potentials offered by process optimization [33].

Expert interviews conducted in resource-intensive industries, such as steel and metal production, the chemical as well as the recycling industry, revealed a similar picture [8]: In all three sectors, the loss of know-how was mentioned as a perceived risk. Potential customers fear the loss of their competitive advantage, if PSS affect their core competencies. Amongst others, the perceived creation of a dependency on the supplier was commonly stated as a barrier to PSS. The interviewees assume the reliability and availability of the PSS provider is not guaranteed and that this can lead to severe production outages.

Those interviewed in resource-intensive industries were also questioned about the opportunities of PSS [8]. One advantage mentioned was that the provider of PSS possesses better know-how about non-core processes than their customers. Moreover such suppliers already have the specialized equipment needed and the technological core competencies for using it at their disposal. This reduces the demand for qualifications at the customers, and allows them to focus on their core competencies and increases their flexibility. Other advantages of PSS mentioned by the interviewees are cost savings, fewer quality problems and a long-lasting business relationship between PSS customer and supplier.

4 An Assessment Approach to Raw Material-Efficient PSS

As already indicated, PSS are a means – apart from conventional technical process enhancements – to harness the raw material efficiency potential in resource-intensive industries. However, as was detected in the expert interviews [9], there is still a lack of awareness of these potentials. A useful decision support tool for companies to facilitate the introduction of PSS is the multi-criteria approach based on PROMETHEE described in Section 2, which takes the opportunities and perceived risks of PSS into account. In the following, the decision criteria needed to assess PSS focusing on raw material efficiency in resource-intensive industries are identified and derived from expert interviews [9] and the relevant literature.

To consider all the aspects that need to be reflected in the decision process, the decision criteria should be aligned with universal company targets as shown in Figure 3. The overall value targets, such as profitability or productivity, are operationalized with factual targets, which are classified as *performance*, *financial*, *leadership and* *organizational* as well as *social and ecological goals*. These four factual targets are then captured by the identified decision criteria, which will be introduced in the following sections.

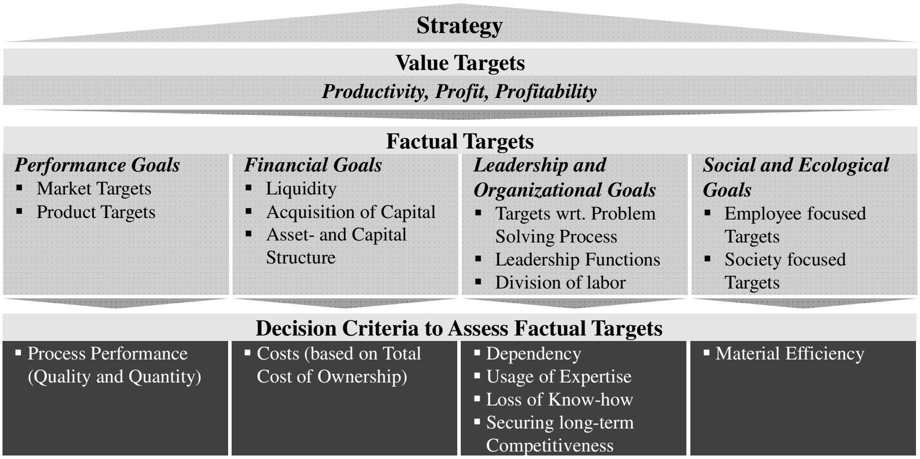


Fig. 3. Decision criteria aligned with universal company targets (Based on targets from [35])

4.1 Performance Goals

Process performance is an important aspect in the application of resource-intensive production value chains. Experts pointed out that technical processes already show a high degree of optimization and that high capacity utilization rates are needed in such asset-intensive industries. Reliability and availability as main drivers of down times contribute significantly to process performance. As a consequence, the evaluation of a PSS is based on aspects such as reliability [9] [36], availability [37] [38], robustness towards peaks (bottlenecks) [9], possible degree of process standardization [38], technical and operational risks [39] and the capacity utilization rate of existing and newly established facilities [9] [40]. Additionally, the robustness of the overall production system and a clear definition of responsibilities with respect to quality measures at process interfaces are taken into account [40].

4.2 Financial Goals

Costs are obviously another important aspect. Bearing in mind that some experts stated PSS do not necessarily lead to cost reductions [9], a thorough cost analysis of assets and processes is required covering the whole life cycle. A total cost of ownership approach is beneficial here as this covers all life cycle costs [9] [41]. When comparing the costs of PSS with a traditional business model, internal overhead expenses need to be taken into account. The discount of values is advantageous with respect to the timely distribution of cash inflows and outflows. In addition, the one-time costs of designing and setting up a PSS [36] [41] [42], coordination and control costs [5] [36], investments [43], lower capital costs due to a reduction of the required capital commitments, changes in liquidity [36] [40] [44] and shifts in the share of fixed and variable costs [38] [40] [45] all impact the assessment result. To sum up, this criterion has advantages due to the increased transparency of all the relevant costs on a life cycle basis [40] [44] [45].

4.3 Leadership and Organizational Goals

The experts named dependency on the provider as one of the major concerns of establishing a PSS [9]. Certainly, bargaining power is an important influence when determining the properties of a PSS. Oligopolistic or monopolistic market structures might be a barrier. Looking at a selection of alternative suppliers before signing long-term contracts reduces this risk. Furthermore, a carefully designed and reviewed contractual regulation helps to avoid such dependencies. However, apart from this dependency [9] [39] [43], many authors suggest that passing on responsibilities from the customer company to the PSS provider offers increased flexibility [9] [37] [44]. This area of concern requires an elaborate discussion and assessment.

Experts commonly see the usage of external expertise as a potential driver for a decision in favor of PSS. More and more advanced technologies and the related process know-how are adapted by specialized companies [43]. Therefore, it is necessary to assess the potential benefits of the technical capabilities gained [36] [44] [40]. Due to the incentive structure of PSS, the customer and the provider are often eager to expand the existing expertise cooperatively [36] [43]. Hence, the assessment should help to identify a PSS which is best able to achieve the listed benefits. In many publications the access to external know-how is described as advantageous in the context of using third party offerings [9] [36] [37].

In contrast to the acquisition of know-how and profiting from external expertise, loss of internal know-how is a commonly cited reason for ruling out the usage of PSS in the expert interviews. PSS have to be integrated smoothly into processes and this sometimes requires the transfer of internal know-how to the service provider. The situation might also occur, in which internal employees are no longer able to manage certain processes. This certainly relates to the aspect of dependency. The knowledge that certain know-how will have to be outsourced requires a proactive handling of risks, e. g. through a comprehensive contractual agreement. This is also a common argument in the literature [9] [38] [45].

Experts pointed out that, in the long run, decision-makers have a strong interest in securing future competitiveness. The positive influence of PSS on this aspect can be subsumed as strategic utility [46]. One strategic concept ensuring competitiveness is the concentration on the customers' core competencies [9] [36] [45]. Therefore, the PSS has to be assessed with regard to this demand. Besides this often mentioned aspect, the enhanced ability to react to changes [36] [40] is listed in various publications. As a result, responsiveness is considered in the operationalization of the decision criteria. The advantage of smaller organizational units can be taken into account [38] [40] [45] with respect to their beneficial properties regarding coordinating, organizing and planning. Other positive influences such as the customer-satisfaction-orientation of the

PSS provider [38], the transfer of risks to the PSS provider [38], increased innovativeness [39] [40], an improved image [44], reduced internal transaction costs [40], increased cost awareness [40], optimized depth of added value [40], competitive differentiation [40], reduced warranty and liability issues and stabilized business relations should also be captured and assessed regarding their impact on increased competitiveness [9] [39] [40]. Furthermore, it needs to be evaluated whether the aspects contributing to long-term competitiveness are outweighed by others such as the employees' refusal to accept the PSS, the interruption of related processes or reduced informal communication [38].

4.4 Social and Ecological Goals

As explained in the introduction, material efficiency is very important due to ecological goals, regulatory requirements and potential cost savings. Particularly in resource-intensive production systems, rising material prices result in an increased leverage effect of percentage material reductions. Advanced technology and process know-how and above all the expediently designed incentive structure of a PSS have the potential to improve material efficiency. While many of the other criteria have been handled in the literature, the aspect of material efficiency is rarely mentioned [9] [40]. This can be primarily attributed to the subordinate importance of this issue in the past.

5 Conclusions and the Need for Further Research

This paper shows that PSS are a strategic option to increase raw material efficiency. Nevertheless, the market share of PSS is still relatively low. To support and make the complex decision process of implementing PSS easier, this paper suggests and discusses an assessment approach based on the multi-criteria decision method PROMETHEE. This allows the assessment of the potential of specific PSS in a transparent way by considering the perceived risks and benefits.

In this paper, the decision criteria were determined as a first step towards developing a decision support tool covering all the aspects of the economic, ecological and technical objectives. The criteria are aligned with the general targets of the company, which are classified in four categories: *performance*, *financial*, *leadership and organizational* and *social and ecological*. To measure and compare the effects of different PSS focusing on raw material efficiency with the traditional business model, the following seven criteria are used: Performance is evaluated by the *process performance;* the financial goals are defined by the *total cost of ownership,* and the social and ecological perspective is covered by the achievements regarding *material efficiency*. The fourth category, leadership and organizational goals, is split into four criteria, *dependency on the provider*, *usage of expertise*, *loss of know-how* and *securing long-term competitiveness*.

Future research should focus on the development of the complete decision support model based on PROMETHEE and testing various case studies to validate its applicability.

Acknowledgments. The research results presented in this paper are part of the integration and transfer project "r^2 – Innovative Technologies for Resource Efficiency – Resource-Intensive Production Processes", funded by the German Federal Ministry of Education and Research (BMBF). The funding source was not involved in the study design, data collection, analysis and interpretation, writing of the paper or the decision to submit this paper for publication. The responsibility for the contents lies with the authors alone.

References

1. Wied, T., Brüggemann, A.: Material- und Rohstoffeffizienz in Unternehmen. In: KfW Bankengruppe (ed.) Perspektive Zukunftsfähigkeit - Steigerung der Rohstoff- und Materialeffizienz, KfW Research, Frankfurt on the Main, pp. 33–52 (2009)
2. BMBF: Forschung für die Nachhaltigkeit: Rahmenprogramm des BMBF für eine zukunftsfähige innovative Gesellschaft, Bonn, Berlin (2006)
3. Lay, G., Copani, G., Jäger, A., Biege, S.: The relevance of service in European manufacturing industries. Journal of Service Management 21(5), 715–726 (2010)
4. Maxwell, D., van der Vorst, R.: Developing sustainable products and services. Journal of Cleaner Production 11(8), 883–895 (2003)
5. Reiskin, E.D., White, A.L., Kauffman Johnson, J., Votta, T.J.: Servicizing the Chemical Supply Chain. Journal of Industrial Ecology 3(2-3), 19–31 (2000)
6. Jäger, A., Maloca, S.: Dokumentation der Umfrage Modernisierung der Produktion. Fraunhofer ISI, Karlsruhe (2009)
7. Ostertag, K.: No-regret potentials in energy conservation: An analysis of their relevance, size and determinants. In: Technology, Innovation and Policy, vol. 15. Physica-Verlag, Heidelberg (2003)
8. Bollhöfer, E., Mattes, K.: Product-Service Systems: Added Value for Productivity and Raw Material Efficiency at one Blow? Status Quo and Potentials in Resource-Intensive Production Processes. In: Greening of Industry Network (GIN) (ed.) Conference on the Greening of Industry Network - GIN 2012 - Support Your Future Today! Linköping, Sweden, October 22-24 (2012) (publication in process)
9. Bollhöfer, E., Mattes, K., Miller, M.: Welche Ressourceneinsparpotenziale können durch Dienstleistungsmodelle bei rohstoffnahen Produktionssystemen erschlossen werden? Fraunhofer-Institut für System- und Innovationsforschung ISI, Karlsruhe (2012) (publication in process)
10. Brans, J.-P., Mareschal, B.: How to Decide with PROMETHEE. ULB and VUB Brussels Free Universities, Brussels (2000)
11. Beccali, M., Cellura, M., Ardente, D.: Decision Making in Energy Planning: The ELECTRE Multicriteria Analysis Approach Compared to a Fuzzy-Sets Methodology. Energy Conversion and Management 39(16-18), 1869–1881 (1998)
12. Pohekar, S., Ramachandran, M.: Application of multi-criteria decision making to sustainable energy planning — A review. Renewable and Sustainable Energy Reviews 8(4), 365–381 (2004)
13. Greening, L.A., Bernow, S.: Design of coordinated energy and environmental policies: use of multi-criteria decision-making. Energy Policy 32(6), 721–735 (2004)
14. Zimmermann, H.-J., Gutsche, L.: Multi-Criteria Analyse. Springer, Heidelberg (1991)

15. Geldermann, J.: Entwicklung eines multikriteriellen Entscheidungsunterstützungssystems zur integrierten Technikbewertung. Fortschritt-Berichte Technik und Wirtschaft, vol. 105. VDI-Verl., Düsseldorf (1999)
16. Brans, J.-P., Mareschal, B.: PROMETHEE Methods. In: Figueira, J., Greco, S., Ehrgott, M. (eds.) Multiple Criteria Decision Analysis. State of the Art Surveys. International Series in Operations Research and Management Science, vol. 78, pp. 163–195. Springer Science and Business Media Inc., New York (2005)
17. Geldermann, J.: Multikriterielle Entscheidungsunterstützung für Automatisierungsprojekte: Effiziente Planung und Entwicklung von Automatisierungslösungen. In: Tagungsband Fraunhofer IPA Workshop. Fraunhofer IPA, Stuttgart (2008)
18. Belton, V., Stewart, T.J.: Multiple criteria decision analysis: An integrated approach. Kluwer Academic Publishers, Boston (2002)
19. Roy, B.: Paradigms and Challenges. In: Figueira, J., Greco, S., Ehrgott, M. (eds.) Multiple Criteria Decision Analysis. State of the Art Surveys. International Series in Operations Research and Management Science, vol. 78, pp. 3–24. Springer Science and Business Media Inc., New York (2005)
20. Statistisches Bundesamt: Umweltnutzung und Wirtschaft - Bericht zu den Umweltökonomischen Gesamtrechnungen, Wiesbaden (2008)
21. Albrecht, S., Brandstetter, P., Bollhöfer, E., Fröhling, M., Mattes, K., Ostertag, K., Peuckert, J., Seitz, R., Trippe, F., Woidasky, J.: Ressourceneffizienzpotenziale von Innovationen in rohstoffnahen Produktionsprozessen. Chemie Ingenieur Technik (2012) (publication in process)
22. Vandermerwe, S., Rada, J.: Servitization of business: Adding value by adding services. European Management Journal 6(4), 314–324 (1988)
23. Stremersch, S., Wuyts, S., Frambach, R.T.: The Purchasing of Full-Service Contracts. Industrial Marketing Management 30(1), 1–12 (2001)
24. Kim, S.-H., Cohen, M.A., Netessine, S.: Performance Contracting in After-Sales Service Supply Chains. Management Science 53(12), 1843–1858 (2007)
25. Tischner, U., Verkuijl, M., Tukker A.: First Draft Report of PSS Review. Suspronet Report, Cologne, Germany (2002), http://www.suspronet.org
26. Becker, J., Beverungen, D., Knackstedt, R., Glauner, C., Stypmann, M., Rosenkranz, C., Schmitt, R., Hatfield, S., Schmitz, G., Eberhardt, S., Dietz, M., Thomas, O., Walter, P., Lönngren, H.-M., Leimeister, J.: Ordnungsrahmen für die hybride Wertschöpfung. In: Thomas, O., Nüttgens, M. (eds.) Dienstleistungsmodellierung. Methoden, Werkzeuge und Branchenlösungen, pp. 109–128. Physica-Verlag, Berlin (2009)
27. Baader, A., Montanus, S., Sfat, R.: After Sales Services — mit produktbegleitenden Dienstleistungen profitabel wachsen. In: Barkawi, K., Baader, A., Montanus, S. (eds.) Erfolgreich mit After Sales Services, pp. 3–14. Springer, Heidelberg (2006)
28. Oliva, R., Kallenberg, R.: Managing the transition from products to services. International Journal of Service Industry Management 14(2), 160–172 (2003)
29. Toffel, M.W.: Contracting for Servicizing. Harvard Business School Working Paper, 08–063 (2008)
30. Hockerts, K.: Property Rights as a Predictor for the Eco-Efficiency of Product-Service Systems, København (2008)
31. Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M., Wilson, H.: State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 221(10), 1543–1552 (2007)

32. Hypko, P., Tilebein, M., Gleich, R. (eds.): Performance contracting as a win-win strategy in the manufacturing industry – a comprehensive overview of benefits and risks for providers and customers. In: Proceedings of the 11th QUIS Conference 2009 Moving Forward with Service Quality, Wolfsburg, June 11-14 (2009)
33. Lay, G.: Betreibermodelle für Investitionsgüter: Verbreitung, Chancen und Risiken, Erfolgsfaktoren. ISI-Schriftenreihe "Innovationspotenziale". Fraunhofer IRB Verlag, Stuttgart (2007)
34. Cavusgil, S., Yaprak, A., Yeoh, P.-L.: A decision-making framework for global sourcing. International Business Review 2(2), 143–156 (1993)
35. Thommen, J.-P., Achleitner, A.-K.: Allgemeine Betriebswirtschaftslehre, 6th edn. Gabler, Wiesbaden (2009)
36. Kakabadse, A., Kakabadse, N.: Trends in Outsourcing: Contrasting USA and Europe. European Management Journal 20(2), 189–198 (2002)
37. Günther + Schramm Gmbh (eds.): Marktstudie: Outsourcing von Materialbevorratung und Anarbeitung, Oberkochen (2010)
38. Picot, A., Maier, M.: Analyse- und Gestaltungskonzepte für das Outsourcing. IM Information Management (4/92), 14–27 (1992)
39. Steven, M.: Keine genannt Schulte, J., Alevifard, S.: Strategisches Controlling von hybriden Leistungsbündeln. In: Meier, H., Uhlmann, E. (eds.) Integrierte Industrielle Sach- und Dienstleistungen. Vermarktung, Entwicklung und Erbringung hybrider Leistungsbündel, pp. 285–307. Springer, Heidelberg (2012)
40. Zmuda, P.: Outsourcing bei Banken: Eine Analyse des strategischen Entscheidungsproblems. Deutscher Universitäts-Verlag, Wiesbaden (2006)
41. Schmitz, G.: Der wahrgenommene Wert hybrider Produkte: Konzeptionelle Grundlagen und Komponenten. In: Bichler, M., Hess, T., Krcmar, H., Lechner, U., Matthes, F., Picot, A., Speitkamp, B., Wolf, P. (eds.) Multikonferenz Wirtschaftsinformatik 2008. Integration von Produkten und Dienstleistungen- Hybride Wertschöpfung, pp. 665–683. GITO-Verlag, München (2008)
42. Kang, A.: Beitrag zur Unterstützung von rationalen Entscheidungen zum Outsourcing von Geschäftsprozessen, 1st edn. Shaker, Aachen (2003)
43. Holcomb, T.R., Hitt, M.A.: Toward a model of strategic outsourcing. Journal of Operations Management 25(2), 464–481 (2007)
44. Zahn, E., Ströder, K., Unsöld, C.: Outsourcing von Dienstleistungen: Ergebnisse einer Unternehmensbefragung der Industrie- und Handelskammern in Baden-Württemberg. Im Auftrag der Industrie- und Handelskammern in Baden-Württemberg (2007)
45. Quelin, B., Duhamel, F.: Bringing Together Strategic Outsourcing and Corporate Strategy: Outsourcing Motives and Risks. European Management Journal 21(5), 647–661 (2003)
46. Seiter, M., Schwab, C., Ahlert, D., Heußler, T., Michaelis, M.: Nutzenmessung von produktbegleitenden Dienstleistungen im Industriegüter-Pricing – erste empirische Ergebnisse. In: Proceedings of the 1st Rostock Conference on Service Research (2008)

Preventing Self-inflicted Product Piracy in Technical Product-Service Systems

Christian Bohr and Jan C. Aurich

Institute for Manufacturing Technology and Production Systems,
Gottlieb Daimler Str., 67663 Kaiserslautern, Germany
bohr@cpk.uni-kl.de

Abstract. Spare parts are the key-modules by the realization of technical Product-Service Systems (PSS). To gain the sustainable realization of PSS, the usage of original spare parts is necessary. Nevertheless, numerous enterprises operate in the market by offering counterfeit spare parts and numerous customers using these spare parts. This problem, known as product piracy, has tremendous consequences for manufacturers of capital goods. Existing strategies usually focus on the potential counterfeiters and attempt to thwart their capabilities. However, this ignores that the main causes for product piracy are internally induced and self-inflicted. The approach quantifies, evaluates and reduces these risks for spare parts step by step in the engineering process of the product.

Keywords: product piracy, spare parts, piracy risk, cost-benefit analysis.

1 Introduction

Spare parts are the key-modules by the realization of technical Product-Service Systems (PSS). To gain the sustainable realization of PSS, the usage of original spare parts is necessary [1]. PSS is defined as a complex physical product core, dynamically enhanced along its life cycle, by non-physical services and spare parts [2].

Nevertheless, numerous enterprises operate in the global market by using the industrial achievements of innovative manufacturers in an unauthorized way. This phenomenon, popularly known as product piracy, has tremendous consequences for manufacturers of capital goods. Spare parts are a particularly frequent target of counterfeit due to their technical simplicity and market volume.

Concepts current in the field of product piracy usually focus on potential counterfeiters as the source of the problem, and try to face their capabilities by protective measures [3]. However, original equipment manufacturers (OEM) do not realize that product piracy in many cases is self-inflicted by their own enterprise structure. In these cases, the corporate risk of getting counterfeited is induced by internally made decisions. This situation is termed self-inflicted product piracy [1].

In this paper, the emergence of self-inflicted product piracy is pointed out and it presents an approach to quantify, evaluate and reduce internally induces piracy risks for spare parts in the engineering process of the product.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 153–164.
DOI: 10.1007/978-3-642-30820-8_14

2 Self-inflicted Product Piracy

2.1 Product Piracy

Product piracy is the unauthorized use of brands, technical inventions, designs and/ or know-how protected either by any intellectual property right or a contract or the general laws against unfair competition. Unauthorized means, use without the permission or the knowledge of the OEM, including the reproduction of any good in a way that closely imitates protected items, and thus that may mislead the customer. If a competitor offers an imitated spare part that fits to the PSS from the OEM, the OEM has to check whether the imitation is illegal (product piracy) or legal [1]. The risk of product piracy for an OEM is characterized by causes and effects.

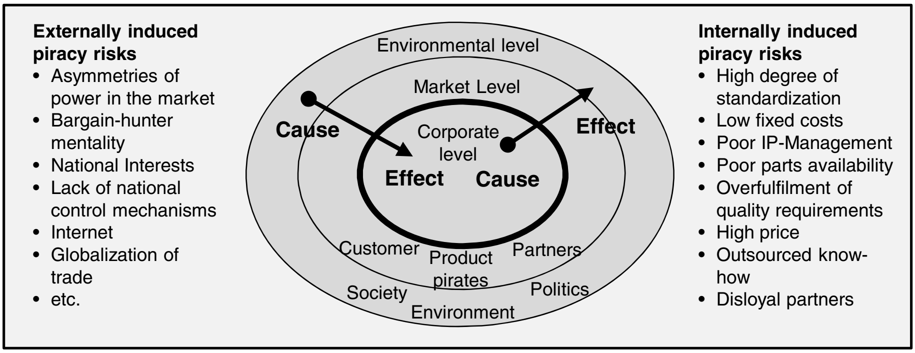


Fig. 1. Causes and effects of piracy risks [1]

Consecutively, several causes of piracy risks are quoted. Once the critical market volume of a product is exceeded, its imitation becomes attractive for product piracy [4]. Fixed costs include both development costs and adaption costs for reverse engineering, fixed costs allocated in the manufacturing process, and marketing costs. The lower these fixed costs the greater is the attractiveness for product piracy [5]. Identification of product piracy is hampered by several factors including the heterogeneity of worldwide markets, the huge number and variety of spare parts and the plurality of suppliers, customers, dealers and competitors [6]. Further causes of product piracy are the price premium of the product [5], an uncontrolled know-how transfer [7], and criminal organization structures [8].

Resulting effects for the manufacturer are, for example, a decline in sales, price erosion, unjustified product liability, and the loss of image and advances in innovation. Resulting effects for the customer are, for example, health and security consequences for the machine operator, the risk of a machinery breakdown, and increased maintenance costs [9].

The identification and avoidance of internally causes and the associated piracy risks are addressed in this paper (Figure 1).

2.2 Internally Induced Piracy Risks

There is a conflict of interest between the engineering process of the product and the protection of spare parts against product piracy (Figure 3).

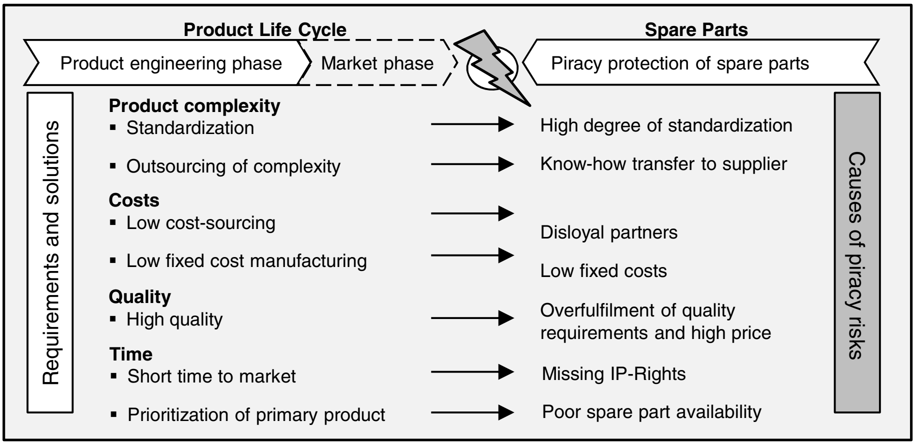


Fig. 2. Self-inflicted product piracy by spare parts

The main requirements of the product engineering process such as managing product complexity, as saving costs and time, and as developing quality, foster product piracy in the after sales market. The technical solutions which are implemented to meet those requirements cause piracy risks in after sales. These kinds of piracy risks are internally induced and avoidable. This knowledge has emerged from a 4 years working group, with leading providers of PSS out of the construction equipment and agriculture industry and with the Institute for Manufacturing Technology and Production Systems (FBK) in Kaiserslautern. For example, two strategies are typically used to manage product complexity: standardization of the product structure and reduction of the vertical range of manufacture (outsourcing of complexity) [10]:

- Outsourcing of complexity necessarily entails outsourcing of contracted know-how to cooperation partners. This runs the risk that the supplier may use the transferred know-how to manufacture and to sell the spare part without informing the OEM [11]. Especially, if the company chooses its cooperation partners primarily under cost aspects. Suppliers with an own distribution structure are afflicted with a high piracy risk. Also disloyal dealers or service providers can misuse the transferred and contracted know-how to order counterfeited components from independent manufacturers [12].
- Standardization focuses on increasing the reusability of equal parts with the realization of standardized interfaces. This contains the risk that the market volumes of the spare parts increase. Additionally, the cost risks by counterfeiting that standardized part decreases [13]. Especially, standard parts which are assembled branch-wide or even industry-wide are afflicted with a high piracy risk [14].

In sum, we found different types of internally induced piracy risks by spare parts. Three categories of internally induced piracy risks are identified and addressed: partner, customer and product. These categories are illustrated in Figure 3.

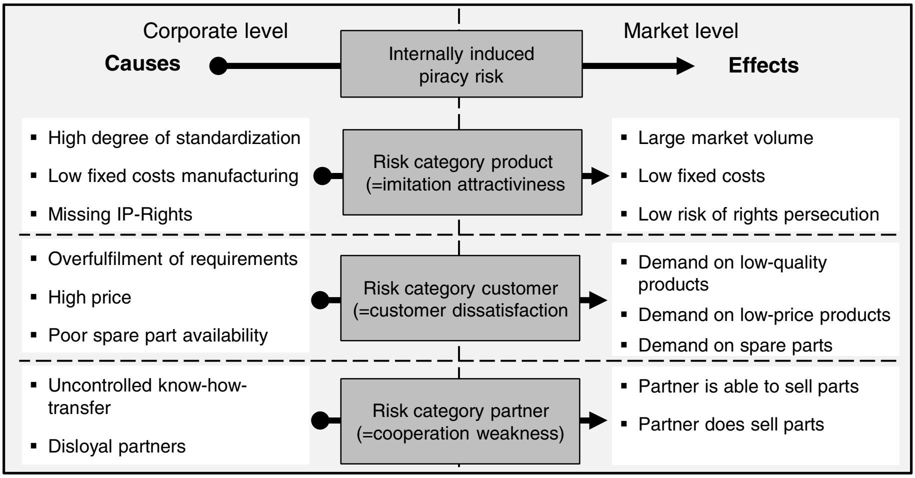


Fig. 3. Categories of internally induced piracy risks

Many types of cooperation partners present piracy risks, including suppliers, development partners, service partners and dealers. The risk is that typically a business partner uses a protected industrial achievement of the OEM in an unauthorized way. With regard to customers, the piracy risk is that they will buy counterfeit products from product pirates. This risk typically results from the OEM creating an unwanted demand in the market. The risk category product refers to the imitation attractiveness of the product or the simplicity to imitate the product. Here are summarized the risks that the market entry barriers are so low that the product pirates can counterfeit products without bearing own risks.

3 Prevention of Self-inflicted Product Piracy

To prevent self-inflicted product piracy by spare parts, it is necessary to identify, to quantify, to evaluate, and to reduce internally induced piracy risks, already in the engineering process of the primary product.

3.1 Quantification and Evaluation of Piracy Risks

To quantify and to evaluate piracy risks, the probability of its occurrence has to be related with the gross loss of product piracy. The probability of piracy occurrence is determined through the quantification of the causes by a rating number between 1 and 10. The gross loss of product piracy is determined through the quantification of the effects of product piracy by an impact factor. The resulting net-piracy risk is the outcome of the multiplication of the probability rating number with the impact factor. Finally, the net-piracy risk has to be evaluated.

Probability of Piracy Risk Occurrence. The probability of piracy risk occurrence is calculated with several morphological boxes. Within each morphological box several internally induced piracy risks are clustered. Furthermore, the morphological boxes are clustered to the risk categories product, customer and partner (Figure 4).

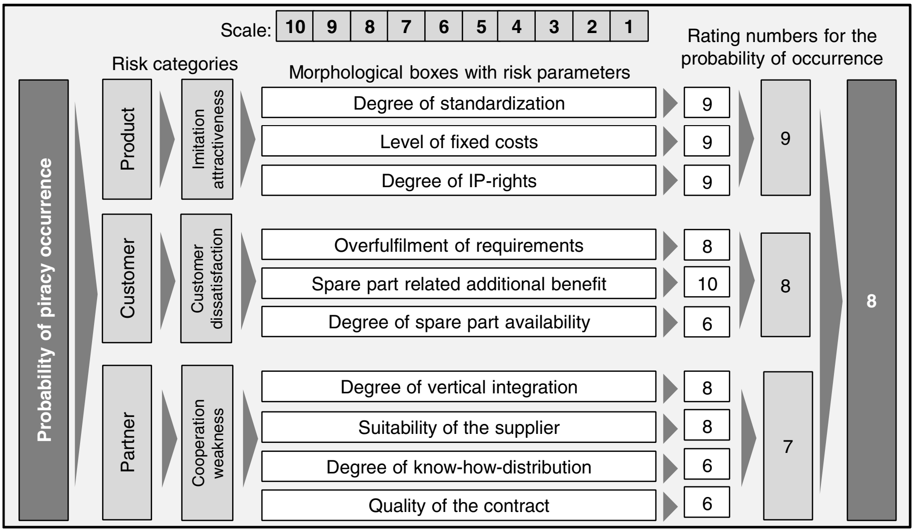


Fig. 4. Probability of piracy risk occurrence

The parameters of the morphological boxes are risk parameters that stand for several internally induced piracy risks. The characteristics of the risk parameters are the alternative solutions in a morphological box. The characteristics fulfill two tasks:

- The characteristics are underlined with rating numbers between 1 and 10 that stand for a specific high or low probability of piracy occurrence. Rating number 1 symbolizes a low probability and rating number 10 a high probability of piracy occurrence. In doing so, with determining the characteristics, the probability of piracy occurrence is calculated.
- Furthermore, the different characteristics of a risk parameter also show alternative solutions to reduce the probability of piracy occurrence.

In Figure 5,6 and 7 are pointed out the morphological boxes to estimate the degree of standardization, the degree of non-integration of spare part additional benefits, and the degree of non-cooperation suitability of the supplier.

To estimate the degree of standardization, the in Figure 5 pointed out risk parameters and related risk characteristics are determined. For example, has to be estimated the novelty grade of the design task. Using in a new machine generation the equal design of a part as in the initial machine generation, contains the piracy risk that product pirates have an extended counterfeiting time without changing anything. Furthermore, has to be estimated how common in the market are the geometrical and material characteristics and the surface of the part to the machine. If other manufacturers in the branch or even in other industries using the same characteristics or the same interface, the market volume of that spare part is obviously higher if the OEM is the only one with a technical specification.

Scale	10	9	8	7	6	5	4	3	2	1	
Risk parameters	Risk characteristics										Result
Novelty grade of the design task	Equal design		Design for variants			Design with adaptions			Design with new tasks		10
	10										
Breadth of the market	General functions industry wide			Branch specific functions			Product specific functions		Special functions		10
	10										
Geometrical characteristics	Geometric characteristics are standardized and accepted in the market			Geometric characteristics are realized in some other applications				Geometric characteristics are realized in a few, or in any application			9
	10										
Material characteristics	Material characteristics are standardized and accepted in the market			Material characteristics are realized in some other applications				Material characteristics are realized in a few, or in any application			7
				7							
Surface of the spare part to the machine	Interface is standardized and accepted in the market			Interface is realized in some other applications				Interface is realized in a few, or in any application			10
	10										
Manufacture of the geometrical and material characteristics	Manufacturing is possible with in the market existing machines and/ or tools					Manufacturing requires special machines and/ or special tools					8
	8										
Extent of equal parts in the product structure	Equal part across several product families				Equal part in other variants of the product family				Individual part		9
	10										
Degree of Standardization											9,0

Fig. 5. Degree of standardization

To estimate the degree of non-integration of spare part additional benefits, the in Figure 6 pointed out risk parameters and related risk characteristics are determined. A spare part with less additional benefit contains a higher piracy risk then a spare part with several additional benefits. For example spare part related additional benefits are benefits in logistic (e. g. lower transport costs), benefits in the handling of the spare part during maintenance (e. g. maintenance time, weight, ergonomic), and benefits in the usage of the machinery through the spare part (e. g. saving resources).

Scale	10	9	8	7	6	5	4	3	2	1	
Risk parameters	Risk characteristics										Result
Spare part related requirements with benefit for the customer	No spare part related requirements			A few spare part related requirements				Several spare part related requirements			10
	10										
Spare part related requirements with benefit for the OEM	No spare part related requirements			A few spare part related requirements				Several spare part related requirements			10
	10										
Degree of non-integration of spare part related additional benefits											10,0

Fig. 6. Degree of non-integration of spare part additional benefits

To estimate the degree of non-cooperation suitability of the supplier, the in Figure 7 pointed out risk parameters and related risk characteristics are determined. For example is a supplier selling already actively several spare parts in several important after sales markets of the OEM, less suitable than a supplier without any role in the after sales business. Furthermore, are the sale and service structure of the supplier risk parameters that have to be estimated. Suppliers with a direct and intensive customer contact contain the risk that they sell components as spare parts to the customer without informing the OEM. Also the location of the supplier and herein the existence of secure property rights in a country is relevant [15].

Scale	10	9	8	7	6	5	4	3	2	1	
Risk parameters	Risk characteristics										Result
Role of suppliers in the after sales business (loyality)	Supplier does sell actively components in the after sales business of OEM				Supplier does sell components in the after sales business of OEM but only on specific requests				No specific role in the after sales		10
	10										
Importance of the markets of the supplier to the OEM	Full coverage		In one or several important markets for the OEM				In a few insignificant markets			In any markets	10
	10										
Product structure of the supplier in the after sales business of OEM	Several product groups		A complete product group				Only single components			No parts	9
	9										
Sales structure of the supplier	Supplier with own sales and distribution network					Supplier does deliver only manufacturer on request					10
	10										
Service structure of the supplier	Supplier does offer actively own product-service systems				Supplier does offer on request service products			Supplier doesn´t offer any service products			10
	10										
Location of the supplier (by IPRI index)	< 5	5-6			6 - 7			7 - 10			4
					4						
Vertical range of manufacture from the supplier	Low vertical range of manufacture			Medium vertical range of manufacture				High vertical range of manufacture			6
				6							
Know-how-protection by the supplier	Supplier is not sensitive with know-how			Supplier is sensitive with know-how				supplier is very sensitive with know-how			8
	8										
Employee turnover	High employee turnover			Medium employee turnover				Low employee turnover			3
								3			
Degree of non-cooperation suitability of the supplier											7,0

Fig. 7. Degree of non-cooperation suitability of the supplier

With this approach, the probability of piracy occurrence can be quantified and reduced step by step in the engineering process of the primary product. The rating numbers of each risk parameter can be related with the impact factor to a net-piracy risk. Furthermore, the rating numbers of each morphological box can be related with the impact factor. The rating number of a morphological box is the average of the risk parameters rating numbers. Finally, can be quantified a total rating number for piracy risk occurrence out of the average of the morphological boxes rating numbers.

Gross Loss of Piracy Risks. The resulting effects of product piracy have consequences for the sustainable usage of product-service system. This includes consequences for the manufacturer, for the customer who bought and uses this spare part, for the environment, and for the health and security of the machine operator. The consequences for a sustainable usage of the product-service system represent the gross loss of product piracy and have to be calculated with an impact factor. The calculation of the impact factor is an expert-based estimation of the consequences for each of the following categories:

- The total cost of ownership (TCO) from the customer relating to the part
- A possible breakdown of the machinery due to a failure of the part
- The security, and the health risk of the machine operator due to a failure of the part
- The image of the OEM relating to the part
- The OEM volume of sale and profit of the part
- The Recyclability of the part,
- The influences on the environment (e. g. emissions, resources) through the part

To quantify the impact factor, the analyzing team has to estimate several impacts of the consequences for the categories if the customer will maintain a counterfeit part instead of the sustainable original one. The range goes from a low impact counted with 1 till a high impact counted with 10. Each category is described with several characteristics which assist the estimation of the impact. For example, characteristics in the category "health risk" are noise, ergonomic, inhalation of toxic, or harmful vapors and vibration. The deposited characteristics of the category "security risk" are squeezing, cutting, hitting, and burning. The total impact factor is the average of the estimated impacts out of the categories.

Evaluation of the Net-Piracy Risk. To quantify and to evaluate the piracy risk of a spare part, the rating number for the probability of piracy risk occurrence has to be multiplied with the estimated impact factor (Figure 8).

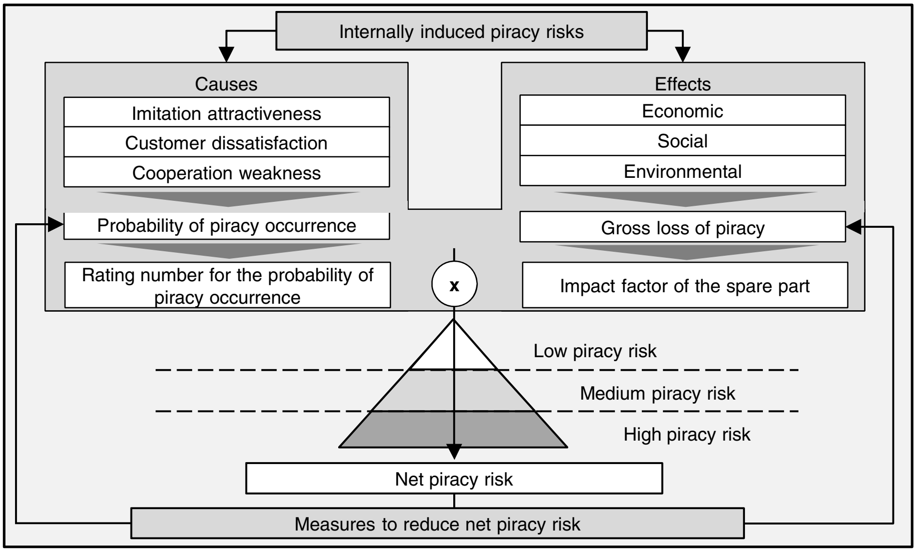


Fig. 8. Net-piracy risk

The range of resulting net-piracy risk goes from 1 till 100. A net-piracy risk smaller than 30 is optimal. A net-piracy risk between 31 and 50 is determined as a medium high piracy risk. The need to reduce a medium high piracy risk depends on the company strategy and is obligatory. A net-piracy risk higher than 51 is critical and has to be reduced with appropriate measures.

3.2 Reducing of Piracy Risks

Measures to Reduce Piracy Risks. To reduce a piracy risk the probability of its occurrence and within this the degree of its causes has to be focused. Therefore several measures are determined. The target of de-standardization is to reduce the market volume of the spare part and with that the imitation attractiveness. At first, in the engineering process of a new machine generation, a spare part with a high impact factor, should be a new design task. Furthermore, additional functions or functions from other components could be integrated to the part concept. Also, the manufacturing of the part could be de-standardized, by using not procurable materials or by changing geometrical or material characteristics that are not manufacturable with standard machines or tools. In addition, changing the geometry of the connection type is another measure in order to unique the spare part. A smart way to change the interface is, changing it by ensure a reverse exchangeability of the new interface also in the initial interface.

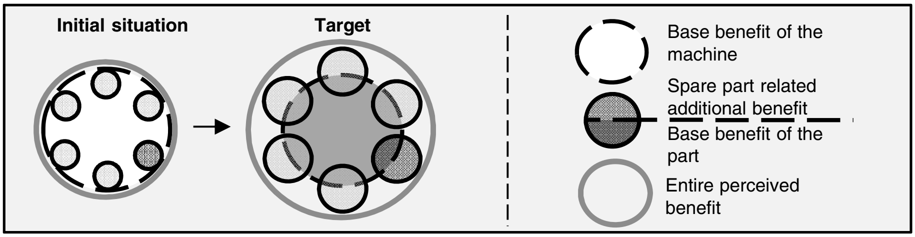


Fig. 9. Integration of spare part related additional benefits

To reduce the degree of non-integration of spare part additional benefits, spare part related requirements have to be integrated in the design task. Each component of the primary product fulfils its function (base benefit) to the function of the entire machine. The target is, in addition to that base benefit of the component, integrating spare part related additional benefits. Examples of spare part related additional benefits are already pointed out. A spare part related additional benefit must be configured in the way that the entire perceived benefit of the machine increases as well (Figure 9). Original spare parts from the OEM must be significant different to third party components that fit to the OEM machine as a spare part.

To reduce the degree of non-cooperation suitability of the supplier, cooperation suitable suppliers have to be chosen in early steps of the engineering process. Beside standard criteria like quality, delivery time, costs etc. the risk that suppliers could sell the part without informing the OEM has to be integrated in the supplier selection [12].

Evaluation of the Measures. To evaluate the measures, relations of the costs and the benefits due to the measure have to be analyzed. Therefore, it is necessary to determine and evaluate the additional costs and benefits in each phase of the product lifecycle. This has to be done for the product lifecycle in the perspective from the OEM and from the customer (Figure 10).

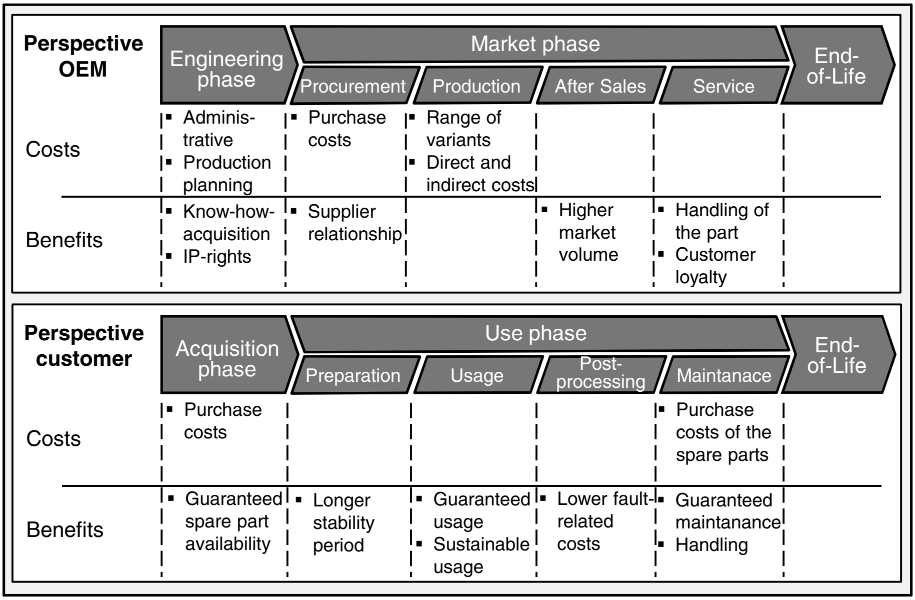


Fig. 10. Cost-benefit analysis

3.3 Integration in the Engineering Process

The engineering process is separated in several phases, starting with a planning and definition phase up to the phase start of production (SOP). The result of the engineering process is an intellectual product with all required product, production and service documents, resources and facilities to start with the series production of the PSS [16]. The development of the intellectual product happens step by step. Therefore, also the quantification, evaluation and the reduction of piracy risks has to be done step by step in the engineering process. The approach to quantify, evaluate and reduce piracy risks of a spare part is to multiply the rating number for the probability of piracy risk occurrence with the estimated impact factor. This has to be done step by step in the engineering process with the rating numbers of each risk parameter (Figure 11).

The quantification of the total piracy risk of the new machine generation has to be done at the end of the engineering process with the rating numbers of the morphological boxes. At the beginning of the engineering process should be determined the piracy risk of the old machine generation.

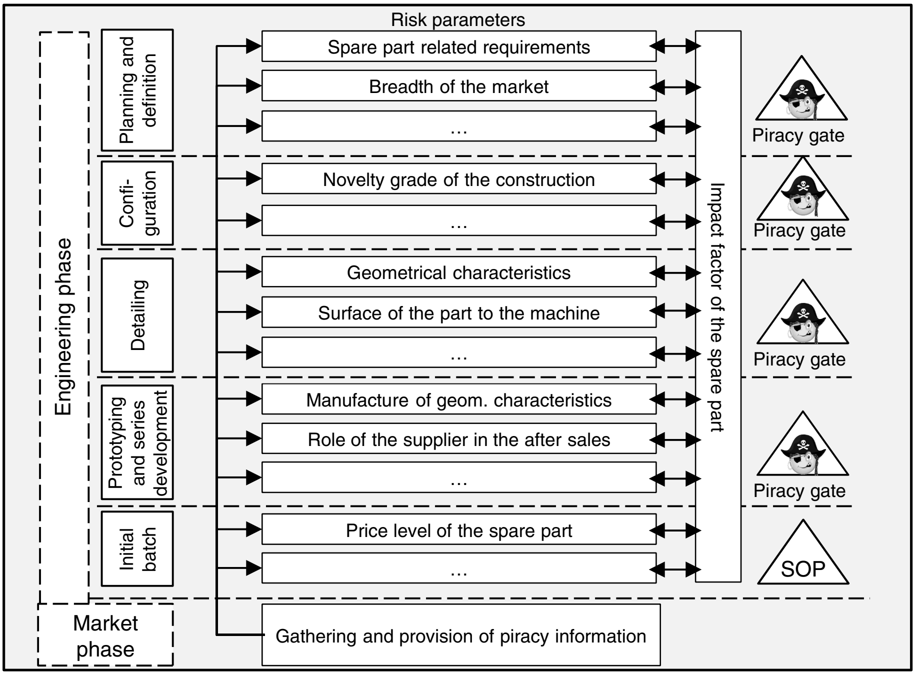


Fig. 11. Integration of piracy preventing in engineering process

Between the engineering process are determined several piracy gates. These gates are located between the engineering phases and review the piracy risk progress of the engineering process for spare parts. The prerequisite to determine all risk characteristics is the knowledge about market and piracy activities in the after sales. Therefore has to be gathered and provided piracy and market information in the market phase of the PSS.

4 Conclusion

Product piracy in the capital goods industry is a corporate risk which addresses in particular the spare parts business of OEM and hinders the sustainable realization of PSS. The causes for these risks are multi-faceted. Especially concepts focusing the capabilities of imitators, which are characterized as external induced piracy risks, have been developed during the last years. But in many cases OEM do not realize that product piracy is also internally induced by their own enterprise structure and self-inflicted within the product engineering process.

The presented approach identifies the causes and main drivers of internally induced piracy risks for spare parts. Furthermore, the approach evaluates a net-piracy risk by quantifying the probability of piracy occurrence and the gross loss of product piracy. To prevent self-inflicted product piracy, the approach points out some measures to reduce piracy risks. Finally, preventing self-inflicted product piracy is integrated in the engineering process.

References

1. Bohr, C., Kranz, J.-K., Aurich, J.C.: Life Cycle oriented Prevention of Product Piracy in technical Product-Service Systems. In: 4th CIRP Conference on IPSS, Tokyo (2012)
2. Aurich, J.C., Fuchs, C., Wagenknecht, C.: Lifecycle oriented design of technical Product-Service Systems. Journal of Cleaner Production 14, 1480–1494 (2006)
3. Gausemeier, J., Glatz, R., Lindemann, U.: Präventiver Produktschutz - Leitfaden und Anwendungsbeispiele. Hanser, München (2012)
4. Jacobs, L., Coskun Smali, A., Jedlik, T.: The Nigjtmare of International Product Piracy. Industrial Marketing Management 30, 499–509 (2001)
5. Neemann, C. W.: Methodik zum Schutz gegen Produktimitationen. Shaker, Aachen (2007)
6. Aurich, J.C., Kranz, J.-N., Bohr, C.: Prevention of Product Piracy for Spare Parts of Construction and Agricultural Machinery. In: 1st Commercial Vehicle Technology Symposium, Kaiserslautern, pp. 68–76 (2010)
7. Kuske, P., Abele, E.: Managing a Company´s Know-how-Strategy by a Strategic Portfolio. In: 44th CIRP Conference on Manufacturing Systems, Madison (2011)
8. Staake, T., Fleisch, E.: Countering Counterfeit Trade. Springer, Berlin (2008)
9. Minagawa Jr., T., Trott, P., Hoecht, A.: Counterfeit, imitation, reverse engineering and learning. R&D Management 37, 455–467 (2007)
10. Schuh, G., Harre, J., Gottschalk, S.: Design for Changeability. Wt Werkstatttechnik Online 94, 100–106 (2004)
11. Lanza, G., Weiler, S., Vogt, S.: Design for low-cost country sourcing. CIRP Journal of Manufacturing Science and Technology 2, 261–271 (2010)
12. Meier, H., Siebel, C.: Holistic Approach against product piracy. In: 43rd CIRP International Conference on Manufacturing Systems, Wien, pp. 609–616 (2010)
13. Schnapauff, K.: Präventiver Nachahmungsschutz bei technischen Produkten. TCW, München (2009)
14. Abele, E., Albers, A., Aurich, J.C., Günther, W.A.: Wirksamer Schutz gegen Produktpiraterie im Unternehmen. VDMA, Frankfurt (2010)
15. International Property Right Index (2012), `http://internationalpropertyrightsindex.org`
16. Eigner, M., Steltzer, R.: Product Lifecycle Management. Springer, Heidelberg (2009)

Managing Emotional Aspects of PSS Functionalities for Sustainability

Mircea Fulea, Emilia Brad, Bogdan Mocan, and Stelian Brad

Research Centre for Engineering and Management of Innovation, Technical University of Cluj-Napoca, 28 Memorandumului Str, 400020 Cluj-Napoca, Romania
{mircea.fulea,stelian.brad}@staff.utcluj.ro,
{emilia.brad,bogdan.mocan}@muri.utcluj.ro

Abstract. For an organization to become sustainable, turning towards PSSs seems appealing. However, the PSS approach is rather a support in this respect, not the solution itself. Although there has been lately a strong focus on methodologies and approaches of designing competitive PSSs, tackling with emotional aspects of functionalities to be provided is still a challenge. This paper addresses this issue by introducing a mean of sketching such unique functionalities and even triggering customer desires. Thus, sustainability is envisaged in two ways: (one) by making customers loyal in a constructive and creative way, and (second) by fitting up the SME with a distinctive (and difficult-to-copy) offer. The approach in this paper is applied within a case study in the domain of railway modelling, in which customers - apart from willing to spend much money for their hobby - are extremely demanding, and the emotional component of their buying behaviour is predominant.

Keywords: sustainability, functionality design, emotional aspects of functionalities.

1 Introduction

From its very beginning, the product-service system concept has been linked to sustainability. Together with sustainable design, production and consumption, PSSs accompany the paradigm shift towards functional economy [1-2]. Nevertheless, the focus on providing functionalities, instead of traditional products and services, raises new challenges in terms of competitiveness. Moreover, the more and more visible customer *emotional connection* concerning the value and benefits of a company's offer further complicates things [3].

Sustainability means to be able to last or continue for a long time [4]. It implies three major aspects - environmental, societal and economical [5-6], which need to be carefully balanced [7].

To sum up, the long-term competitiveness of a business determines its sustainability, and the PSS approach is an appealing framework for supporting “modern” requirements

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 165–175.
DOI: 10.1007/978-3-642-30820-8_15

like increased product or service customization or much shorter product (or service) life cycles, which in turn determine competitiveness [4].

However, being competitive also implies providing *those* functionalities that create satisfaction to the customer, while being specific to the provider and hard to be copied. Moreover, domains where customers buy products and services rather on an emotional basis further complicate the "equation" of sustainability. Therefore, although the PSS approach is a great support for business sustainability, it raises new challenges in terms of designing adequate functionalities. This is the case mostly for smaller businesses acting in creative domains, where the buying behaviour of their customers is more and more determined on an emotional basis.

To date, it is commonly accepted that product-service systems are able to support manufacturers to differentiate their products by meeting diversely segmented customer needs in a sustainable manner [8]. In the same time, several sources point out the *emotional reaction* as the key driver of buying decisions [3] [9] [10]. Additionally, they state that customers *emotionally engaged* to service providers may be more willing to tolerate inherent service or quality shortfalls [3] which occur mostly with new, innovative products and/or services, especially in creative domains.

Customer experience is widely accepted as being a key to a business' sustainability [11-12], being even considered the next competitive battleground [13]. However, managers mostly focus on *measuring customer satisfaction*, although it is more an outcome. Unfortunately, customer satisfaction surveys do not capture the emotional effect of the *service interaction* or the value that customers perceive from it. Many factors drive satisfaction and loyalty, based on a mixture of expectations, needs and reactions to the organisation and the perceived value received by the customer [3].

In general, tackling with emotional aspects of functionalities to be provided is a challenge; with PSSs, this challenge becomes critical, especially in terms of business sustainability. To address it, this paper focuses on a key aspect of a PSS life-cycle – its design - providing a mean of sketching unique functionalities and even triggering needs or desires of the customer.

2 The Problem

The increasing significance of knowledge to all aspects of economic production, distribution and consumption is strongly correlated to the creative industries [14], and creativity has become a key input into all sectors where design and content determine competitive advantages [14-15]. Lately, creative industries have received much interest, as organizations acting in creative domains face specific challenges, among which the emotional aspects of customers' behaviour are increasingly important.

Advertising, architecture, arts (also performing arts), crafts, design, fashion, software, publishing, and mass-media are all creative industries [16] [14]. However, there are other highly creative domains, with a niche market, like railway modelling (dating from 1910), requiring highly-skilled actors from domains like software, arts, architecture, design, and automation. Being superficially treated by many people like a hobby or simply toy stuff, railway modelling can be seen as an industry itself, with many model producers, hobbyists, clubs, magazines, and exhibitions worldwide. Aggregate figures regarding the railway model market size are difficult to be found, but – to get a glimpse on costs and extent – the Miniatur Wunderland permanent exhibition in Hamburg, Germany (with over 1.2 million visitors in 2011) represents an approx. EUR 12 million investment [17], while the railway model market in the US was estimated for 2010 at $424 million (and being on an ascending trend) [18].

Such niche domains raise even more challenges for businesses striving for sustainability: companies are usually small, human resource should be highly qualified and dedicated, structured approaches in management are rather uncommon, the products and services are expensive and *emotional buying is highly predominant* among customers. There are several additional factors that affect competitiveness (and therefore business sustainability) in such domains: technology dynamics, high demands (e.g. realistic models and landscapes, realistic automation), and buying behaviour unpredictability. PSSs might be a great support for such businesses; however, their design should systematically address the issues highlighted above.

The target group of such businesses is – to some extent – atypical. As such domains are specific to passionate and somehow "unpredictable" people, very few can estimate the amount of spending, the degree of involvement or the knowledge they will accumulate in the domain. Merchandisers cannot estimate such aspects either, so counting on specific customers can be an issue.

To achieve results and fulfilment in such a domain, one needs to be extremely creative, technically skilled and open-minded. In railway modelling, for instance, buying model cars and engines is far from being satisfactory if tracks are laid on the floor; adequate scenery (landscape, region, historical period) is a must for many people. Building such scenery (and automating models) requires a lot of expertise and creativity, but – in case of success – fulfilment (which is a pure emotional aspect) is worth the money they invest.

Merchandisers are directly affected by the (lack of) creativity and expertise of their customers. Simply playing with models, or just collecting them, might not be a motivation to invest in scenery products, tracks, turnouts or automation; on the other hand, a realistic diorama costs significantly more (possibly up to ten times) than the models themselves.

Businesses within such domains are in general focused towards traditional sales (models, accessories, scenery elements) and related services (model personalization, maintenance and diorama building). No reference could be found to reveal a systematic orientation towards supporting customers to get more skilled, which in turn could significantly increase revenue and customer loyalty. Moreover, no competitive advantages can be identified within such business models; therefore, sustainability might be a serious issue.

To conclude, the problems that such businesses face while striving for sustainability are – to a great extent – atypical. Less experienced customers do not generate enough revenue, experienced customers are extremely demanding and unpredictable, and the customer base is determined apparently only by chance, in an era in which entertainment alternatives abound. Turning towards PSS is an appealing alternative, but determining *those* functionalities to solve the above problems should be the real concern. This paper proposes a PSS design framework that systematically addresses the above issues, aiming towards business sustainability.

3 Current Approaches

To identify the current approaches in designing PSSs towards business sustainability, along with design approaches regarding customer satisfaction and emotional buying, a survey was conducted both within the scientific literature and the community.

Business sustainability requires investments made today for future results [2]. It requires a strategic approach of the way in which an organization's employees evolve, of how the organization understands its customers, their preferences, of how it makes them discover unexpected qualitative features of its product or service portfolio; and of how innovative and creative it is. Nowadays, only approaches at a very general level regarding PSS design for sustainability could be identified. For instance, in [19], designing PSSs for sustainability is tackled in terms of designing innovation strategies to shift the business focus from traditional product design towards PSS. While addressing sustainable PSS design ([20]), the design thinking concept is employed, stressing the importance of developing empathy for the people that will ultimately be impacted by the service or product being designed; however, it's more oriented towards rising awareness than towards the design process itself. Other identified approaches are similar to, or as general as, these ones.

Regarding customer satisfaction, a method that allows designers to compare PSS design solutions in the conceptual stage, based on a customer satisfaction estimation procedure, is presented in [8]. It uses a non-linear value function (called the satisfaction-attribute function) to quantify customer satisfaction. As a support tool, customer experience modelling is approached in [11], aiming to represent the different aspects of customer experience (which determines customer satisfaction) in a holistic, diagrammatic representation. No further significant references have been found that approach customer satisfaction (or experience) within the PSS design process.

It's worth noting that there are several approaches that effectively support the PSS design phase. However, in the particular context analysed in this paper, a new approach is needed with respect to the issues above.

4 The Methodology

To address the issues highlighted in the previous session, a PSS concept design methodology is proposed, to help assess functionalities according to the emotional aspects they're linked with, and to trigger needs or desires of the customer (in terms of new functionalities), by employing methods like AFD [21] and ASIT [22]. The methodology has been developed in the railway modelling domain context, but it can be applied for shaping PSSs in any similar creative domain. Sustainability is envisaged through increasing the competitiveness of the PSS, determining customer loyalty (making them “want more” in terms of functionalities that can be anticipated and designed accordingly), and making functionalities hard-to-be-copied.

Step I. Examine characteristics of the target group (existing and possible customers) and determine four typologies – or *personas* [8] - that describe it: three typologies for customers (be they existing or potential) and one for passionate people in the community that participate in thematic clubs. Each *persona* should be described by a set of particularities. For instance, 'collectors' would be those customers that are very demanding in terms of rolling stock details, that are mainly looking for historical models, for rare items, and which are not that interested in running performance or stability. The reason for describing the *persona* regarding people in thematic clubs is in the context of raising awareness and triggering desires for functionalities; it will be further explained below. The outputs of the first step are the four sets of *persona* characteristics.

Note: the authors have proposed a number of three (plus one) *personas* within this methodology, which is considered adequate, but more typologies can be used, if needed. However, this will result into a more elaborate work while applying the methodology.

Step II. Formulate market needs the PSS will respond to, and define target functions according to the market needs (examples of target functions could be 'increased realism', 'increased automation', 'scenery consistency', etc.). Using a concurrent approach, determine local solutions (local functional perspectives) in relation to each of the target functions [23-24]. The output of the second step is a local functionality set for each target function.

Step III. Extend the local functionality sets to an exhaustive set of (possible or implementable) functionalities, using a systematic and creative approach; methods like AFD and ASIT can be employed. To support this highly creative step, specific search operations could be conducted; for instance image web search based on relevant keywords and their synonyms. The output of this step is an extensive list of functionalities (ideally, 'all one can dream of', given they are – or seem - implementable).

Step IV. Formulate (and rank) criteria for assessing the functionalities identified in the previous step. For railway modelling, criteria should include – but not be limited to – uniqueness, attractiveness to customer, implementation difficulty, difficulty of being copied, degree to which it can trigger desire for other (related) functionalities, and implementation cost.

Step V. Assess (rank) the extended set of functionalities, using the criteria from step IV, in the context of each *persona's* particularities. Separate analyses should be done from the perspective of each *persona*. For instance, automated routes might be less appealing to collectors, while for other *personas* this could more likely trigger the desire for other functionalities like realistic turnout switching. Choose, for each *persona*, the best ranked functionalities that, on one hand, are most adequate to suit the initial target functions, and – on the other hand – have *the greatest potential of triggering the user's desire for other functionalities* (being also “on the list”). From this point on, there will be a slightly different PSS sketch for each *persona*, as target functions will have different local functional perspectives (see step II).

Starting with this step, *technical aspects regarding functionality implementation* should be considered. Only a small part of the functionalities identified in step III will be part of the (initial form of the) PSS, but, within its life-cycle, they should trigger the user's desire for other functionalities (also on the list in step III), which should be easily implementable from a technical point of view.

Step VI. Based on information from the previous steps, local solutions should be aggregated into one final functional perspective for each PSS. Each PSS concept should be best suited for its corresponding persona in terms of wow-features and exciting-quality, and eventually competitiveness.

Step VII. Perform a 9-Window analysis [25] for each functional perspective to sketch the future system, the future super-system and the future sub-system. The aim of this analysis is to support the identification of possible trends in terms of both customer expectations and technologies. The information obtained can be further used in step V (or even step I), in case of a spiral approach of the methodology.

Four PSS concepts (expressed as functional perspectives) are the output of the methodology, out of which one corresponds to the *persona* describing community members forming thematic clubs. As mentioned in the introductory sections of this paper, emotional fulfilment in such domains is strongly dependent on one's creativity, technical skills and passion. These characteristics are usually “incubated” in thematic clubs, where members share experiences, perspectives, and learn from each other. Thematic clubs are an important opportunity for merchandisers (PSS providers) not only to sell, but to promote their expertise and competitive advantages. In return, thematic clubs usually need support for various events, such as exhibitions or contests.

To *improve the potential customer's experience* in the domain, rather than wait for opportunities, a strategic partnership could be established between a PSS provider and a thematic club. The PSS concept developed with respect to the fourth *persona* would be the free-of-charge contribution of the PSS provider to the community; in turn, a great opportunity to learn about passions, skills, needs and wants of the representative target group (even trend setters) is opened. The authors of this paper believe that such a partnership is much more likely to be effective, in terms of *understanding* the target group, than market or customer satisfaction surveys. Having a PSS used by “top customers” in terms of skills and demand allows the understanding of both the rational and emotional aspects that drive the interaction with its functionalities. Moreover, having built-in functionalities that trigger the user's desire for other functionalities directly exposed to trend setters is a very effective way of promotion.

To sum up, this methodology actively deals with emotional aspects of PSS functionalities, which means identifying, assessing and even triggering them. However, a significant amount of effort is required in this respect, and – for increased effectiveness – adaptation of business processes might be highly necessary.

5 Application Example

This section presents the most relevant results of a case study in the railway modelling domain, in which the products and services of a merchandiser running a “traditional” business are turned into a PSS, using the methodology and approach introduced in this paper.

Step I. Four customer typologies (*personas*) were determined; for brevity, only one – the “thematic scenery modeller” – will be presented. This type of customers is mostly interested in diorama details, buying rolling stock according to a theme (be it modern railways, World War II themes, or the so-called “Epoch I”, up to 1925). He's usually skilled at landscaping, being less interested in automation or rolling stock running performance.

Step II. The market needs, expressed as general requirements, are RQ_1 – diorama to run trains on, RQ_2 – rolling stock, RQ_3 – diorama and rolling stock maintenance, RQ_4 – control and automation, RQ_5 – modifications allowed by users, RQ_6 – user skill improvement. According to these market needs, the following target functions were being formulated: TF_1 - increased realism, TF_2 - increased usability, TF_3 - increased automation, TF_4 – scenery consistency, TF_5 – short diorama building time, TF_6 – reduced costs. Using the approach in [23], local specifications have been determined for each target function. For exemplification, the following functionalities are part of the local solution for TF_1 *- increased realism*: (a) realistic trainsets, (b) theme-consistent scenery elements (buildings, nature, track layout, etc.), (c) rolling stock weathering, (d) consistent signalling, (e) sound (and steam) modules for locomotives, (f) turnout realistic switching.

Step III. Extending local functionality sets can be done either on an *ad-hoc* approach (by one's experience) or through specific methods (like AFD and ASIT). For instance, it's quite straightforward to extend the functionality (b) by identifying an exhaustive set of scenery elements: grass, bushes, trees, fences, paved roads, country roads, etc. for nature; non-circular track layouts, realistic trackbed (mix of differently coloured stones), bridges, tunnels, rail crossings, abandoned tracks, etc. for track layout and so on. However, many surprising possible functionalities may be discovered by using systematic methods. Two examples will be presented: one for the AFD and one for the ASIT method.

III.a. The starting point of this example is (b.3.3) *providing theme-consistent scenery elements – bridges*. AFD will be applied in the attempt to determine more functionalities. The “standard” problem formulation could be “bridges may not keep tracks fixed in specific conditions”. The inverted problem formulation could be “how could a bridge *not* keep tracks in place?”; the inverted and amplified problem formulation could be “how could a bridge not keep tracks in place *using available resources only*?” The available resources are detailed in Table 1.

Continuing with the AFD formalism, the result of the undesired phenomena is “unsteady track due to tension or vibrations”.

Table 1. AFD – available resources

Energy	Substances
Tensioned track Vibrations	Engines Cars

The next AFD step is the determination of phenomena with a similar result. In this case, these could be: diorama exposed by intense sunlight (through a window, at a precise time of day), which may cause track deformation (and derailments), or diorama exposed by significant temperature variation (for instance placed near a heater), which may cause track dilatation (and derailments if passed over with high speed).

The actual AFD analysis can stop here; several possible new functionalities can be inferred: (b.3.3.1) automatically have speed restrictions over bridges when a certain temperature variation is detected (this is related to TF_3 - *increased automation*), (b.3.3.2) include, in the track layout, "run down" bridges, by applying adequate weathering (for instance by painting small bracks on piles) and speed restriction signs, (b.3.3.3) incorporate a sensor (and warning sound) for exposure in direct sunlight, (b.3.3.4) automatically speed down trains over "run down" bridges, and (b.3.3.5) automatically speed down (only) locomotives over "run down" bridges (the latter two are also related to TF_3 - *increased automation*).

Note: functionalities like (b.3.3.1), (b.3.3.4) and (b.3.3.5) can be very easily implemented, even *after* the diorama is completed and automated, if they are taken into account in the stage of PSS concept development. Otherwise, the costs for implementing them afterwards might be very high.

III.b. The starting point for this second example is (b.2) *providing theme-consistent nature elements*. ASIT will be applied to identify new functionalities. The *product*, in this case, is "theme-consistent nature elements", which is adapted to a season of choice. The *problem world* is formulated as follows: "the diorama is decorated with natural scenery elements (grass, trees, and flowers), but, after a period of time, it may become boring as it is too static". The applied ASIT *thinking tool*, in this case, is *breaking symmetry*. The *object* that can be made asymmetrical is "nature elements". The *core idea* is to change nature elements in accordance with the seasons. Dioramas are usually modular, to make them movable and to ease servicing. Diorama modules are usually rectangular supports made of wood or polystyrene, on top of which track and scenery elements are mounted (most often by gluing). The idea is to add, on the module's base, an additional modular layer of polystyrene. One such sub-module will correspond to the area occupied by tracks and will be fixed, while others will support scenery and will allow dismounting. Up to four versions for such sub-modules should be built, having a similar layout but adapted to each of the four seasons. For instance, a forest area sub-module will have four versions containing trees with spring, summer, autumn (and without) leaves; trees should be placed on sub-modules using a consistent layout, to make them look-alike. The sub-modules will be interchanged each three months.

Note: the costs for having this functionality implemented are low, if diorama modules are designed accordingly, while the impact on realism is significant (it may be considered a wow-feature).

Step IV. The following criteria (and their ranks) are considered in this case study: uniqueness (4.8), attractiveness (9.2), wow-feature (5.1), difficulty (7.7), triggers desire for other functionalities (9.5), hard-to-be-copied (4.0), implementation cost (4.5).

Step V. The extended functionalities are ranked according to the criteria from step IV; only results for the "thematic scenery modeller" *persona* are presented here. To analyse them against the "triggers desire for other functionalities" criterion, a matrix was used (see Table 2; for brevity reasons, only partial results are presented): each cell contains the degree in which the functionality on the line triggers the functionality on the column (a Saaty scale [0, 1, 3, 9, 27] was used). Table 3 contains an excerpt of the ranked functionalities (with respect to all criteria).

In Table 2, results are calculated by summing up values on lines and normalising them afterwards. To calculate results in Table 3, values on columns are multiplied with the criteria rank and then summed; the result is multiplied with the emotional impact value (estimated on a scale from 0.1 to 0.9, in the context of the "thematic scenery modeller" *persona*).

Step VI. In the context of a specific *persona*, the functionality list is revised (extended) for each target function, according to information from step V. Using the approach in [23], a global PSS solution (functional perspective) is built for each *persona*.

Table 2. To what extent does a functionality trigger the desire for another one?

	...	(i)	(i+1)	(i+2)	...
...		...	...	...	...
(i) "run down" bridges (with adequate weathering)	...		27	9	...
(i+1) automatically speed down trains over "run down" bridges	...	3		3	...
(i+2) automatically speed down (only) locomotives over "run down" bridges	...	1	0		...
...	...	...	...	...	

Table 3. Functionalities ranked using criteria from step IV.

		...	(i)	(i+1)	(i+2)	...
uniqueness	4.8	...	3	27	27	...
attractiveness	9.2	...	9	27	27	...
wow-feature	5.1	...	-	9	9	...
difficulty	7.7	...	1	3	3	...
triggers desire for other functionalities (from table 2)	9.5	...	27	1	-	...
hard-to-be-copied	4.0	...	-	9	9	...
implementation cost	4.5	...	1	3	3	...
emotional impact		...	0.1	0.6	0.5	...
functionality rank		...	37	304	248	...

For the “thematic scenery modeller”, the final PSS concept is built around the idea of lending high-end diorama modules and selling customized rolling stock. The diorama control should be completely automated and controllable over the internet, to allow functionalities such as remotely programming new routes.

6 Conclusions, Limitations, Future Work

No “direct” or “correct” route towards business sustainability can be determined. However, sustainability can be attained through long-term competitiveness; especially in niche and creative industries, this implies a thorough knowledge of one's domain, customer needs, skills and – most important – the emotional impact of provided functionalities.

PSSs are great competitiveness supports for businesses acting in creative domains. The approach introduced in this paper adds robustness to this support in terms of shaping PSS functionalities that make customers loyal in a constructive and creative way, and are difficult to be copied. Also, customers are supported to achieve more fulfilling results within the domain, with a positive impact on the PSS provider's business. To sum up, this means *investments made today for future results*, i.e. sustainability.

The above approach aims to increase the effectiveness of PSS design. Nevertheless, it has also limitations. Business in such domains is usually small, and the skills of competitive engineering, required by the methodology, need to be developed. Moreover, the results (in terms of benefits) of such a methodology are difficult to be measured, thus proving its effectiveness is not straightforward.

Future research, related to this approach, will be conducted in two respects: (a) a mean to measure the costs and benefits of the PSS developed for the community persona, and (b) a more detailed analysis of the mechanism of triggering customer desires for specific functionalities.

References

1. Strahel, W.: The Functional Economy: Cultural and Organizational Change, `http://www.product-life.org/en/archive/the-functional-economy-cultural-and-organizational-change`
2. Geum, Y., Park, Y.: Designing the sustainable product-service integration: a product-service blueprint approach. Journal of Cleaner Production 19, 1601–1614 (2011)
3. Customer Experience: Everything Is An Emotional Buy, `http://www.customerservicemanager.com/customer-experience-everything-is-an-emotional-buy.htm`
4. Candea, D.: Conjectures about the Relationship among Business Sustainability, Learning Organization, and Management Systems Integration. Review of Management and Economical Engineering 6(5), 138–143 (2007)
5. Seliger, G., Severengiz, S., Weinert, N.: Sustainable Industrial Value Creation Nets. In: Proceedings of the 15th CIRP International Conference on Life Cycle Engineering, Sydney, Australia, pp. 1–4 (2008)

6. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems - IPS2. CIRP Annals - Manufacturing Technology 59, 607–627 (2010)
7. Schonsleben, P., Vodicka, M., Bunse, K., Ernst, F.O.: The changing concept of sustainability and economic opportunities for energy-intensive industries. CIRP Annals - Manufacturing Technology 59, 477–480 (2010)
8. Kimita, K., Shimomura, Y., Arai, T.: Evaluation of customer satisfaction for PSS design. Journal of Manufacturing Technology Management 20(5), 654–673 (2009)
9. Emotional Buying – MTD Sales Training Blog, http://www.mtdsalestraining.com/mtdblog/tag/emotional-buying
10. Five Emotional Marketing Triggers that Determine Why We Buy, http://www.torok.com/articles/marketing/5EmotionalTriggers.html
11. Teixeira, J., Patrıcio, L., Nunes, N., Nobrega, L., Fisk, R., Constantine, L.: Customer experience modeling: from customer experience to service design. Journal of Service Management 23(3), 362–376 (2012)
12. Shaw, C., Ivens, J.: Building Great Customer Experiences. Palgrave Macmillan, Basingstoke (2005)
13. Pine, B., Gilmore, J.: Welcome to the experience economy. Harvard Business Review 76, 97–105 (1998)
14. Flew, T.: Beyond ad hocery: Defining the creative industries. In: 2nd International Conference on Cultural Policy Research, Te Papa, Wellington, New Zealand (2002), http://eprints.qut.edu.au/archive/00000256
15. Nguyen, L., Shanks, G.: A framework for understanding creativity in requirements engineering. Information and Software Technology 51, 655–662 (2009)
16. Creative Industries Statistical Estimates Statistical Bulletin, London, UK, Department of Culture, Media and Sport (2006)
17. Miniatur Wunderland, http://de.wikipedia.org/wiki/Miniatur_Wunderland
18. Model Retailer Magazine, http://www.modelretailer.com/en/The%20Industry/Industry%20News/2011/04/Size%20of%20Hobby%20Industry.aspx
19. Manzini, E., Vezzoli, C.: A strategic design approach to develop sustainable product service systems: examples taken from the ‘environmentally friendly innovation’ Italian prize. Journal of Cleaner Production 11(8), 851–857 (2003)
20. Young, G.: Design thinking and sustainability (2010), http://zum.io/wp-content/uploads/2010/06/Design-thinking-and-sustainability.pdf
21. Visnepolschi, S., Zlotin, B., Kaplan, S., Zusman, A.: New Tools for Failure and Risk Analysis: Anticipatory Failure Determination (AFD). Ideation International Inc., Southfield (1999)
22. Turner, S.: ASIT -a problem solving strategy for education and eco-friendly sustainable design. International Journal of Technology and Design Education 19(2), 221–235 (2009)
23. Brad, S., Fulea, M., Brad, E.: A PSS Approach in Software Development. In: Proceedings of the CIRP IPS2 Conference, Linköping, Sweeden, pp. 291–298 (2010)
24. Fulea, M., Brad, S.: Ontology-based approach for supporting creativity in a PSS design methodology. In: Proceedings of the 3rd CIRP IPS2 Conference, Braunschweig, Germany (2011)
25. Evaluate - and Solve - Your Problem Through 9 Windows, http://www.realinnovation.com/content/c070730a.asp

Economic and Environmental Impacts of Product Service Lifetime: A Life-Cycle Perspective

Minjung Kwak and Harrison Kim*

Department of Industrial and Enterprise Systems Engineering,
University of Illinois at Urbana-Champaign, 104 S Mathews Ave., Urbana, IL 61801, USA
{kwak14,hmkim}@illinois.edu

Abstract. This paper presents a generic model for evaluating the economic and environmental impacts of product service lifetime, which is important and useful in the design and management of PSS. From a PSS provider's perspective, the presented model conducts life-cycle costing (LCC) and life-cycle assessment (LCA) simultaneously and quantifies the total life-cycle cost and environmental impact associated with the product lifetime. The entire life cycle of the product is considered, including its manufacturing (or purchase), usage, maintenance, and end-of-life treatment. Applied with a sensitivity analysis of varying product lifetime, the model can identify the optimal service lifetime at which the life-cycle cost and environmental impact can be minimized. To illustrate, the developed model is applied to the example of a piece of currently-marketed agricultural machinery.

Keywords: Product life cycle, life-cycle costing (LCC), life-cycle assessment (LCA), product lifetime planning, optimal equipment replacement.

1 Introduction

As awareness and concern for environmental issues increase, business and government are faced with the key challenge of determining how best to promote and facilitate sustainable production and consumption. Products must be designed and manufactured carefully so that the entire lifecycle of a product (i.e., manufacturing, usage, maintenance, and end-of-life treatment) satisfies customers' needs while minimizing adverse environmental impacts. Product service system (PSS) can be a promising solution to this challenge. By selling functions instead of physical products, a PSS can satisfy customers' needs while reducing adverse environmental impacts [1].

This paper highlights the importance of a product's lifetime (i.e., the length of service) in the design and management of PSS. From a PSS provider's perspective, product service lifetime (hereinafter referred to as product lifetime) is an important factor that influences the total cost and environmental performance of their business.

* Corresponding author.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 177–189.
DOI: 10.1007/978-3-642-30820-8_16

To maximize the economic and environmental sustainability of a PSS, it is critical to understand the impact of product lifetime. This paper presents a generic model that can be used to evaluate product lifetime. Life-cycle costing (LCC) and life-cycle assessment (LCA) are conducted simultaneously to evaluate the economic and environmental consequences of product lifetime. To illustrate, the developed model is applied to an example of currently-marketed agricultural machinery.

The remainder of the paper is organized as follows. Sections 2 and 3 describe the models for life-cycle costing and life-cycle assessment, respectively. Section 4 presents an illustrative case study with the example of an agricultural machine. Section 5 provides a summary of the study and concludes the paper.

2 Life-Cycle Costing

2.1 Overview

Life-cycle costing (LCC) is a technique for calculating the total costs related to a product and its entire life cycle. The life cycle of a product can be divided into four stages, i.e., manufacturing (or purchase), usage, maintenance, and end-of-life treatment. This section presents an LCC approach to calculating costs associated with the four life-cycle stages. The approach also incorporates costs for taxes, insurance and storage. Equation (1) provides the total life-cycle cost, C^{total}, under consideration:

$$C^{total} = C^{mfg} + C^{usage} + C^{maint} + C^{eol} + C^{tis} + C^{it} \tag{1}$$

where C^{mfg}, C^{usage}, C^{maint}, and C^{eol} denote the costs of manufacturing, usage, maintenance, and end-of-life treatment, respectively, C^{tis} denotes the costs for property taxes, insurance, and storage (TIS), and C^{it} denotes the income tax effects.

The cost models in this paper provide the total and per-hour costs of product life cycle, given a specific product lifetime, *TY* (in years). Time value of money is considered in all models. More specifically, the models first calculate present equivalent of the total cost, and convert it into a series of equivalent uniform annual costs occurring at the end of each year for *TY* years. The capital recovery factor $i/[1-(1+i)^{-TY}]$ is used for the computation [2]. (See Equation (2) for example.) The resulting annual cost is then divided by the annual hours of product usage, *AH* (in hours), to obtain the hourly cost of the product (e.g., Equation (3)). In this paper, annual compounding with the real interest *i%* is applied, and the year-end occurrence is assumed for all costs—all cash flows associated with the year occur at the end of the year.

2.2 Manufacturing (Purchase)

The cost occurring at this stage is the manufacturing cost or the purchase expense. Suppose that the total cost at this stage is C^{mfg}. Since the product is acquired at time zero, there is no need to consider time value.

Equation (2) finds the uniform annual cost, AC^{mfg}, occurring at the end of each year that would be equivalent to the present cost C^{mfg}. Finally, Equation (3) gives the hourly cost of manufacturing, HC^{mfg}, by dividing AC^{mfg} by AH.

$$AC^{mfg} = C^{mfg} \cdot \left[\frac{i(1+i)^{TY}}{(1+i)^{TY} - 1} \right] \tag{2}$$

$$HC^{mfg} = AC^{mfg} / AH \tag{3}$$

2.3 Usage

Product usage generally involves the costs of energy consumption, such as cost of fuel, gas, or electricity. Suppose that a product consumes fuel for its operation, and the average fuel consumption rate (i.e., the amount of fuel consumed for an hour of operation) is estimated as FR (in kg fuel/hour). Equation (4) then calculates the per-hour cost of usage by multiplying FR by the unit price of fuel (i.e., c^{fuel}). It is also possible to compute the total usage cost, C^{usage} (in present value), as shown in Equation (5). First, the uniform annual cost, AC^{usage}, is obtained by multiplying HC^{usage} by the annual hours of product usage, AH. For each annual cost, its present equivalent is obtained considering the timing of its occurrence, and all the resulting present equivalents are summed up to the total usage cost, C^{usage}.

$$HC^{usage} = c^{fuel} \cdot FR \tag{4}$$

$$C^{usage} = \sum_{N=1}^{TY} AC^{usage}(1+i)^{-N} = \frac{AC^{usage}}{i} \cdot \left[1 - \frac{1}{(1+i)^{TY}} \right] \tag{5}$$

where $AC^{usage} = HC^{usage} \cdot AH$

2.4 Maintenance

Maintenance activities, i.e., the replacement of parts and lubricants, are another factor that affects the life-cycle cost of a product. To capture the cost of maintenance, one should know the number of replacements during the life cycle, the unit cost of each replacement, and the timing of cash flow for each replacement.

Equation (6) computes the total number of replacements of part k during TY years, i.e., RN_k, where λ_k denotes the replacement cycle of part k (in hours), and TH refers to the total product lifetime (in hours), i.e., total accumulated hours of usage during TY years. In Equation (6), the first replacement cycle is subtracted from TH, since the first part is included in a new machine and does not constitute a replacement.

$$RN_k = \left\lceil \frac{\max(0, TH - \lambda_k)}{\lambda_k} \right\rceil \quad \text{where } TH = AH \cdot TY \tag{6}$$

$$C^{maint} = \sum_{k \in K} \sum_{M=1}^{RN_k} c_k^{maint} \cdot \propto_k \cdot (1+i)^{-\lceil \lambda_k M / AH \rceil} \quad (7)$$

Equation (7) computes C^{maint}, the present equivalent of the total maintenance cost. Here, μ_k denotes the number of units of part k in the product, and e_k^{maint} denotes the per-unit cost (or purchase price) of replacement part k. Since all cash flows occur at the end of years, it must be identified for each replacement when it happens, in other words, what year the cost should be assigned to. The exponent using ceiling function is developed for this purpose. Similar to Equations (2) and (3), the total cost of maintenance can be converted into its equivalent costs per year and per hour. The same capital recovery factor and AH are used for the calculation.

2.5 End-of-Life Treatment

The end-of-life phase involves activities such as third-party resale, recycling and disposal. It incorporates processing of the used product and all the waste from its maintenance (i.e., replaced part k). The product is sold for the salvage value of c_{prod}^{eol}, while the waste is processed with the unit cost of c_k^{eol}. Equation (8) computes the total cost of end-of-life treatment in its present equivalent. The total cost of end-of-life treatment can be converted into its equivalent costs per year and per hour, using the capital recovery factor.

$$C^{eol} = c_{prod}^{eol} \cdot (1+i)^{-TY} + \sum_{k \in K} \sum_{M=1}^{RN_k} c_k^{eol} \cdot \propto_k \cdot (1+i)^{-\lceil \lambda_k M / AH \rceil} \quad (8)$$

2.6 Property Tax, Insurance, and Storage

Taxes (property taxes, not income taxes), insurance, and storage (TIS) are another cost component due to product ownership. This paper assumes that this cost of TIS is paid at the end of each and every year, and that it equals to a fixed rate (i.e., α) of the market value of a product, mv_N, that may depreciate over time [3].

$$C^{tis} = \sum_{N=1}^{TY} \alpha \cdot mv_N \cdot (1+i)^{-N} \quad (9)$$

2.7 Income Tax Effects

This paper considers three income tax effects, i.e., tax savings from depreciation, c_1^{it}, tax deductions due to deductible expenses, c_2^{it}, and the income tax related to product resale at the end of year TY, c_3^{it} [4]. The sum of all three components gives the total income tax effect over the lifetime, C^{it}.

$$C_1^{it} = -\sum_{N=1}^{TY} \gamma \cdot \beta_N \cdot C^{mfg} \cdot (1+i)^{-N} \quad (10)$$

The value of product depreciates over time. The depreciation can be regarded as expense, which in turn reduces the income taxes. Equation (10) quantifies the total tax saving from product depreciation. The total saving has negative value since it reduces costs. The effective income tax rate is given as γ. The annual tax in year N is determined by the depreciation rate of the year, β_N. The depreciation rates are defined by the tax law, and the sum of all depreciation rates over time reaches up to one; they are unconnected to the depreciation of market value.

Equation (11) computes the total tax deductions over the lifetime. The expenses at the usage and maintenance stages are assumed tax deductible [5]. Since time value was already considered in C^{usage} and C^{maint}, there is no need to discount the value.

$$C_2^{it} = -\gamma \cdot (C^{usage} + C^{maint}) \tag{11}$$

Equation (12) calculates the income tax for the gain or loss at the end-of-life stage. When the used product is sold to a third-party at the end of year TY, the differences between its salvage value, c_{prod}^{eol}, (i.e., the actual selling price at the end of year TY) and the book value (i.e., value assessed based on the tax law and the depreciation rates, β_N) determines the tax amount.

$$C_3^{it} = \gamma \cdot (c_{prod}^{eol} - C^{mfg} \cdot \sum_{N=1}^{TY} \beta_N) \cdot (1+i)^{-TY} \tag{12}$$

3 Life-Cycle Assessment

3.1 Overview

Life-cycle assessment (LCA) is an essential tool for achieving design for life cycle. LCA evaluates the potential environmental impact associated with a system (i.e., a product, a service, or a PSS), considering its entire life cycle. As shown in many previous studies (e.g., [6, 7]), an effective LCA can demonstrate how much environmental impact is caused by a system and how different life-cycle phases and/or subsystems contribute to the total impact. The results of the LCA help identify priority areas for improvement and ways to reduce environmental impacts.

$$I^{total} = I^{mfg} + I^{usage} + I^{maint} + I^{eol} \tag{13}$$

Equation (13) computes the total life-cycle impact of a product, I^{total}. Here, I^{mfg}, I^{usage}, I^{maint}, and I^{eol} denote the impacts of manufacturing, usage, maintenance, and end-of-life treatment, respectively. It should be noted that the environmental impacts has no time value, unlike the life-cycle costs in Section 2. In the remainder of the section, it is discussed how to assess the impact of each life-cycle stage. Given specific product lifetime TY, the models calculate the total environmental impact; the hourly impact is then obtained by dividing the total impact by TH (= $AH \cdot TY$).

3.2 Manufacturing

The impact of manufacturing is determined by the design of a product. More precisely, it is defined by the material composition and manufacturing processes of the product. Transportation is also included. The mass, travel distance, and transportation mode (e.g., truck, oceanic freight shipping) determine the impact of transportation.

Equation (14) computes the impact of manufacturing, where e_r^{matl}, e_p^{mproc}, and e_q^{tproc} denote the per-unit impacts of raw material r ($r \in R$), manufacturing process p ($p \in P$), and transportation mode q ($q \in Q$), respectively; x_r, x_p, and x_q denote the total number of units of material r, manufacturing process p, and transportation mode q, respectively, that are used in manufacturing the product.

$$I^{mfg} = \sum_{r \in R} e_r^{matl} \cdot x_r + \sum_{p \in P} e_p^{mproc} \cdot x_p + \sum_{q \in Q} e_q^{tproc} \cdot x_q \tag{14}$$

3.3 Usage

The impact of usage can be divided into the impact of energy consumption and the impact of emissions. For the product using fuel for its operation, the former includes the impacts from producing and delivering fuel. The latter focuses on the emissions from diesel fuel combustion, such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM).

Equation (15) formulates the environmental impact of fuel consumption, I^{fuel}. In the equation, e^{fuel}, FR, and TH denote the unit impact of fuel (i.e., impact per kg fuel), the average fuel consumption rate (in kg/hr), and the total product lifetime in hours, respectively. Equation (16) formulates the impact of emissions, where $e_l^{emission}$ and ER_l denote the unit environmental impact (impact per kg of emission) and the average emission rate (in kg/hr) of emission j, respectively.

$$I^{fuel} = e^{fuel} \cdot FR \cdot TH \tag{15}$$

$$I^{emission} = \sum_{l \in L} \left(e_l^{emission} \cdot ER_l \cdot TH \right) \tag{16}$$

3.4 Maintenance

Equation (17) computes the impact of maintenance, where e_k^{maint} denotes the per-unit impact of a replacement part k. As described in Section 2.4, μ_k denotes the number of units of part k in the product, RN_k denotes the total number of replacements of part k over the lifetime TH, and λ_k denotes the replacement cycle of part k in hours. Again, the first replacement cycle is subtracted from TH, since the impact of the first replacement was already counted at the manufacturing stage.

$$I^{maint} = \sum_{k \in K} \propto_k \cdot RN_k \cdot e_k^{maint} = \sum_{k \in K} \propto_k \cdot \left\lceil \frac{\max(0, TH - \lambda_k)}{\lambda_k} \right\rceil \cdot e_k^{maint} \tag{17}$$

3.5 End-of-Life Treatment

The impact of end-of-life treatment includes both the impacts of processing the end-of-life machine and processing all replacement parts and fluids consumed over the life cycle. Equation (18) provides the impact of end-of-life treatment, where e_{prod}^{eol} and e_k^{eol} denote the unit environmental impacts of used product and used part *k*, respectively. As described in Section 2.5, the used product is assumed to be sold to a third-party at the end of year *TY*. Thus, its impact may include the impact of delivering the product to the third-party. The unit impact of used part *k* includes both the impact of its transportation to the treatment facility and the impact of its recycling and/or disposal.

$$I^{eol} = e_{prod}^{eol} + \sum_{k \in K} \propto_k \cdot \left\lceil \frac{\max(0, TH - \lambda_k)}{\lambda_k} \right\rceil \cdot e_k^{eol} \tag{18}$$

4 Illustrative Case Study: Agricultural Machinery

4.1 Background

To illustrate the developed model, a case study of an agricultural harvester is presented in this section. The target machine is characterized by a complex product structure with a large number of constituent parts, and it has high fuel consumption throughout its long lifetime. Throughout its lifetime, the machine is assumed to be used following a constant usage pattern: 400 hours of operation per year (i.e., *AH* = 400) with 75% of the time spent for actual production (25% idling).

Suppose there is a company planning a PSS business with the target machine. The company aims to find the optimal machine lifetime *TY** (in years) whereby the total life-cycle cost and environmental impact of the machine would be minimized. In this study, 9% real interest rate was assumed based on the company's after-tax weighted average cost of capital (WACC) [2]. Regarding the income tax, the effective tax rate was assumed to be 25%. The trend of book values is assumed following the 7-year MACRS (Modified Accelerated Cost-Recovery System) depreciation rule; for the first seven years, the depreciation rates are 10.71, 19.13, 15.03, 12.25, 12.25, 12.25, 12.25, and 6.13%, respectively [5]. Afterwards, the depreciation rates are zero. Figure 1 shows the depreciation trend of the target machine.

In this case study, global warming potential (GWP) was used as the measure of environmental impact, even though the model generally is applicable with any other impact metrics as well, such as an Eco-Indicator 99 score. LCA software SimaPro 7.3 and life-cycle impact assessment (LCIA) method IPCC 2007 were used for the impact assessment. IPCC 2007 quantifies the GWP of product life cycle considering greenhouse gas emissions for a fixed time period (in this study, 100 years). The unit of GWP is kg CO_2 equivalent (kg CO_2e).

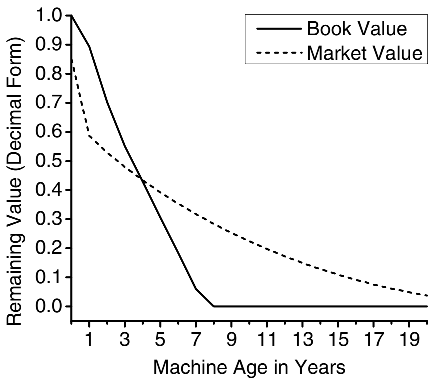


Fig. 1. Value depreciation assumed for the target machine [3, 5]

Table 1. Assumptions on maintenance: major parts replacement

Part	Replacement cycle	Replacement cost
Tires (6 units)	3000 hours	$12,400
Engine	5000 hours	$42,700
Transmission	3000 hours	$38,700
Hydraulic components	3000 hours	$45,500
Axles	5000 hours	$9,600

Table 2. Fuel consumption (kg/hr) and emission rates (g/hr) assumed for the target machine

Type	Nonidling	Idling	Average
Diesel fuel	47.07	21.37	40.65
Nitrogen oxides (NO_x)	372.73	143.16	315.34
Particulate matter (PM)	1.76	0.67	1.49
Carbon monoxide (CO)	23.84	9.16	20.17
Hydrocarbons (HC)	5.42	2.08	4.59
Sulfur dioxide (SO_2)	0.99	0.45	0.86
Carbon dioxide (CO_2)	149627.50	67944.69	129206.80

Purchase and TIS. The weight of the target machine is approximately 23,000 kg, and more than 16,000 parts are used in its manufacturing. The machine consists mostly of steel and cast iron (approximately 90%). Rubber and plastics are the second and third prevalent materials. The price and environmental impact (impact of manufacturing only) of a new machine were assumed to be $350,000 and 83,000 kg CO_2e. The market value depreciates over time, and the cost of TIS (i.e., property tax, insurance, and storage costs) also decreases accordingly. In this study, the depreciation model from Ref. [3] was adopted for the market value estimation. The model estimates the market value trend of a machine by considering its age and the annual hours of usage. It gives the market value at the end of each year. Figure 2 shows the market value trend assumed for the target machine. Finally, the TIS rate was assumed to be 2% in total (i.e., $\alpha = 0.02$).

Maintenance. The type and frequency of maintenance activities were assumed based on the average maintenance schedule recommended by the equipment's manufacturer. Table 1 shows some of the assumptions relative to the replacement of major parts. It was assumed that the first major rebuilding will occur at 3,000 hours (in year 8) and that the engine will be replaced at 5,000 hours (in year 13). Minor parts, oil, filters, and fluids also were replaced following its own maintenance schedule. The costs per replacement were assumed based on the manufacturer's parts catalog.

For simplicity, this study assumed that the major repairs and overhauls do not affect the book value or the market value of the machine. However, if they require adjustments of the values, a more sophisticated approach may need to be applied in assuming value depreciation in Figure 2 [4].

Usage. The use phase of the target machine involves two impact sources: diesel fuel consumption and emissions. Table 2 shows the fuel consumption (in kg/hr) and emission rates (in g/hr) assumed for the target machine. The density and cost of diesel fuel were assumed as 0.855 kg/liter and $1.08/kg (= $3.5/gallon), respectively.

End-of-Life Treatment. At the end-of-life stage, the machine is sold to a third-party. The salvage value was assumed to be identical with the market value of the machine. Zero environmental impact was assigned in case of the third-party resale.

All waste from maintenance is either recycled or discarded. In terms of weight, 90% of steel and iron is recycled while the rest 10% is discarded by landfill. The other materials are discarded either by landfill (80%) or incineration (20%). The processing cost was assumed as $40 per metric ton. For allocation of environmental impact, the "cut-off approach" was applied. In other words, the environmental impacts or benefits from recycling were not allocated to the current life cycle [8, 9].

4.2 Evaluation Result: Implications of Product Service Lifetime

The stacked column charts in Figures 2 and 3 present the results of life-cycle costing and life-cycle assessment, respectively. Per-hour values are illustrated for various lengths of product lifetime from 1 to 20 years.

Life-Cycle Cost. Figure 2 shows the per-hour cost of product life cycle with different lengths of service lifetime. Each stacked column shows how the eight cost components (i.e., four life-cycle stages, TIS, and income tax effects) contribute to the total cost for the given product lifetime. A negative value indicates that the cost component saves taxes or recovers some costs (e.g., end-of-life stage recovers the purchase expense of the machine).

Figure 2 shows how the per-hour life-cycle cost would change with the lifetime of the machine, *TY*. Basically, the per-hour cost in the black line shows a decreasing trend with the age of the machine. This is due mainly to the reduced cost of manufacturing; the more years a machine is used, the more hours there are to spread the cost of manufacturing over. However, as the lifetime increases more, the benefit of longer lifetime is sometimes offset by the increasing cost of maintenance. Although maintenance expenses accompany some income tax savings, they become one of the most expensive components with the age of the machine. Especially, the major rebuilding and parts replacements create significant rise in the total cost, especially in year 8, year 13, and year 16.

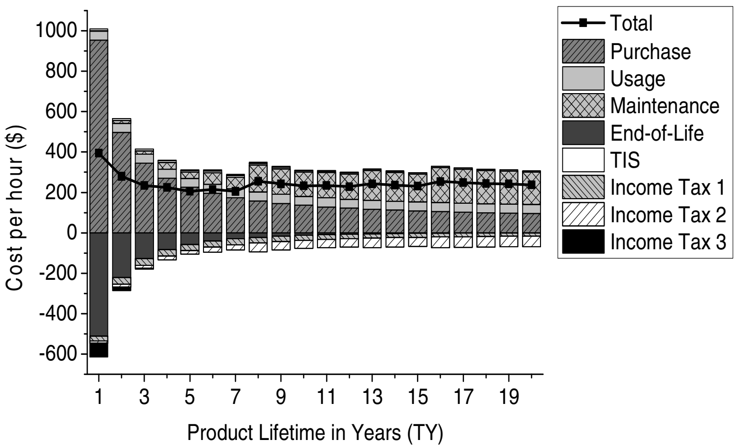


Fig. 2. Per-hour costs of product life cycle varying for different lifetime lengths

A trade-off also exists between the costs of end-of-life stage and TIS. Since the market value of the machine depreciates with machine age, the longer lifetime implies the less salvage value at the end of life stage. However, the depreciation can help save TIS (and sometimes income taxes, as well).

Life-Cycle Impact. Figure 3 shows the results of the environmental impact assessment with various years of machine lifetime. All impacts are for an hour of operation. Each column in the figure shows the amount and contribution of the global warming potential impact associated with different life-cycle phases. The overall trend of the per-hour impact is similar to that of per-hour cost. The per-hour impact shows a decreasing trend with the age of the machine due to the reduced impact of manufacturing. However, the major rebuilding and parts replacements sometimes cause some increases in the per-hour impact.

Implication of Product Lifetime. One major difference to note for Figure 3 is that, the usage stage is the main contributor for the total environmental impact, and the maintenance stage is less emphasized. Accordingly, the influence of maintenance is not much significant in Figure 3. Such difference leads to different consequences for the same product lifetime. Figure 4(a) compares the trends of per-hour cost and per-hour impact for the same range of product lifetime from 1 to 20 years. When $TY = 8$, 13, and 16 – the years of machine rebuilding and major parts replacement, both the

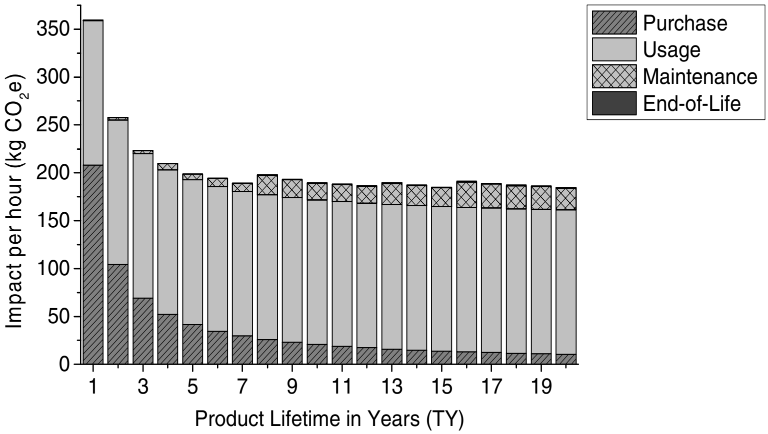


Fig. 3. Per-hour impacts of product life cycle varying for different lifetime lengths

cost and impact show the same increasing trends. However, the degree of increase in per-hour impact is marginal compared to the degree shown in per-hour cost.

Figure 4(b) compares different lengths of product lifetime using a two dimensional map. The x-axis represents the per-hour cost, and the y-axis represents the per-hour environmental impact. As highlighted in the figure (red circles), four lifetime lengths were revealed as Pareto optimal alternatives. These are *TY* = 7, 12, 15, and 20 years. The lifetime with the minimum cost is 7 years, while the lifetime with the minimum environmental impact is 20 years.

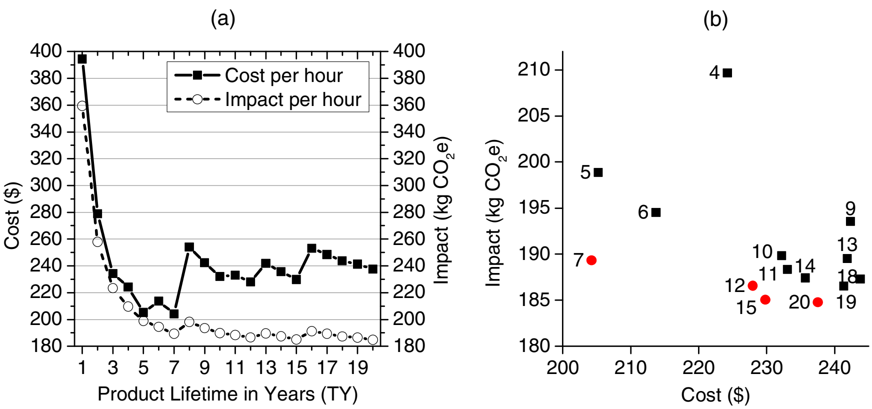


Fig. 4. Implications of product service lifetime: (a) Trends in economic and environmental consequences, (b) Pareto optimal for service lifetime (data label: product lifetime in years)

5 Discussion

To minimize costs and environmental impacts associated with a PSS, it is important to carefully set the product lifetime. Understanding the economic and environmental impacts of product lifetime is critical in this regard. This paper presents a generic model that can be used to evaluate the service lifetime of a product.

The model consists of two parts, i.e., life-cycle costing (LCC) and life-cycle assessment (LCA), which simultaneously evaluate the economic and environmental impacts of product service lifetime. The model considers the entire life cycle of a product, including its manufacturing (or purchase), usage, maintenance, and end-of-life treatment. Important economic factors, such as time value of money, taxes, and value depreciation, were also taken into account. Applied with a sensitivity analysis of varying product lifetime, the model can identify the service lifetime at which the life-cycle cost and environmental impact can be minimized. The developed model was demonstrated with a currently-marketed agricultural harvester.

In the future, sensitivity analyses will be conducted to clarify how various parameters and variables affect the economic and environmental impacts of product lifetime. Optimal product lifetime is also affected by improvement in the performance of new products [10]. In future research, the current model, which only considers a single product, should be extended to a more sophisticated model that could consider multiple generations of products with significant technological changes.

Acknowledgments. This material is based upon the work supported by Deere and Company and the National Science Foundation under Award No. 0953021. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of Deere and Company and the National Science Foundation.

References

1. Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M., Wilson, H.: State-of-the-Art in Product-Service Systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 221, 1543–1552 (2007)
2. Sullivan, W.G., Wicks, E.M., Koelling, C.P.: Engineering Economy, 14th edn. Pearson Education, Inc., Upper Saddle River (2009)
3. Terry, K.: Farm Machinery Operation Cost Calculations. Kansas State University (1997)
4. Peurifoy, R.L., Schexnayder, C.J.: Construction Planning, Equipment, and Methods, 6th edn. McGraw-Hill, New York (2002)
5. Edwards, W.: Income Tax Considerations When Buying Farm Machinery. Iowa State University (2005)
6. Haapala, K.R., Brown, K.L., Sutherland, J.W.: A Life Cycle Environmental and Economic Comparison of Clothes Washing Product-Service Systems. Transactions of NAMRI/SME 36, 333–340 (2008)

7. Sousa, S.R., Ometto, A.R.: Application of Life Cycle Assessment in Service Industries: A Review. In: Proceedings of LCM 2011 (2011)
8. Ekvall, T., Tillman, A.M.: Open-Loop Recycling: Criteria for Allocation Procedures. International Journal of Life Cycle Assessment 2, 155–162 (1997)
9. Vogtländer, J.G., Brezet, H.C., Hendriks, C.F.: Allocation in Recycling Systems: An Integrated Model for the Analyses of Environmental Impact and Market Value. International Journal of Life Cycle Assessment 6, 344–355 (2001)
10. Van Nes, N., Cramer, J., Stevels, A.: A Practical Approach to the Ecological Lifetime Optimization of Electronic Products. In: Proceedings of the EcoDesign 1999, pp. 108–111 (1999)

Case Studies of Sustainable PSS Business Models for City Mobility

Jialiang Hu and Günther Seliger

Institute for Machine Tools and Factory Management, Technische Universität Berlin, PTZ 2 Pascalstr.8-9, 10587, Berlin, Germany
{jhu,seliger}@mf.tu-berlin.de

Abstract. From the viewpoint of sustainability development, the living standard could be increased by the economic development without worsening resource shortage and environmental stresses. As an innovative business model, Product-Service Systems (PSS) give the chance to satisfy the sustainability of consumption and production, but PSS are not automatic sustainable by itself. Increasing the resource efficiency is the goal and also the means of realizing sustainable development. Therefore, resource efficiency is becoming one of the key indicators of the sustainability development. In the areas of human living, city mobility brings the convenience and comfort, and also the problems of energy shortage and environmental/social negative impacts. This paper presents two case studies of PSS-oriented city mobility systems, i.e. sustainable e-Bike renting and e-Car sharing. The relevant products and services are designed systematically with the consideration of increasing the resource efficiency along the whole PSS-lifecycle.

Keywords: Product-Service Systems, Sustainability, Lifecycle, Resource Efficiency, City Mobility.

1 Introduction

Sustainable development is defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs in the year of 1987 by UN [1]. From this definition, the emphasis of sustainability development lies on the continuous satisfaction of the human needs which are realized and satisfied by using natural resources. In case of improving their ability to meet their primary needs like food, clothes, living and mobility by own competence and initiative while complying with sustainability standards, good opportunities to essentially balance the uneven global distribution of wealth can be tapped. Production technologies in the broadest sense determine the relation between benefit and the required use of resources [2]. For this purpose new production processes and products, a decreasing intensity of resource consumption and a closed loop economy are required [3].

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 191–202.
DOI: 10.1007/978-3-642-30820-8_17

Urban transport is one of the important sections in human living environment. Urban transport has various modes in the urban area and can be roughly classified as road transport, rail transport, water transport and cable transport. In this paper, city mobility is defined as the means of road transport in urban areas i.e. car, bus, motorcycle and bike. According to the three dimensions of sustainable development (economic, social and ecological aspects), city mobility presents both of challenges and opportunities from the viewpoint of sustainability development. In the economic aspect, various kinds of mobility enable the production and trade in urban and rural areas by supporting the goods transportation. In the social aspect, people use the mobility to reach their desired places and join the social events. In the ecological aspect, mobility causes the problems of resource shortage and environmental pollution.

Since last decades, the politics and society have pushed the companies to take the responsibilities of environment protection and resource reservation. Besides facing to the social pressures, the companies also have to confront to the problems of resources such as shortage and increasing price of raw material, energy and water. Those external and internal threats force the companies to shift their traditional business in a sustainable way. There is a tendency towards combined offers of products and services, which are sold together to fulfill customer demands. These combinations of products and services are called Product-Service Systems (PSS) [4]. According to its goal groups, the PSS business model can be divided as B2B market and B2C market. Especially, PSS in B2B market is defined as Industrial PSS (IPS²). PSS give the chance to satisfy the sustainability of consumption and production. PSS are trying to satisfy all the three dimensions of sustainability simultaneously along the lifecycle of PSS.

In recent years, amount of PSS business models are developed in the field of city mobility which are facing to the individual customers more than the industry or company. These PSS-based city mobility systems provide the practical examples for implementing and developing the IPS² in a sustainable way. In this paper, two case studies are presented to design a sustainable PSS business models in city mobility with the consideration of lifecycle resource efficiency.

2 Product-Service Systems for City Mobility

2.1 Sustainability of City Mobility

Due to the growing urbanization, the needs of speed, comfort and safety in city mobility are becoming more and more important. By 2030, 60% of the population will live in a city as predicted by [5]. An increasing human population expands the demands on city infrastructures for transport. Meanwhile, the problems related to urban transport that have interrelated impacts on the environment, the economy and society, are always getting bigger as the cities are growing in size and population. On one hand, city mobility has indeed changed the mode of human life and increased the quality of life; on the other hand, the existing city mobility is facing to the challenges from the viewpoint of sustainability development. For example, cars enable a free individual lifestyle but can be possessed only by few people due to the limited road capacity and high expenditure. Public transports like buses provide a more environmental transport mode but less flexibility. Motorcycles have been the primary transport mode in many developing countries, e.g. in Southeast Asia, but motorcycles are by their nature far less crashworthy than closed vehicles [6]. Besides the dangerousness, motorcycles lead to the inefficient traffic due to its disordering on road. Comparing with the above motorized city mobility modes, bikes can be regarded as a kind of green mobility, but its advantages always depend on the condition of weather, infrastructure, topography and the intended distance.

As Fig. 1 shows, the challenges of city mobility are related to many issues within sustainability and its three dimensions. The utility of city mobility strongly depends on the transport infrastructure. The governments are responsible for the investment in roads and the affiliated facilities. In developed countries like in Western Europe, car as a public transportation are still the most effective way to travel. In developing countries, cars are not easy to access due to the high expenditure and also the weak infrastructure. Meanwhile, an efficient city mobility system helps the economic and social activities. City mobility is also influenced by the increasing price of fuel and other costs in the long-term. Therefore, city mobility has a close connection with economy. These motorized transport means are the notable cause of social problems such as noise, air pollution and traffic congestion. Cars and other light duty vehicles are a major source of greenhouse gas emissions, producing around 15% of the EU's

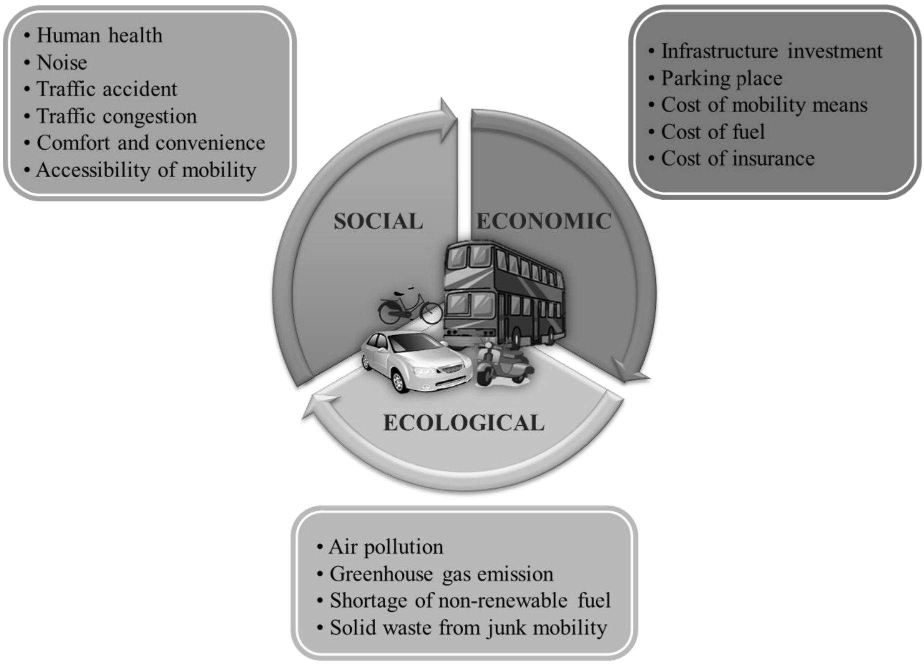


Fig. 1. Challenges of city mobility from the viewpoint of sustainability

emissions of CO_2 [7]. Actually, some of the problems could be stated in different dimensions, for example, the traffic congestion can be regarded as a social problem and also an economic problem due to the wasted time and energy. The vehicle exhaust during the congestion causes a significant impact to the environment.

2.2 PSS Business Models for City Mobility

In recent years, amount of PSS-based business models are introduced into the field of city mobility. Due to their common characteristic that transfers the functionality without shifting the ownership of product, these business models can be regarded as use/function-oriented PSS. For example, since 2002 German Railway (Deutsche Bahn) provides a service, so called "Call a Bike" [8], which can rent the bike to customers automatically through the hotline supported locking system. Furthermore, similar services have occurred on automobile due to its higher speed and better accessibility of long distance, for example, Car2go [9] and DriveNow [10]. The most contributions of such PSS in city mobility lie in resource saving.

According to the existing examples of PSS business models around the world that introduced in [11], the contributions on sustainability by PSS are:

- Ecology: saving resources by more intangible service, improving recycling activities,
- Society: increasing users' satisfaction by high quality service and product, creating new job opportunity in service section, provide access to modern technology,
- Economy: creating new business field and keep competitiveness of company motivated by market.

In other words, PSS are born under the needs of sustainability development. As an innovative business model, PSS are placed high hopes on improving the sustainability. But PSS are not automatically sustainable [12]. In the reference of [13], 14 sorts of barriers of PSS are concluded and analyzed. Companies are facing such risks and uncertainties which could obstruct the implementing the PSS. Those potential problems also weaken the enthusiasm of PSS providers and customers, who would confront with many difficulties during the implementation of PSS, for example, undefined responsibility, unprotected privacy and technical problems. In the industrial PSS, the use of technology is limited due to the shortage of qualification. Especially in developing countries the qualification level of worker and technicians is not comparable to the one in the developed world. Actually, the developing or emerging countries provide a huge market for implementing PSS with the help of low cost human resources. In order to ensure the products are usable and reliable, as promised in the contract, the PSS provider has to qualify the local worker and technician from the customer or contractors and supervise their work from distance.

To increase the sustainability of such business models for city mobility, PSS are still facing many challenges of sustainability. A sustainable PSS is not only environmentally reasonable but also a chance for making profits. The PSS providers need to earn profits based on their businesses. The other conventional companies should be encouraged by the benefits and profits from the innovative business model. Therefore, the profit model of a PSS needs to be strengthened and presented for the potential PSS providers. This point might be connected with another question: why have PSS not been widely implemented yet? The recognition between PSS providers and customers is one of the most crucial barriers in the implementation of PSS. For example, selling functionality or result instead of selling products alone is advantageous once additional costs for information processing and logistics are less than costs for underutilized capacity. But from the viewpoint of customers, they might only recognize that they should pay more for enjoying the combination of product and service but ignore the benefits from the new business model.

Besides the aspect of business, the resource efficiency is a challenge to PSS while the existing PSS models usually ignore the resource efficiency by providing the PSS. So called Jevons Paradox (also known as rebound effect) shows the dilemma between the technological progress with increased efficiency and the rebounded consumption of resource [14]. In some PSS business models like renting or sharing a vehicle, the original intension is to reduce production and save resource. But in fact, the customers might enjoy the easy access of automobile regardless of the energy saving or product maintaining. The problems occur usually in the availability-/results-oriented PSS, because the ownership of products will be never shifted to the end customers, and due to the weak public awareness related to sustainability, the providers should pay for the economic and environmental losses that caused by inefficient consumption of customers.

3 Resource Efficiency in Product-Service Systems

3.1 PSS Lifecycle and Resource

According to life cycle thinking, the resource use for products and services in PSS should be considered, because the impacts of products and services should be analyzed from cradle to grave, i.e. from resource extraction to final waste disposal [15]. Aurich and Schweitzer presented the concept of Lifecycle management of IPS² [16] and further continuous improvement process [17] of it. Thinking of the product lifecycle alone, there are many phases included, e.g. material extraction, design, production, delivery, use, recycling and disposal. Service lifecycle was presented by Torney et al. [18] and Meiren et al. [19]. The lifecycle of service includes idea finding, requirement analysis, service design, service implementation, evaluation, and displacement. As a system, PSS should always coordinate both of product and service sections. Some new phases are required between them such as PSS configuration. Referred to the existing product lifecycle, the PSS-lifecycle is generally divided into five phases, e.g. organizational implementation, PSS-planning, PSS-design, PSS-configuration and PSS-realization. The PSS-lifecycle is shown in two directions, i.e. one from manufacturer point of view, and the other from customer point of view as Fig. 2 shows. The difficulty is to systematically integrate the service section together with the product lifecycle.

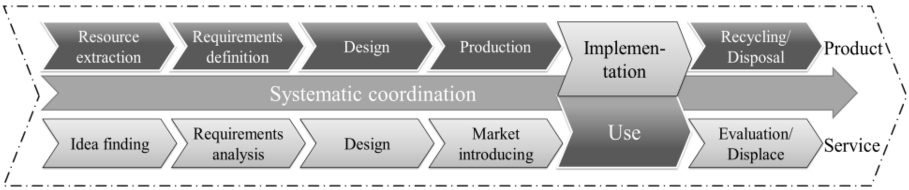


Fig. 2. Lifecycle of Product-Service Systems

As mentioned before, the aim of sustainability development is defined as to satisfy the needs in the future. From Maslow's theory, the needs of human-being could be concluded as a hierarchy with five levels such as physiological, safety, love and belongingness, esteem and self-actualization [20]. These basic needs are put in the bottom of the pyramid-like hierarchy which presents the preconditioning between each level. These basic needs of human-being are always realized and satisfied by using natural resources, which plays an important role in the sustainability development. Normally, the resource is understood as the natural resource which can be found within the environment, such as water, air, energy carrier and so on. Specifically, resource is defined in [21] as market access, innovative products and capital in the viewpoint of national economics and focus on the production management which is aiming to produce goods optimally with such resources. The resources can be specified as personnel, equipment, material, time and information. In fact, time and information are the intangible resource that must be attached to the production process and during the use of information, an upgrading of information leads to knowledge generation. Personnel are used as the main body of production where their capability to operate the equipment to process the material into end products. Therefore, all kinds of resources are involved with each other in the different phases of product and service lifecycle.

On one hand, the natural resources provide the necessary raw materials, energy carriers and water to support the production and human living, but due to the limitation and increasing demands, resource undersupplying and increasing price is becoming a problem of society, especially industry. On the other hand, during the lifecycle of resource, i.e. extraction, usage and disposal, the natural environment has been exploited by the wrong treatments. People cannot live in this worsening environment. Furthermore, resource productivity also determines the competitiveness and profitability of company. Thus, the resource is involved within the three dimensions of sustainability. From the economic and ecological point of view, realizing the sustainable development can be partly simplified as a process of increasing the resource efficiency. The resource efficiency determines the sustainability of PSS. Along the lifecycle of PSS, different resources will be used in the lifecycle phases of product and service. According to the using insensitivity of resource, the product and service can be classified as different types due to resources-intensive product or service in the lifecycle phases.

3.2 Designing PSS Concerning Resource Efficiency

Resource efficiency means using the Earth's limited resources in a sustainable manner while minimizing impacts on the environment. In other words, resource efficiency aims to create more with less and to deliver greater value with less input [22]. Designing a PSS based on the traditional business model, namely selling the product alone, new services should be designed and adapted to the existing products. When the PSS business runs well, more ideas of new services would appear, and then more requirements on products would be requested by those new services. In other words, the providers would improve their products and services simultaneously, so that they could provide a set of available services with required products or products with suitable services continuously.

Designing a sustainable PSS business model with the consideration of resource efficiency is the core concept of the paper. An approach is to be designed with efficient technology which can shift the resource use into a high efficient way. Resource efficiency could work as the indicator of the designed business model. Therefore, realizing the sustainability of the PSS could be simplified as increasing the resource efficiency. Resource will be not always used in product lifecycle, but also can be saved by technology that plays a key role in sustainable development. As mentioned before, the resources are used to realize the product and service lifecycle, in other words, tangible product itself should be designed to create more value with less resource. As an intangible activity, service contributes as an add-on function beside of product and also creates new value by dematerialized way. Thus, the Value-Resource ratio could be taken into account to measure resource efficiency. By analyzing the existing product and its resource consumption the value of resource input could be generated, e.g. water volume or material weight, which used as input reference for the functional realization. Hereby, the approach begins with the thoughts of resource consumption and value creation, and further provides a new viewpoint for product design with consideration of resource consumption.

4 Case Study

Research [23] has found that 46% of bikes are used only once or twice a week, with a further 30% being used once a fortnight or even less. And cars are used only about 60 minutes per day. The rest idle tie, all the bike or cars are placing in the parking place which causes other social problems. Therefore, the basic idea is renting or sharing the idle city mobility for public using. With the analysis of existing PSS business models for city mobility, two case studies, i.e. PSS based e-Bike renting and e-Car sharing, was designed in a sustainable way. So that three dimensions could be satisfied simultaneously.

4.1 PSS Business Model for e-Bike Renting

Based on the existing business model of bike renting systems, the case study of PSS based e-Bike renting system is done. Comparing with the conventional city mobility, e-Bike has many advantages in viewpoint of sustainability, as Fig. 3 shows.

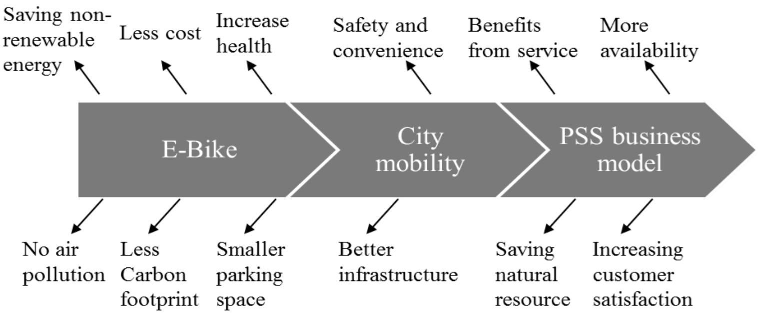


Fig. 3. Advantages of PSS business models for city mobility based on e-Bike

An e-Bike can maintain a higher average speed than a conventional bike, yet take advantage of the same network of cycle facilities, giving access to routes that cars and motorcycles cannot reach. The result is a faster door-to-door journey time than any other mode. By nipping along the relatively uncongested cycle network, but eliminating hills and headwinds, electric bikes are often the most consistent mode of travel. An e-Bike increases the average speed and enabling the physical disabilities or aged people. The easing effect would be getting larger in hilly areas where usually are under developed. The speed of e-Bikes is limited as 25kmh in law, so they require no tax, insurance or license. A recent survey of e-Bike owners reveals that a third rides their bike at least once a day and 81% use the bike at least once a week [24]. Especially, e-Bike introduces the renewable energy into the city mobility system and improves the sustainability of it in a large scale. So, an innovative business model of bike renting should to be designed for the sustainable use e-Bike.

Comparing with the conventional bike, e-Bike has its own characteristic, namely, the battery charging. With the battery the bike can be more effective but it takes also the problem, not like the petroleum powered mobility which can be tanked in few minutes, the bottleneck of e-Bike lies on the duration of battery and the time of battery charging. Furthermore, the normal e-Bikes are designed with a 3-5 kg embedded motors which cannot be removed from the bike, so the bikes are getting troublesome due to the weight of battery and motor, when the battery is empty or the customer just want to ride on a single bike without electric driving system.

For these challenges of e-Bike and the business model, the core concept of this development is based on a “Service automat”. A service automat is designed with a touch screen and spaces which can store the batteries, and also other accessories, so called toolkits. Fig. 4 shows the process of renting an e-Bike which can be divided into three sections, i.e. registration and renting, riding and probably upgrading, and return.

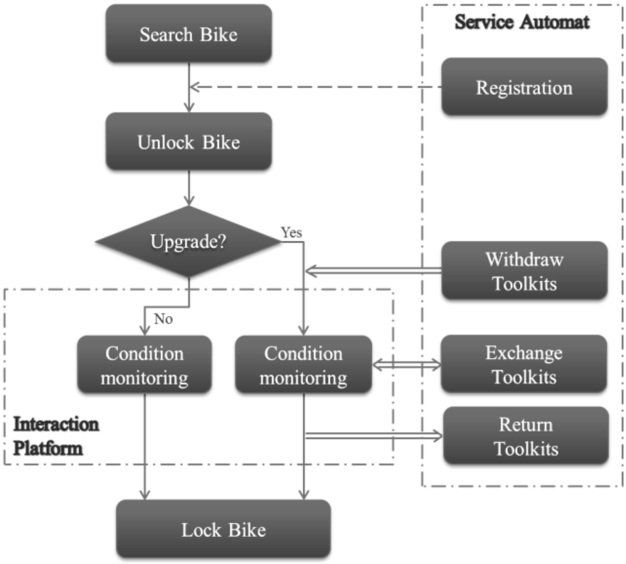


Fig. 4. Concept diagram of e-Bike renting system

A serial of "plug-play style" toolkits are developed under the principle of quick-fix, so that the customers can install the toolkits within minute-scale period. The problem of battery charging can be solved by the approach of changing the backup batteries which are stored in the service automat. And some other value-added services are provided based on these toolkits. Customers find one of the service automats in the city and withdraw the toolkits according to their needs. With a simple installation instruction, service will be enabled and charged by renting time. A motor kit is designed to improve the flexibility of e-Bike. The motor kit presents a new approach for the electric motorization. In comparison with the existing e-Bike with embedded irremovable motor, the motor kit drives the bike in external way and can be easily installed or removed from the bike in few minutes. The removable motor kit improves the flexibility of the bike.

To enable the PSS based e-Bike renting and service providing, lots of information and communication technologies (ICT) have been implemented. Besides the toolkits in service automat, the ICT powered interaction platform enables the information service during the whole renting process. The smart phone works as a portable computer for data acquirement and data transition. A smart phone application was developed to collect the information from condition sensors, GPS receiver and RFID reader. Based on the real-time information, the application provides more service-like functions, for example, Location-based Service guides the customers to their wished goals; Condition-based Monitoring enables the remote supervision of the bike; Data analyzing provides the transport advising.

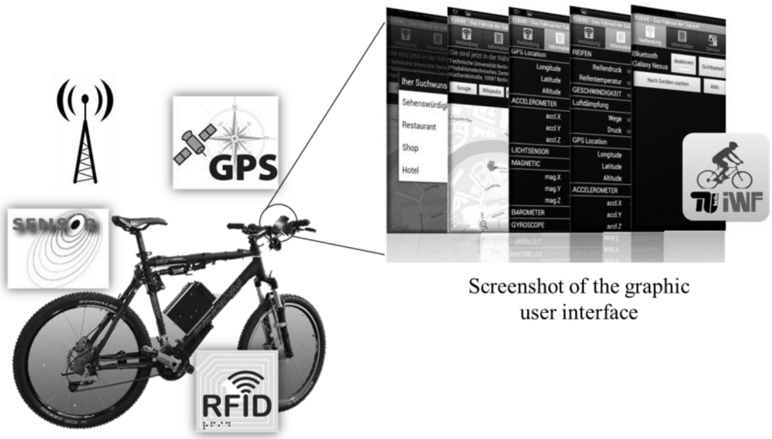


Fig. 5. ICT powered interaction platform on e-Bike

As Fig. 5 shows, an interaction platform is developed on the smart phone. Customers can download the application to their own smart phone by swiping the Near-Field-Communication tag or scanning the bar code or QR-code. Using the interaction platform, customers can get the service information, such as battery status and predicted distance, condition parameters of the e-Bike, location based services and the nearest service automat. To interact with the PSS provider, customer can call or send message to the information center to access more services. In the final step of e-Bike renting, customer need to report the probable damage and pay the charge through user account.

4.2 PSS Business Model for e-Car Sharing

In comparison with the e-Bike renting, the second case study e-Car sharing lays the emphasis on PSS based sharing system. As mentioned before, cars are still the most freedom mode in the city mobility, but facing the requirements of sustainability, relevant problems in social, economic and ecological dimensions should be solved. With the development of battery technology, e-Car is becoming the most feasible transport means with low carbon emission and no air pollution. To support the implementation of e-Car, many charging networks have been built in cities worldwide, but similar to the conventional cars, the e-Car has also the problem of low resource efficiency which increases the investment of car and makes large parking place occupied. Thus, the general thinking of the case study is share the cars, namely let more people who are in need of the car be able to access it in the idle time.

The business models include two kinds of owners. One is the car renting companies which own a number of cars or e-Cars in the city. And the other is the private sharers who want to share the car for the sharing system. The owners of cars can submit the information of car location and available time to the sharing platform. Customers are able to find the available cars by the web-based platform. After positioning the suitable car, customers can get the car with the member card.

The resource efficiency for maintenance of car can be regarded as the most important point in the e-Car sharing system. Due to the separated ownership, the customers tend to use the shared car in an irrational way. In order to divide the responsibility of probable damages on car, the condition of the cars should be monitored by using on-board measurement which is pre-installed on the cars with several sensors to record the condition parameters and GPS information. The PSS-providers, e.g. car sharing platform takes the charge of supervision and other legal issues according to the agreed general business terms.

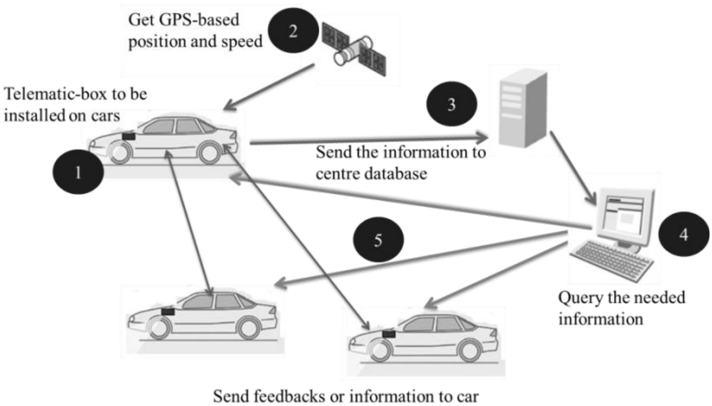


Fig. 6. e-Car sharing and the data flow

As Figure 6 shows, the data flow of condition based monitoring between all the objects in the car sharing system. Condition based monitoring enables the efficient maintenance activity and avoids the dispute due to car damage. Without that, the PSS business model could not be implemented in a profitable way, although the e-Car sharing concept has satisfied the requirements of sustainability in ecological and social dimension.

5 Conclusion

City mobility inclusive cars, buses, motorcycles and bikes which provide the customers convenient transport mode in urban areas. With the development of urbanization and world population, city mobility is facing to the challenges from requirements of sustainability development, and several problems need to be changed. Product-Service Systems as an innovative business model provides a change for the sustainable city mobility system. In this paper the resource efficiency of PSS lifecycle has been regarded as the key to improve the sustainability of city mobility. Two case studies about designing sustainable PSS business model for city mobility have been presented with the consideration of lifecycle resource efficiency. The further research would be taken in the work of integrating the resource management for the production of PSS-based city mobility system.

References

1. United Nations General Assembly: Towards Sustainable Development, Report of the World Commission on Environment and Development: Our Common Future (1987)
2. Collaborative Research Centre 1026: Sustainable Manufacturing - Shaping global value creation, DFG Proposal (2011)
3. Seliger, G.: Sustainability in Manufacturing - Recovery of Resources in Product and Material Cycles. Springer, Heidelberg (2007)
4. McAloone, T., Andreasen, M.M.: Design for Utility, Sustainability and social virtues: Developing Product Service Systems. In: International Design Conference - Design (2004)
5. United Nations Population Fund: State of world population 2007 - unleashing the Potential of Urban Growth (2007)
6. Insurance Information Institute: Motorcycle Crashes, `http://www.iii.org/`
7. European Commission: Road transport: Reducing CO2 emissions from vehicles, `http://ec.europa.eu/`
8. Deutsche Bahn: Call a bike, `http://www.callabike-interaktiv.de/`
9. DriveNow GmbH, `https://www.drive-now.com/`
10. Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., et al.: State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 221(10), 1543–1552 (2007)
11. Sakao, T.: Introduction to Product/Service-System Design. Springer, London (2009)
12. Kuo, T.C., Ma, H.Y., Huang, S.H., Hu, A.H., Huang, C.S.: Barriers analysis for product service systems using interpretive structural model. International Advanced Manufacturing Technology 49(1-4), 407–417 (2010)
13. Alcott, B.: Jevons' paradox. Ecological Economics 54(1), 9–21 (2005)
14. Mont, O., Bleischwitz, R.: Sustainable consumption and resource management in the light of life cycle thinking. European Environment 17(1), 59–76 (2007)
15. Schweitzer, E., Mannweiler, C., Aurich, J.C.: Continuous improvement of industrial product-service systems. In: Proceedings of the 11st CIRP Industrial Product-Service Systems (IPS2) Conference. Cranfield University Press (2009)
16. Aurich, J.C., Schweitzer, E., Fuchs, C.: Life cycle management of industrial product-service systems. In: Proceedings of 14th CIRP Conference on Lifecycle Engineering, pp. 171–176. Springer, London (2007)
17. Torney, M., Kuntzky, K., Herrmann, C.: Service Development and Implementation - A Review of the State of the Art. In: Proceedings of the 1st CIRP Industrial Product-Service Systems (IPS^2) Conference. Cranfield University Press (2009)
18. Meiren, T., Barth, T.: Service Engineering in Unternehmen umsetzen. Leitfaden für die Entwicklung von Dienstleistungen. Fraunhofer-Verlag (2002)
19. Maslow, A.H.: A Theory of Human Motivation. Psychological Review 50, 370–396 (1943)
20. Gienke, H., Kämpf, R.: Handbuch: Produktion. Carl Hanser Verlag München (2007)
21. European Commission: The roadmap to a resource efficient Europe. Online Resource Efficiency Platform, p. 18 (2011)
22. Davies, D.G., Hartley, E.: New Cycle Owners: expectations and experiences. Transport Research Laboratory (1999)
23. Guthrie, N.: The New Generation of Private Vehicles in the UK (2001)

Design Buckles to Facilitate Eco-design of Product-Service Systems

Lucile Trevisan, Alan Lelah, Peggy Zwolinski, and Daniel Brissaud

G-SCOP Laboratory, University of Grenoble, 46 avenue Félix Viallet, 38031 Grenoble, France
lucile.trevisan@g-scop.grenoble-inp.fr

Abstract. Eco-efficiency in Product-Service Systems (PSS) is one of today's challenges for achieving sustainability and reducing the environmental burden of our production and consumption patterns. However, there are few eco-design methods and tools for the development of eco-efficient PSS and some issues are still not solved for systematic design of environmentally friendly PSS. This paper aims to show that the 'design buckle' object - previously developed in the PSS literature - is a concept which can support the system design by enabling the generation and comparison of alternative solutions. An environmental assessment can be performed on the buckles and facilitate the design process for providing eco-efficient PSS.

Keywords: Product-Service Systems, eco-efficiency, design, eco-design, environmental assessment.

1 Introduction

Modern societies have to reduce their consumption of physical resources enormously. In this context, Product-Service Systems could be seen as a lever to improve the environmental performance by a factor X [1] while providing the same benefits to the customer as a traditional product. Mont defined PSS as systems in which, products, services, supporting infrastructure and necessary networks, are designed to provide a certain quality of life to customers, and at the same time, minimize environmental impacts of the system [2]. By focusing on the final user's satisfaction instead of on the product itself, PSS should create new consumption behaviors. Renting, sharing and pooling could lead to important environmental gains [3]. Nevertheless, most of the authors dealing with these issues emphasize on the importance of carefully designing PSS in a holistic perspective to achieve sustainability [4] and then eco-efficiency. However, PSS eco-design raises several issues and methods and tools are still largely missing in the PSS literature.

The concept of "design buckles" (DB) has previously been developed by Maussang et al. [5] in a global PSS design methodology. The purpose of this paper is to show how the DB concept can facilitate the eco-design of PSS by enhancing the integration of environmental considerations and the evaluation of alternative solutions at the buckle level. Following this introduction, this paper describes in Section 2 the

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 203–214.
DOI: 10.1007/978-3-642-30820-8_18

issues raised by the design of eco-efficient PSS and details the existing methods attempting to solve these issues. The DB concept is then explained in Section 3 and an extension of this concept is proposed to show how it can be helpful in the eco-design of PSS. Finally, in Section 4, a case study on a refrigerating system illustrates how the buckles can be evaluated to compare solutions and facilitate the eco-design of PSS.

2 Issues Raised in Designing Eco-efficient PSS

2.1 Integration of Products and Services

Many design methods to develop products and services have been proposed in literature. In a general manner, major differences exist between Product- and Service-oriented design methods. Product-oriented design methods mainly focus on the technical performance given to the products. Series of "Design for X" methodologies exist and aim at attaining specific goals (X) on the products [6]. Products are physical units often described by the functions they provide. In Service-oriented design methods, the design object is not a physical artifact but the description of processes and activities. Indeed, in a service delivery process, designers have to focus on the customer experience, and value is considered as created for the user during an activity and based on the performance and outcome of the activity [7].

However, services are always supported by products [8], which have to be integrated into the description of the system. One of the difficulties raised by the PSS design is coupling product- and service-oriented methods focusing on different design objects. Aurich et al. [9] emphasize this question for the development of technical PSS, noticing that service and product design are often performed separately, resulting in a lack of consideration of the mutual influences of products and technical services. They argue that these two design processes need to be linked to achieve integrated PSS design processes. Without this consideration of the whole system in an integrated design process, it seems to be difficult for designers to adopt a holistic approach, encompassing the environmental, social and economic considerations, which are major challenges for the development of sustainable PSS [4].

2.2 Eco-design Issues

Eco-design aims to integrate environmental considerations into the design process. Bovea and Pérez-Belis [10] proposed a taxonomy of existing eco-design tools, which aims to help designers selecting the most appropriate ones according to several criteria. The framework of the taxonomy raises some general observations. First, there is no tool which enables the integration of both technical and functional aspects into the product requirements in addition to the environmental ones. Secondly, there is no tool covering all the design process stages and there are few tools enabling to generate design alternatives. This framework represents existing eco-design tools for integrating environmental requirements into the product design process and does not deal with the service aspect. Nevertheless, it makes the lack of global methodology for eco-design appear. The major problem raised by eco-design is then to integrate the environmental requirements with others in a multi-criteria analysis and to cover all the stages of the design process. To solve these issues, some authors have combined existing tools. Sakao [11] proposed a method centered on QFD (Quality Function Deployment) and coupling Life Cycle Analysis (LCA) and TRIZ to design eco-efficient products. In the PSS design field, the PSSDAE (PSS design and evaluation) [12] [13] has been proposed. It is an integrated two-phase approach which combines six existing methods and tools supporting the global development process.

Eco-design of services also raises many difficulties, which have been identified and largely discussed in literature. There is a lack of tools for measuring the environmental impacts of services. Indeed, services are often assimilated to the concept of dematerialization, where 'pure services' are considered as having, in theory, no environmental impact. However, services are always supported by products, which impact the environmental burden, just as PSS do [8]. Thus, the evaluation of environmental impacts of services is challenging for multiple reasons. For Brezet et al. [8], the choice of the system boundaries can be complicated because of the principles of environmental assessment. Indeed, measurement of environmental impact is done for a new system by comparing with the old one, providing the same functionality. However the choice of the functional unit is often not obvious when the system impacts consumer behavior and requires a shared infrastructure. Consequently, the system boundaries can be blurred. Brezet et al. [8] proposed a method dealing with the design of eco-efficient services (DES) by integrating multiple tools and actions to follow through during the design process. Beyond the difficulties raised by the service notion, LCA can be done retrospectively on PSS cases to evaluate their environmental impacts, as shown by Sundin et al. [14]. Nevertheless, in an eco-design perspective, a method enabling this evaluation at a detailed level to guide design choices is still missing.

2.3 Existing Methods and Gaps in Design of Eco-efficient PSS

Some authors propose PSS eco-design methods aiming at coupling product and service design techniques with the objective of providing eco-efficient or sustainable solutions. Geum and Park [15] provided a ''product-service blueprint' representation to visualize the use of the product throughout its' life cycle, the service flow, and the relationship between products and services. Sustainability is represented by the "point of sustainability achieved" to show how the PSS improve sustainability in the global process. Maxwell et al. [16] proposed the Sustainable Product and Service Development (SPSD) to guide PSS development. During the concept development, a focus on functionality, expressed by a functional need and its life cycle, aims at determining the most sustainable way of providing that function (through a product, service or a PSS). Lelah et al. [17] proposed a methodology based on LCA and an associated model to describe a complex PSS collaborative network and the roles of the involved actors. The PSS network is seen as imbrications of successive B2B (Business To Business) PSS offers. Sustainability is defined as depending on the organization of activities built around physical objects and the aim is to show how these objects are used individually or collectively within an actor's network.

All these design methods aim at integrating product and service aspects while taking into account eco-design issues in order to achieve eco-efficiency in PSS: integrating a life cycle approach, identifying opportunities for decreasing environmental impacts, measuring the environmental burden and integrating global support systems like the supply chain or the actor's network. However, if the previous methods can be useful at a macro level, the transition towards a detailed design seems to be hard. To enable the full integration of the environmental considerations during the entire design process, it seems necessary to be able to generate convenient scenarios of PSS solutions at each step of the design process. The previous methods can be used for the design of the global offer. Amaya et al. [18] propose a more detailed method considering the organization of the system elements (products and services) and the system parameters to support the generation of use scenarios aiming at intensify the products use in PSS.

This paper presents a complementary point of view. Noticing that there is no method supporting the eco-design of the internal elements of the system, this paper proposes to explore the 'Design Buckle' (DB) concept to help at a detailed design level. The proposed approach can generate scenarios that couple functional aspects and possible elements of solutions. "The PSS designer […] needs to constantly move from a global vision of the system down to detailed features describing the interactions between the physical and service elements that compose it" [4]. In the next section, this paper exposes prior work in this field and exploits the DB concept as an artifact that can help designers move from a global to a detailed vision of the system and thereby support the design of eco-efficient PSS.

3 Potential of the Design Buckle Concept to Facilitate PSS Eco-design

3.1 Design Methodology and Design Buckles

Maussang et al. [5] developed a PSS engineering design methodology to provide designers with technical specifications for the development of the physical objects involved in the system. PSS are defined as systems composed of service units and physical objects. The physical objects are functional entities and the service units are (often technical) entities ensuring the smooth functioning of the system. The elements are related to and interact with one another. Their representation facilitates the integration of the specificities of each element during the design process.

The methodology begins with an external functional analysis, supported by a graph of inter-actors. It represents the system as a 'black box' which interacts with customers and actors involved during the life cycle. The goal is to provide the external functions expected. Then, these functions are characterized by external criteria, defining level and allowance, corresponding to the satisfaction of the external requirements. The external analysis is followed by an internal analysis of the system, where each function is deployed to define the technical functions the PSS has to generate as well as potential principles for solutions. To model these principles, the internal structure of the system is described using the functional block diagram (FBD) representation (see Figure 1). The FBD representation describes different elements. The frontiers between the PSS and the outer environment are represented by two horizontal lines. The different components of the system appear (products and service units) as well as the inter-actors existing in the outer environment of the PSS. The interaction functions (IF) correspond to the functions provided by the system to an outer environment during its life cycle. The DBs represent an organizational choice, which means that each DB ensures a technical function, which is described by a particular scenario. The methodology also proposes modeling scenarios by using the structured analysis and design techniques (SADT) representation. Use scenarios as well as operational scenarios are described to illustrate the interaction between the system and external agents (such as the customer or actors involved) but also the activities performed internally for the system to operate. Authors argue that the FBD has to be completed by the definition of scenarios at the same time as proposing a convenient solution, because scenarios link the elements of the solutions that emerge during the deployment of the functions.

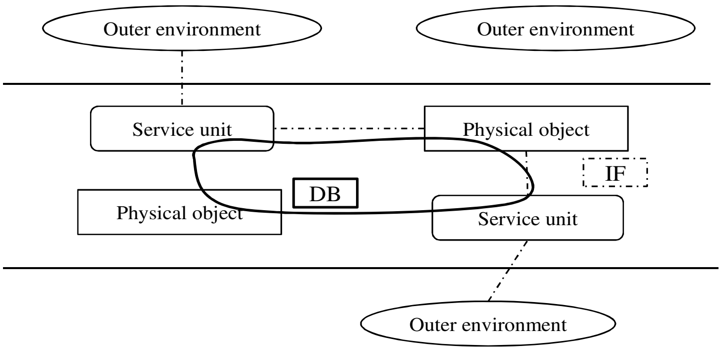


Fig. 1. Functional bloc diagram representation [5]

3.2 Interest of the Design Buckles for PSS Eco-design

The methodology previously presented has several advantages when dealing with eco-efficiency issues in PSS design. First, the functional and behavioral descriptions of the system are produced concurrently. This coupling provides better integration of the product- and the service-based approaches. 'What' (functions) the system has to provide is described as well as 'how' (activities) it has to be provided. Secondly, the approach proposes FBD representation. Even if it provides only a partial view of the whole system, the FBD models the elements of the system as well as their relationships and organization. The choice of the system's elements and the way they are organized to provide the expected function and behavior can be changed to establish scenarios of solutions with different environmental impacts. These impacts depend on the elements as well as their organization.

The DBs are also an interesting object for the environmentally conscious design of PSS. Indeed, although they result from the technical functions and their associated operational scenarios, they are determined before the solutions, in order to generate alternatives at a design level when the final solution is not yet completely known. These intermediary objects seem to be one of the best compromises to generate alternatives and to evaluate them. They link the problem space and the solution space, keeping in mind design choices and reveal the effects produced by a change in the solutions on the other elements of the system. This intermediary position of the DB allows designers to move from a global vision of the system down to detailed features of the interrelated elements [4]. This paper argues that it can be a lever in the eco-design of PSS. Indeed, simultaneously designing all the elements of the system is not a reasonable option. The issue in design is to select a convenient part of the system to focus on without neglecting the complex interactions with the other parts in order to build scenarios for solutions. The DBs are the objects entering into this choice. Several elements of the solution can be involved in different DBs, and DBs are linked to the technical functions and to the activities. These links are clearly visible, limiting the environmental assessment necessary to a convenient set of functions and solutions and facilitating decision-making when the entire system is not yet defined.

4 Case Study

4.1 Presentation of the Case

This paper now completes the study of the case introduced by Maussang et al. [5] to compare and evaluate two scenarios using the design buckles they proposed. The case dealt with a high temperature superconducting (HTS) project supervised by the US Department of Energy, to transport energy in superconducting cables. A French company is responsible for providing the refrigeration system of the HTS cables. The cables are enveloped and refrigerated with liquid nitrogen (LN2). A refrigerator ensures the regulation of the temperature of the LN2 coolant. In the original study, the methodology presented in section 3.1 for designing PSS was followed. An external analysis provided the functions of the system. Several DBs were identified resulting from the function 'provide to the customer the cable refrigeration'. This paper focuses on two of the DBs, which are: 'to modify the performance of the fridge' (DB1) and 'to repair the equipments' (DB2). The study proposes two scenarios. In each scenario, the operational scenarios and the elements used as solutions are different.

In the first scenario, a team composed of technicians is 'on-site' and can modify the fridge performances (see Figure 2). Moreover, this team can also do simple repair on the equipment (DB2). The customer contacts the call centre that serves as a go-between who transmits the needs to the on-site team. However, in cases requiring more important repairs, an external expert maintenance team must intervene.

In the second scenario, calls are centralized by an expert supervision unit, which monitors the fridge and controls the equipment via a remote supervision module (see Figure 3). In this scenario, the technical function 'to repair the equipments' is performed by the supervision unit via the supervision module. However, as in scenario 1, if serious reparations are needed, an external maintenance unit goes directly to the site. For this buckle,the supervision module is able to diagnose failures and transmit them to the maintenance unit.

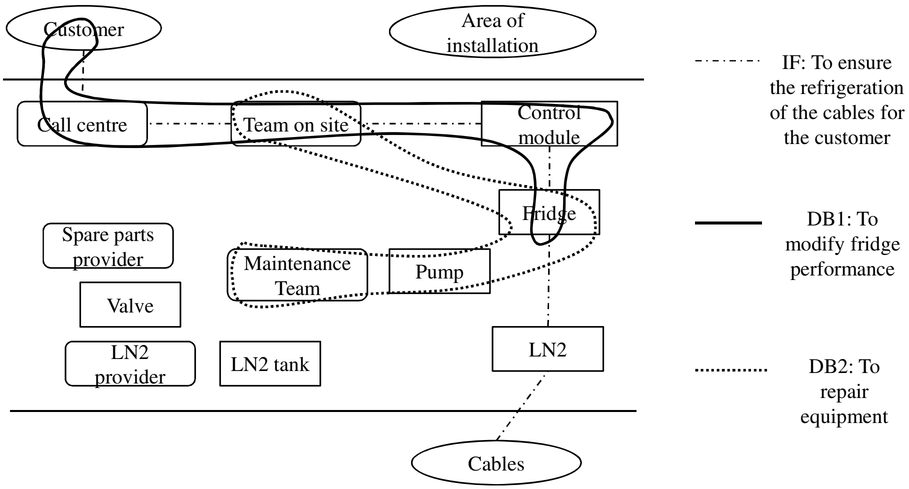


Fig. 2. Scenario 1: Functional Block Diagram and design buckles

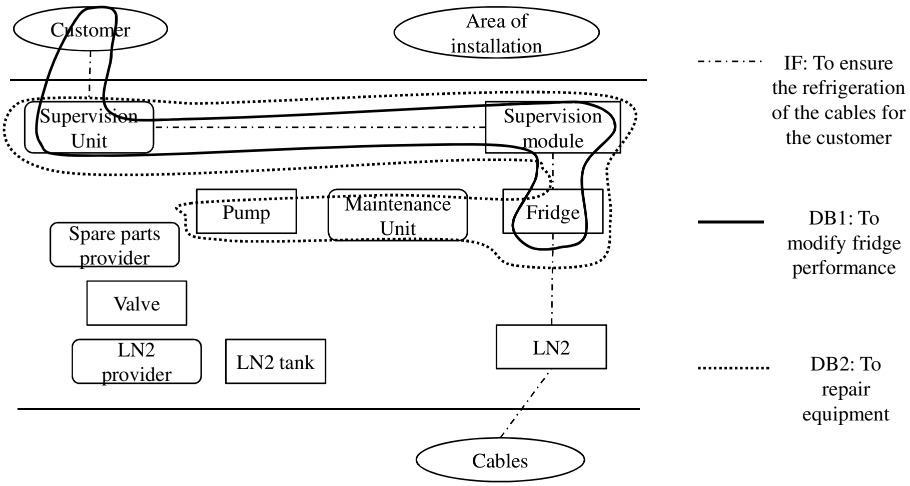


Fig. 3. Scenario 2: Functional Block Diagram and design buckles

4.2 Application of the Methodology

This paper will now compare these two scenarios by evaluating their environmental impacts in the first DB (DB1) and then in the first and second DBs (DB1 + DB2) in order to illustrate the use of DBs in PSS eco-design.

Environmental Indicators. The case focuses on a refrigerating system. From this point of view, this paper uses MEErP (Methodology for Ecodesign of Energy-related Products) [19], which is particularly well-adapted to this kind of product, that the European Commission (EC) identified as 'Energy-related products'. This methodology has been developed by the EC together with an associated tool called ErP Ecoreport, using a benchmark of cases created by the EC [19]. The tool enables a quick life cycle description of a product to obtain the impacts for a selective list of indicators (see Table 1). ErP Ecoreport is a simplified tool for analyzing the life cycle impacts. In the next section, this paper identifies the main hypothesis adopted for the study.

Table 1. Environmental indicators used in the ErP Ecoreport

Resources & Waste	Total Energy (GER)
	Water consumption (process and cooling)
	Waste (non-haz., landfill / Hazardous, incinerated)
Emissions (Air)	Greenhouse Gases in GWP100
	Acidification, emissions
	Volatile Organic Compounds (VOC)
	Persistent Organic Pollutants (POP)
	Heavy Metals
	PAHs
	Particulate Matter (PM, dust)
Emissions (Water)	Heavy Metals
	Eutrophication

Study Boundaries and Hypotheses. In order to compare the two scenarios, it is first necessary to identify the differences between the scenarios in each DB. Once this is done, the ErP Ecoreport can be used to facilitate the environmental assessment of the products identified in the DBs. The analysis needs only to focus on the products involved in the DBs and the impacts of the other elements (service units and support products) are estimated and included by the tool. In this study, the functional unit can be defined by the availability of the fridge (required to be over 99.8%) during 5 years (the normal life time of the fridge). To simplify the case study, the impacts caused by the different maintenance and call center teams, in both buckles and scenarios, have been omitted. They all require infrastructures and other transportation facilities that are shared with other services or other clients and so the impacts are hard to estimate and somehow can be assumed to compensate one another in this initial simplified analysis. In DB1, the supervision module is quite similar to the control module, but it requires the partial use of a computer and a communication network for remote control. The energy consumed by the supervision module is higher than by the control module, because of the remote monitoring and the failure detection. The fridge is the major element involved in BD2 because its availability depends on maintenance. In the first scenario the fridge is repaired on-site by the customer's maintenance team but less efficiently than in the second scenario, where the supervision module provides more information to an expert team. This means that repairing the fridge is easier in scenario 2 and maintenance interventions can be more frequent. The design requirements of the fridges for the two scenarios fulfilling the same functional unit are therefore quite different, however in this simplified analysis, it is supposed that their impacts are equivalent. In the second scenario, thanks to the expert team and the supervision module, the fridge's life time is extended by 25%. The impacts of the components are therefore reduced proportionally. To summarize, DB1 considers only the control and supervision modules, whereas the integration of DB2 means taking the fridge into account. To simplify, the pump is excluded from the scope of this study and considered as being available all the time. The technical descriptions of the scenarios are presented in Table 2.

Table 2. Technical descriptions of the products' life for the two scenarios in DB1 and DB2

	Functional unit: Availability of the fridge > 99,8% during 5 years	
	DB1: To modify the fridge performances	DB2: To repair equipments
Scenario 1	**Control module 400 g**	**Fridge 592 Kg**
	Printed Wiring Board; Screen; Integrated Circuit; Box	Fan motor, Fan blade, Fan grid, lighting, temperature control, other materials
		10 m3
	Power on-mode: 0,005 kW; over the life cycle	Power on-mode: 3,4 kW, over the life time
Scenario 2	**Product: Control module 420 g**	**Fridge 443 Kg**
	Printed Wiring Board; Screen; Integrated Circuit; Box	Fan motor, Fan blade, Fan grid, lighting, temperature control, other materials
	Computer and ICT network	7,8 m3
	Power on-mode: 0,02 kW; 150 hours Power standby-mode: 0,005kW; rest of the life time	Power on-mode: 3,4 kW, over the life time

4.3 Environmental Evaluation of the Buckles

The environmental analysis is done on the first DB and then on both the first and the second DBs comparing the two scenarios in each case. The analysis shows that the two scenarios have almost equivalent environmental impacts for DB1, and the scenario 1 seems to be slightly more environmentally-friendly than scenario 2 (see Figure 4). But when considering the two DBs simultaneously, scenario 2 has less environmental impacts than the scenario 1 (see Figure 5).

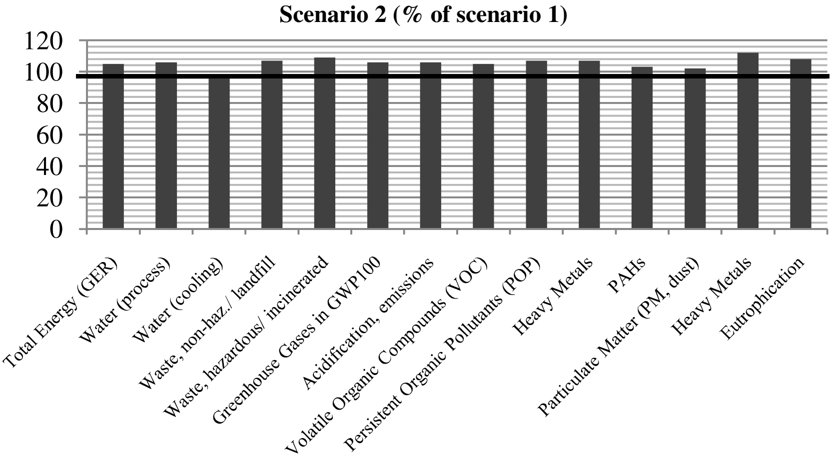


Fig. 4. Comparison of the scenarios in DB1

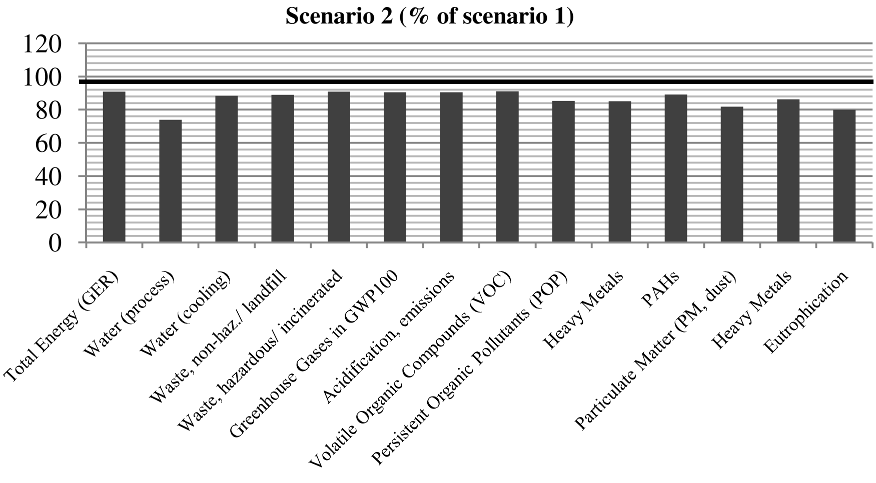


Fig. 5. Comparison of the scenarios in DB1 and DB2

4.4 Discussion

This study shows how the design buckles can be used during an environmental assessment of different solutions. Using the DBs, the interactions between the solutions and the function fulfilled are clarified very simply. DB1 satisfies the function of control of the fridge's performance. Environmental impacts generated by a remote module are higher than for the on-site control module, because of the associated ICT network and equipments. However, when both DB1 and DB2 are considered, the links between the designs of the solutions to fulfill the technical functions can be discussed. Several issues are raised, such as the expected results of the new services introduced by scenario 2. For example, in scenario 2 of DB2, designers can decide to introduce a less reliable fridge taking advantage of the efficient additional repair services; or, as chosen in the study, use better services with a robust fridge to extend its' life time. All these solutions fulfill the same functional unit. The choice depends on many parameters, other than environmental considerations. Therefore the assessment proposed here could be extended to other criteria, such as cost, user's acceptance, etc. The method links the DBs with the solutions and identifies issues for designers. The re-design of the fridge, for example, should be discussed to improve the environmental performance of DB2. The case study is simplified but can be completed more precisely by integrating information on the environmental impacts of the infrastructures. The tools and working spaces used by the on-site team (scenario 1) or the equipments used by the supervision unit (scenario 2) can be integrated into the analysis. The same method can be extended to a more detailed study taking into account a complete environmental analysis of the solutions.

Nevertheless, the study shows that, even with the simplifications made, a simplified assessment performed on the two DBs provides a quick understanding of the issues involved. In the case study, the second scenario appears as the better choice. The impacts generated using the ICT network are compensated by the prolonged life time of the fridge. This preliminary analysis is helpful to understand ways to improve the environmental performances of the solutions (for example, extended life time); or to choose between different scenarios.

5 Conclusion

This paper supports the idea that the design buckle objects are useful for the design of eco-efficient PSS. Design buckles make the links between the functions to provide, the expected functional/operational behaviors and the possible solutions, appear clearly. This representation helps designers to evaluate the environmental performances of a set of solutions linked by their functional and behavior aspects. A method to assess the entire system would be time consuming and very difficult during the conceptual design phase. Design buckles are a sort of intermediary objects of design by which a quick understanding of the interactions in the organization of the system is made possible. In this way alternatives for solutions can be easily identified and assessed. A comparison of these alternatives can be done conveniently. The results can support decision-making even when full knowledge on the design objects is not yet available.

References

1. McAloone, T.C., Andreasen, M.: Design for utility, sustainability and societal virtues: developing product service systems. In: Procedings of Design 2004 8th International Conference on Design, Dubrovnik, Croatia, pp. 1545–1552 (2004)
2. Mont, O.: Institutionalisation of sustainable consumption patterns based on shared use. Ecological Economics 50, 135–153 (2004)
3. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems - IPS2. CIRP Annals - Manufacturing Technology 59, 607–627 (2010)
4. Vasantha, G.V.A., Roy, R., Lelah, A., Brissaud, D.: A review of product–service systems design methodologies. J. of Engineering Design 23, 635–659 (2011)
5. Maussang, N., Zwolinski, P., Brissaud, D.: Product-service system design methodology: from the PSS architecture design to the products specifications. J. of Engineering Design 20, 349–366 (2009)
6. Kuo, T.C., Huang, S.H., Zhang, H.C.: Design for manufacture and design for 'X': concepts, applications, and perspectives. Computers & Industrial Engineering 41, 241–260 (2001)
7. Tan, A.R., Matzen, D., McAloone, T.C., Evans, S.: Strategies for designing and developing services for manufacturing firms. CIRP Journal of Manufacturing Science and Technology 3, 90–97 (2010)
8. Brezet, J., Bijma, A., Ehrenfeld, J., Silvester, S.: Design for eco-efficient services: method, tools and review of the case study based 'designing eco-efficient services' project. DES report. DfS, Delft University of Technology, MIT, The Netherlands (2001)
9. Aurich, J.C., Fuchs, C., Wagenknecht, C.: Life cycle oriented design of technical Product-Service Systems. J. of Cleaner Production 14, 1480–1494 (2006)
10. Bovea, M.D., Pérez-Belis, V.: A taxonomy of ecodesign tools for integrating environmental requirements into the product design process. J. of Cleaner Production 20, 61–71 (2012)
11. Sakao, T.: A QFD-centred design methodology for environmentally conscious product design. Int. J. of Production Research 45, 4143–4162 (2007)
12. Shih, L.H., Chen, J.L., Tu, J.C., Kuo, T.C., Hu, A.H., Lin, S.L.: An integrated approach for product service system development: I Design Phase. J. of Environmental Engineering and Management 19, 327–342 (2009)
13. Shih, L.H., Hu, A.H., Lin, S.L., Chen, J.L., Tu, J.C., Kuo, T.C.: An integrated approach for product service system development: II Evaluation Phase. J. of Environmental Engineering and Management 19, 343–356 (2009)
14. Sundin, E., Lindahl, M., Larsson, H.: Environmental and Economic Benefits of Industrial Product/Service Systems. In: Proceedings of the 2nd CIRP Industrial Product/Service Systems Conference, Linköping, Sweden, pp. 91–98 (2010)
15. Geum, Y., Park, Y.: Designing the sustainable product-service integration: a product-service blueprint approach. J. of Cleaner Production 19, 1601–1614 (2011)
16. Maxwell, D., Sheate, W., van der Vorst, R.: Functional and systems aspects of the sustainable product and service development approach for industry. J. of Cleaner Production 14, 1466–1479 (2006)
17. Lelah, A., Mathieux, F., Brissaud, D.: Contributions to eco-design of machine-to-machine product service systems: the example of waste glass collection. J. of Cleaner Production 19, 1033–1044 (2011)
18. Amaya, J., Lelah, A., Zwolinski, P.: Environmental Benefits of PSS Strategies: A Bicycle Sharing System Case Study. In: Proceedings of the 4th CIRP International Conference on Industrial Product-Service Systems, Tokyo, Japan, pp. 339–344 (2012)
19. Methodology for the Ecodesign of Energy-related Products, `http://www.meerp.eu`

A Method for Exploring PSS Technologies Based on Customer Needs

Koji Kimita[1] and Yoshiki Shimomura[2]

[1] Department of Management Science, Tokyo University of Science, Kagurazaka 1-3, Shinjuku-ku, Tokyo 162-8601, Japan
[2] Department of System Design, Tokyo Metropolitan University, Asahigaoka 6-6, Hino-shi, Tokyo 191-0065, Japan
kimita@ms.kagu.tus.ac.jp,
yoshiki-shimomura@center.tmu.ac.jp

Abstract. Recently, a system called the Product-Service System (PSS) has been attracting attention. Since a PSS includes a broad range of customer needs, compared with a product-selling business, there are many business opportunities for manufacturers that correspond to possible candidates of a PSS provider. This study aims to support manufacturers' trying to find new business opportunities by offering PSSs. To do so, this study assumes that it is useful for manufacturers to explore technologies that can be applied to fulfill customer needs in a PSS. In addition, these technologies should be explored across different business areas. The objective of this study is therefore to propose a method for classifying various business technologies from the viewpoint of customer needs in a PSS. The proposed method thereby enables manufacturers to explore technologies for fulfilling customer needs.

Keywords: technology management, business model, self-organizing map.

1 Introduction

At present, since many products are involved in low-price competition against products produced with cheaper labor, it is difficult for many manufacturers to make their business more profitable by only selling products [1]. Against this background, a system called the Product-Service System (PSS) has been attracting attention. PSSs, which offer a product in combination with services, are a specific type of value proposition that a business offers to its customers [2-4]. A PSS consists of a mix of tangible products and intangible services designed and combined so that jointly they are capable of fulfilling final customer needs [2-4].

PSS providers need to fulfill customer needs in product usage as well as in the other customer activities related to the product, such as maintenance, installation, training, and so on [2]. A PSS includes a broad range of customer needs, compared with a product-selling business. In other words, there are many business opportunities for manufacturers that correspond to possible candidates of a PSS provider. In order to

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 215–225.
DOI: 10.1007/978-3-642-30820-8_19

fulfill such broad customer needs, the technologies required in a PSS usually include not only one of the core products but also ones from different business areas. For example, in a car-sharing business, the PSS provider needs to use technologies of the core product, i.e., a car, as well as technologies from different business areas, such as monitoring techniques to manage the availability of the car. However, problems remain in exploring technologies across different business areas. For many manufacturers, technologies are generally managed with respect to each business and/or product area, and therefore it is difficult for them to explore technologies for a PSS across different business areas. This situation makes it difficult for them to find new business opportunities in order to move away from a business selling products toward a business offering a PSS.

This study aims to support manufacturers' trying to find new business opportunities by offering PSSs. To do so, this study assumes that it is useful for manufacturers to explore technologies that can be applied to fulfill customer needs in a PSS. In addition, these technologies should be explored across different business areas. The objective of this study is therefore to propose a method for classifying various business technologies from the viewpoint of customer needs in a PSS. The proposed method thereby enables manufacturers to explore technologies for fulfilling customer needs. The effectiveness of the proposed method is demonstrated in an application of a PSS to a gas turbine business, a case in which a heavy industrial company corresponded to a provider.

2 Approach of This Study

2.1 Overview

In order to explore technologies for fulfilling customer needs in a PSS, in the proposed method, technologies held by a manufacturer are classified from the viewpoint of customer needs in the PSS. To do so, first, customer needs are extracted in consideration of product usage as well as in the other customer activities related to the product. For the extraction, a method called Business-Process and Goal-Oriented Requirements Analysis [5-6] is adopted. Secondly, technologies held by a manufacturer are classified based on several dimensions. As to the dimensions, in the proposed method, customer needs extracted by the requirement analysis are used. In addition, the self-organizing map (SOM) [7] is used as the classification and visualization tool. In the remainder of this section, first, the methods for the requirement analysis and the SOM are introduced, and then, the procedure for exploring PSS technologies is proposed.

2.2 Method for Extracting Customer Needs

To analyze the customer and to identify requirements in a business to business (B2B) service, a method called Business-Process and Goal-Oriented Requirements Analysis has been proposed [5-6].

The first step in this method is reanalyzing the business to identify customers. Market surveys, interviews, or questionnaires are useful for this step. Based on the collected data, customers' business activities are modeled visually, and goals, which indicate objectives that should be achieved for each business task [8], are identified for each business activity. The modeled customer's business activities are then translated into a service script. The service script is written in natural language; thus, it enables designers to analyze the customer's behavior in more detail. From the script, designers identify some "key words" that can be considered important elements for the PSS. Finally, each key word is associated with required items/qualities and quality elements using a predefined template and vocabulary list (see Figure 1). Here, "required items" refers to what customers want to do, and "required quality" is a linguistic expression of customer needs related to the quality of the provided product/service [9]; namely, the required items/qualities indicate representations of "customer needs" in a PSS. On the other hand, quality elements work as criteria for evaluating the quality [9]. Thus, the quality elements are observable and controllable for designers and could be regarded as requirements in a PSS, since these are elements that satisfy the required items/qualities, i.e., customer needs.

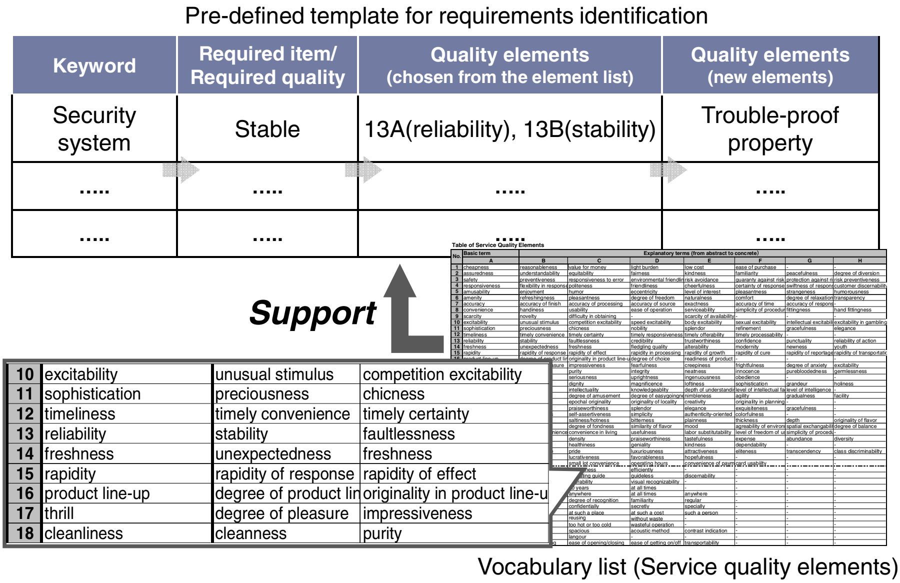


Fig. 1. Identification of customer needs using vocabulary list [5-6]

2.3 The Self-organizing Map

The SOM [7] is a useful tool for the visualization of multidimensional data. It converts complex, nonlinear statistical relationships between high-dimensional data into simple geometric relationships on a display that is usually represented as two dimensions, i.e., a map. The map consists of elements that are associated with high-dimensional data. Based on the high-dimensional data, in the SOM, these elements become ordered on the map so that similar elements are close to each other and dissimilar elements are far from each other. Since the SOM compresses information about high-dimensional data while preserving the most important topological and metric relationships among elements on the display, results of the SOM can be useful for carrying out classification, data mining, visualization, and so forth. For example, Yoon applied the SOM to R&D management by representing complex relationship among patents and the dynamic pattern of technological advancement [10]. On the other hand, in order to support designers' idea generation in PSS design, Akasaka proposed the PSS Business Case Map where the SOM was adopted as a mapping tool [11]. As shown in Figure 2, in this method, PSS business cases are located on the map based on their similarities; the similarities are evaluated by high-dimensional data consisting of the types of product, service, customer, and added value [11].

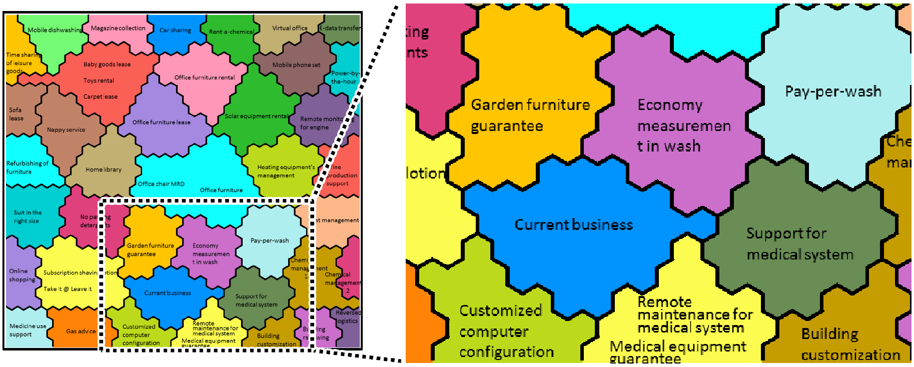


Fig. 2. PSS Business Case Map by using the self-organizing map [11]

3 Procedure for Exploring PSS Technologies Based on Customer Needs

3.1 Step1: Extraction of Customer Needs

From the viewpoint of offering products in combination with services, value is always determined by customers [2]. Therefore, this procedure begins with the extraction of customer needs in a PSS. For the extraction, the method for requirement analysis that is introduced in section 2.2, is adopted. First, the business's core product is analyzed to identify possible customers in a PSS. Customers' business activities related to the core product are subsequently described based on market surveys, interviews, questionnaires, and so on. In each business activity, goals, which indicate objectives that should be achieved for each business task, are identified. Next, the described customer's business activities are translated into a service script to analyze the customer's behavior in more detail. According to the script, finally, customer needs in the PSS are extracted. In this method, customer requirements are represented as the required quality, which is a linguistic expression of customer needs related to the quality of the provided product/service.

3.2 Step2: Classification of Technologies from the Viewpoint of Customer Needs

According to the customer needs extracted in the previous step, technologies held by a manufacturer, which corresponds to a PSS provider, are classified by using the SOM. In the proposed method, the extracted customer needs are used as dimensions for the classification. As a unit of "technology," a patent and/or technical report would be suitable. This information should be collected from the core product, as well as from different business areas. Each technology is associated with customer needs that possibly can be fulfilled by the technology; similarities among technologies are evaluated by the dimensions, i.e., the customer needs. Each technology is thereby located on the map so that similar technologies are close to each other and dissimilar technologies far from each other. As classifications of the technologies, finally, clusters of technologies are identified on the map. Each cluster consists of technologies that possibly fulfill similar customer requirements.

3.3 Step3: Exploring Technologies Applied to a PSS

Based on the clusters identified in the previous step, the manufacturer is able to explore technologies across different business areas for fulfilling customer needs in the PSS. If a cluster contains technologies of both the core product and different business areas, technologies of the core product could be enhanced to fulfill relevant customer needs, in combination with the technologies from different business areas. If a cluster contains technologies only from different business areas, these technologies can be applied to fulfill relevant customer needs, and worked as supplemental technologies in order to realize the PSS of the core product. In addition, combining technologies from these clusters enables the manufacturer to offer a PSS that can fulfill customer needs more comprehensively; it results in increasing their business opportunities around the core product.

4 Application

4.1 Objective of This Application

The proposed method was applied to a PSS of gas turbine business, a case in which a heavy industrial company corresponded to a provider. Recently, a demand for power supply is increasing in many emerging countries. As a result, in emerging countries that have vast national territories and problems with their power grid systems, electrical power failure often occurs in areas far from electricity-generation plants. In addition, as an environmental consciousness increases in these countries, power generation systems with low CO2 emission and low energy consumption are required much more. In accord with this situation, the dispersed power system has grown in importance in many emerging countries. Especially as a source of power supply for the dispersed power system, gas turbines have been attracting attention. Since some parts of gas turbines are used in harsh conditions, such as high temperature and/or high centrifugal force, these parts need to be repaired and exchanged in a short period. As users of gas turbines increase in emerging countries, its manufacturers are much more often required to rapidly address trouble with and failures of gas turbines. Therefore, the manufacturers need to not only provide a product itself, i.e., a gas turbine, but also offer a PSS that includes the product-related services, such as monitoring, customer supports, maintenance, and so forth.

This application aims to explore technologies that can be applied to realize a PSS for a gas turbine in emerging countries. In particular, in this application, the gas turbine, which corresponds to the core product, is provided by a heavy industrial company that conducts several businesses, involving airplanes, ships, plants, and so forth. Technologies were therefore collected from the business areas conducted by the company.

4.2 Results: Classification of Technologies for a PSS of Gas Turbine Business

Step1: Extraction of Customer Needs. For the extraction of customer needs, first, business of a gas turbine was analyzed, and then, an operator managing dispersed power systems for industrial sectors was identified as a customer in the PSS. Customer's business activities related to the gas turbine were subsequently described based on market surveys. Eight activities related to the gas turbine were identified: installation, operation, monitoring, diagnosis, maintenance planning, prevention, maintenance, and emergency response. The described customer's business activities were translated into a service script to analyze the customer's behavior in more detail. Table 1 shows the result of the service script in each business activities. According to the script, finally, customer needs in the PSS were extracted as shown in the right row in Table 1. For example, from the activity "monitoring," where customers collect and analyze data about conditions of the gas turbine, "efficiency of data collection and analysis" was extracted as a customer need for the PSS.

Step2: Classification of Technologies from the Viewpoint of Customer Needs. According to the customer needs extracted in the previous step, technologies of the heavy industrial company were classified by using the SOM. In this procedure, the eight extracted customer needs were used as dimensions for the classifications. As a unit of "technology" of the heavy industrial company, technical reports published by the company were used. In such technical reports, the company introduces its new technology and product in a manner similar to academic journal papers, and therefore, one technical report can be considered as one technology. Technical reports were collected from twelve businesses areas conducted by the heavy industrial company, such as airplanes, ships, plants, robots, trains, and so forth. As a result, 123 reports were collected as sources of technologies. Each technology introduced in a technical report was associated with customer needs that possibly could be fulfilled by the technology, and then similarities among technologies were evaluated according to the

Table 1. Service script and customer needs in each business activity for a PSS of gas turbine

Activities	Service scripts	Customer needs
Installation	For the installation of a gas turbine, we need to consider the weight of the gas turbine as well as its vibration. Since this vibration causes hazardous noises, users of the gas turbine need to take a measure to reduce this vibration. In addition, a gas turbine requires large amount of air supply and exhaust compared to a diesel engine, and therefore, the users need to prepare enough space to install it. Using a gas turbine in a cold weather region, we need to keep its heat to prevent failures. Using it in a high altitude region, on the other hand, its performance deteriorates to 90 to 95 percent.	- Noise-reduction - Flexibility of the space for the installation - Robustness in a high altitude region
Operation	Recently, due to restructuring efforts for operating gas turbines, the shortage of operators who have lots of knowledge and technique about gas turbines become serious problems. This situation increases the occurrence of failures in operating gas turbines.	- Reduction of operation cost - Knowledge of operators
Monitoring	In order to detect potential failures and to cope with them, it is an effective measure to collect and analyze lots of data about a gas turbine, such as temperature and pressure, by using many sensors. However, compared with gas turbines held by electrical power suppliers, gas turbines used in general enterprises for their power supply have small number of sensors. This is because that gas turbines of electrical power suppliers can be a large size for the purpose of selling electrical power, and therefore, it is possible to equip lots of sensors to monitor the its performance precisely. On the other hand, the gas turbine for general enterprise is usually used for the purpose of cost reduction. Its sensors are therefore kept to the minimum necessary to monitor it.	- Efficiency of data collection and analysis
Diagnosis	Some parts of gas turbine are used in harsh conditions, user need to check their damages during both operation and maintenance, and to make a decision correctly if they have to repair, disposal or continue to use the parts. In order to reduce maintenance cost, users need to reduce the number of times for replacing parts by using technologies to extend life time of the parts. However, since the life time are influenced by various factors, it is difficult to develop technologies for life time assessment that can be applied to all situations. Therefore the life time assessment need to be carried out based on the data result from the analysis and evaluation of actual operating conditions.	- Promptness of responses - Accuracy of life time evaluation
Maintenance planning	Parts used in high temperature need to use special techniques in repairing, and therefore, it takes longer time to repair them compared with the other parts. Therefore, users need to predict their life time, and to prepare alternatives of them.	- Adequacy of the maintenance plan
Prevention	In the electricity-generation plants where demands for high efficiency and operation availability are prioritized, users need technologies to prevent failures, such as delay to start running, preventing accidents and so on.	- Accuracy of preventions
Maintenance	Recently, for the purpose of increasing the operation availability, users reduce the number of times for maintenance. This situation causes failures of quality frequently. Therefore, it is required to increase the efficiency of the maintenance. In addition, due to merger and acquisition between companies those provide gas turbine, users are not necessarily receiving maintenance even if they used to receive it. According to this situation, some users are trying to avoid relying on original companies providing gas turbine about maintenance.	- Safety of maintenance - Efficiency of maintenance - Consistency of maintenance
Emergency Response	For emergency cases, such as natural disasters, it is required to keep robustness to use electricity as much as possible. For example, under the situation limited to supply electricity, gas turbine manufactures and users need to consider systems that supply electricity to high prioritized facilities, such as equipment in a hospital. In addition, dispersing systems for the connection and control about power supply enable users to keep functions of the system even if a part of them are broken down.	- Robustness of power supply

customer needs. Each technology was thereby located on the map so that similar technologies were close to each other and dissimilar technologies far from each other. As for classifications of the technologies, as shown in Figure 3, ten clusters of technologies, in which technologies in the same cluster are colored with the same one, were identified on the map. For example, as shown in Table 2, cluster colored with green consisted of 7 technologies, such as "I2: a technology for an urban transportation system," "A6: a technology for gas turbines," and "J3: a technology for capacitors in train systems." In addition, "X" in Table 2 shows the association between the technologies and customer needs. The technologies in the cluster colored with green were associated with eight customer needs: "Noise-reduction," "Flexibility of the space for the installation," and "Reduction of operation cost." For example, a technology described in the technical report, "I2: a technology for an urban transportation system," was associated with customer needs: "Reduction of operation cost" and "Robustness of power supply."

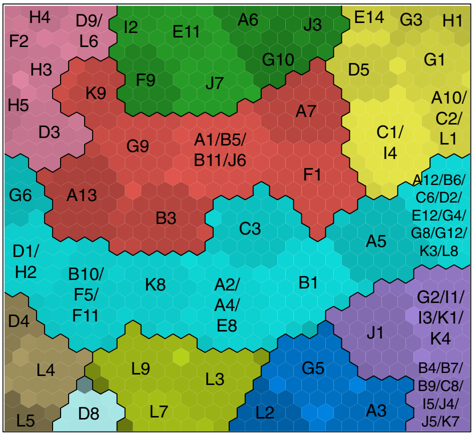


Fig. 3. Classification of technologies in the heavy industrial company

Step3: Exploring Technologies Applied to a PSS. Based on the clusters identified in the previous step, the company was able to explore technologies across different business areas for fulfilling customer needs in the PSS. For example, the cluster colored with green contained technologies of both the gas turbine and different business areas, such as "I2: a technology for an urban transportation system," "E11: a technology for solar power generation systems in plants," and "F9: a technology for container vessels." The technology of the gas turbine could be enhanced to fulfill relevant customer needs, in combination with the technologies from different business areas. In order to enhance the fulfillment of customer need "Robustness of power supply," the company could use the technology of a train management system that realized a power supply in the case of emergency, which is introduced in "J3: a technology for capacitors in train systems". On the other hand, a cluster colored with gray contained technologies only from different business areas, such as "D4: a technology for the information system about production management," "L4: a technology for the transfer robot of semiconductors," and "L5: a technology for operating robots." These technologies

Table 2. Technologies and associated customer needs in cluster colored with green

Customer needs \ Technologies	I2	A6	J3	E11	G10	F9	J7
Noise-reduction			X			X	
Flexibility of the space for the installation			X		X		
Robustness in a high altitude region							
Reduction of operation cost	X		X		X		
Knowledge of operators							
Efficiency of data collection and analysis					X		
Promptness of responses		X			X		
Accuracy of life time evaluation							
Adequacy of the maintenance plan							
Accuracy of preventions		X	X		X		X
Safety of maintenance							
Efficiency of maintenance		X	X				
Consistency of maintenance							
Robustness of power supply	X	X	X	X	X	X	X

I2: a technology for an urban transportation system in consideration of environmental consciousness
A6: a technology for gas turbines
J3: a technology for capacitors in train systems
E11: a technology for solar power generation systems in plants
G10: a technology for power efficiency in in machinery for ships and motor cycle
F9: a technology for container vessels
J7: a technology for virtual simulation in train systems

could be worked as supplemental technologies in order to realize the PSS of the gas turbine. For example, for the customer need "Efficiency of maintenance" associated with the technologies in this cluster, robot technologies could reduce workloads in the disassembly of the gas turbine in the maintenance phase. Combining technologies from these clusters enabled the company to offer the PSS that supported the customer's business activities, such as maintenance, emergency response, and so on.

5 Discussion

In this study, the proposed method was applied to the PSS of a gas turbine business, a case in which a heavy industrial company corresponded to the provider. An operator managing dispersed power systems for industrial sectors was identified as a customer, and then their business activities were analyzed to extract their needs. As a result, eight customer needs were extracted. Meanwhile, as to the technologies of the heavy industrial company, 123 technical reports were collected, and then these technologies were classified into the ten clusters from the viewpoint of the customer's needs. From clusters containing technologies of both the gas turbine and different business areas, for example, the cluster colored with green, technologies that could enhance technologies of the gas turbine were explored. With regard to clusters containing technologies only from different business areas, for example, the cluster colored with gray, technologies that could be worked as supplemental technologies to realize the PSS of the gas turbine were explored. Since these technologies are currently not applied to the gas turbine business, the proposed method is effective for the company to explore technologies that can be applied to fulfill customer needs in a PSS. In addition, these technologies included gas turbine technologies as well as technologies from different business areas. This means that the proposed method enables the company to explore technologies in different business areas. The result of the method is useful to develop a realization structure for customer needs in the PSS design. For example, Shimomura proposes a function model for the PSS design, called view model [12]. The view model represents functional relationship between customer needs and entities. Designers first develop functions that fulfill the customer needs, and then, deploy these functions into detail. The detail functions are associated with entities. Technologies explored in the proposed method are useful to determine functions and entities in the view model. In combination of the proposed method with PSS design methods, such as the view model, the result of the method is useful for the company trying to find new business opportunities by offering a PSS.

In this application, however, the technologies of the heavy industrial company were associated with customer needs manually. This procedure imposes a high workload. In addition, its results may easily include bias from the people who follow this procedure. To solve this problem, a method for designing knowledge management [13] could be used. In this method, design knowledge would be associated with quality items automatically. Such a method would be expected to associate technologies with customer needs automatically. In order to apply this method to the association of technologies with customer needs in the proposed method, first, we need to develop an on ontology of customer needs in PSSs. The database of technologies is subsequently constructed. Each technology in the database is associated with at least one primal customer need, and then, relevant customer needs are automatically associated with the technology according to the ontology of customer needs.

6 Conclusion

In order for manufacturers to find new business opportunities by offering a PSS, this paper proposed a method for classifying various business technologies in a PSS from the viewpoint of customer needs. Applying this proposed method revealed that it would be effective for manufacturers that are exploring technologies that could be applied to fulfill customer needs in a PSS. In addition, these technologies could include technologies of a core product as well as technologies from different business areas. Therefore, the proposed method is useful for manufacturers looking for new business opportunities in a PSS.

Future studies will include a method to reduce the workload and bias in the association of technologies with customer needs.

References

1. Neely, A.: The Servitization of Manufacturing. An Analysis of Global Trends, POMS (2007)
2. Mont, O.: Clarifying the concept of product–service system. Journal of Cleaner Production 10(3), 237–245 (2002)
3. Tukker, A., Tischner, U.: Product-services as a research field: past, present and future. Reflections from a decade of research. Journal of Cleaner Production 17(14), 1552–1556 (2006)
4. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems IPS2. CIRP Annals - Manufacturing Technology 59(2), 607–627 (2010)
5. Kimita, K., Akasaka, F., Ronnback, A., Sakao, T., Shimomura, Y.: Requirement Analysis for User-Oriented Service Design. In: The 42nd CIRP Conference on Manufacturing Systems (2009)
6. Akasaka, F., Hosono, S., Kimita, K., Nakajima, M., Shimomura, Y.: Requirement Analysis for Strategic Improvement of a B2B Service. In: CIRP IPS2 Conference 2010, pp. 117–124 (2010)
7. Kohonen, T.: The self-organizing map. The IEEE 78(9), 1464–1480 (1990)
8. Lamsweerde, A.V.: Goal-Oriented Requirements Engineering: A Guided Tour. In: The 5th IEEE International Symposium on Requirements Engineering (RE 2001), pp. 249–263 (2001)
9. Akao, Y.: Quality Function Deployment. Productivity Press (1990)
10. Yoon, B.-U., Yoon, C.-B., Park, Y.-T.: On the development and application of a self-organizing feature map-based patent map. R and D Management 32(4), 291–300 (2002)
11. Akasaka, F., Fujita, K., Shimomura, Y.P.: Business case map: supporting idea generation in PSS design. In: The 2012 International Design Engineering Technical Conference - IDETC 2012 (2012)
12. Shimomura, Y., Tomiyama, T.: Service Modeling for Service Engineering. In: IFIP International Federation for Information Processing, vol. 167, pp. 31–38 (2005)
13. Kitai, Y., Oki, K., Kimita, K., Watanabe, K., Chiba, R., Shimomura, Y.: A proposal for a service design support system using knowledge from Web resources. In: The 44th CIRP Conference on Manufacturing Systems (2011)

Business Models and Product Service Systems for Transformable, Modular Plants in the Chemical Process Industry

Stefan Lier[1], Dominik Wörsdörfer[1], and Judith Gesing[2]

[1] Lehrstuhl für Fluidverfahrenstechnik, Ruhr-Universität Bochum, Bochum, Germany
[2] Marketing Department, Ruhr-Universität Bochum, Bochum, Germany
{dominik.woersdoerfer,stefan.lier}@fluidvt.rub.de,
judith.gesing@ruhr-uni-bochum.de

Abstract. This paper examines business models and product service systems in the chemical industry. Three main players are currently involved on the market (equipment manufacturers, plant engineering companies and plant operators). Business models between engineering companies and plant operators are transaction oriented. Services such as maintenance and continuous improvements are not standard practice. As modular transformable production concepts emerge, the market structure is due to change. A new player, the module manufacturer, joins the market and competes with plant engineering companies. A modular and decentralized production concept requires different business models and service offers such as remote control or module substitution. Business models between operator and module manufacturers have to be more service orientated with risks shifting more towards the module manufacturer's side.

Keywords: product service systems, business models, chemical industry, modular production concept, container modules.

1 Introduction

At present plant engineering in the process industry is characterized by limited interaction between the plant engineering and the operator company during the operation phase. In addition plants are usually constructed ready-to-use, terminating the business relationships with the start of production. Services such as maintenance, repair and overhaul are carried out by the operator himself. Plant construction is thus dictated by cost effects in order to reach economies of scale. Nevertheless companies in the chemical process industry are facing the challenges of increased competition, pressure on costs, lead times and quality, shortened product life cycles and increased product differentiation. Additionally markets are becoming more volatile. This leads to increasingly low utilization and shortfalls of products. Meanwhile central production sites which are often far away from customers do not allow for lean supply chain and production processes. When new products emerge, equipment cannot be transformed as quickly as needed.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 227–238.
DOI: 10.1007/978-3-642-30820-8_20

Therefore, new transformable, mutable and versatile production concepts for the process industry are at the stage of development, attending to these challenges. Modularized production systems can be operated decentralized at customers' locations. Consequently these new production concepts require new business relationships that span the whole product life-cycle as the customer may not possess the required know-how and resources. Hence, plant engineering companies and equipment manufacturers start offering operating services such as maintenance, repair and overhaul. In order to perform services more efficiently, process and equipment development are increasingly merging together ensuring short times to market. Therefore, product service systems (PSS) are starting to evolve within the process industry.

The paper at hand seeks to analyze the status-quo of business models in the process industry. Based on this, a scenario is set up which deals with the developments of PSS in this area. New structures including business relationships and alternative business models are proposed for transformable production concepts. Therefore two in-depth interviews with main players in the industry have been conducted.

2 Business Models for PSS

Business models for PSS are "characterizing the relationship between a customer and a provider (network)" [1]. Hence, a business model settles the value creation and delivery for customers, how the customer pays for this value, how profits are derived and elements of the value chain [2]. For PSS every customer-supplier relationship is characterized by a specific business model.

Rese, Meier, Gesing, Boßlau (2012) have identified three categories of business models which differ in their degree of collaboration between customer and supplier during the operation phase. The lowest degree of collaboration is present in *transaction-based business models*. In these models products or services are sold as part of one-time transactions. These models do not represent PSS since products and services are not integrated and no long-term relationship is established. The supplier sells the products and/or services and the customer operates them himself.

In *provider-driven business models* the supplier takes over most of the processes from his customer during the operation. These consist, for example, of build-own-operate models. The provider is responsible for performing the processes and sells the result of these processes to his customer.

In between these two models *collaboration intense business models* are situated. They distinguish themselves through a high degree of collaboration. In these models customer and supplier both conduct sub-processes within the customer's overall production process and hence have to collaborate and coordinate.

Furthermore business models are composed of different parts. Rese, Meier, Gesing, Boßlau (2012) set up a morphology in which they identified five characteristics of a business model. The *value proposition* depicts the value that is delivered to the customer [3]. In the case of transaction-based business models the value is delivered offering only products or services and not PSS. In the case of collaboration intense business models the value is determined by an integrated combination of products and services, e.g. a guaranteed availability. In provider-driven business models the provider guarantees the result of a certain process.

A consequence of the value proposition of a PSS is the division of labor. Agreeing upon different value propositions simultaneously results in different responsibilities in the production process shown in the *organization model***.** Thus, it describes the responsibility during usage and thus the degree of co-creation.

In agreeing on a PSS, customer and supplier automatically have to agree on *risk sharing* issues [4]. For instance if the supplier guarantees a contractual performance, the risk of early wear out of physical parts or obsolescence shifts to his side. Additional risks also arise in cooperative agreements due to interdependencies between the partners [5].

Delivering value and sharing risks is always connected to some kind of compensation for the supplier, which is analyzed in the *revenue model* [3]. When selling products or services in time-to-time transactions the basic and most commonly used way of compensation is a one-off payment. In the case of PSS revenues change and cover the whole life cycle. The *property rights* determine who owns the rights to the physical part (e.g. machines) of the PSS.

3 Status Quo and Changes in the Chemical Industry

3.1 Methodology

To assess the status quo and possible developments in the chemical industry the authors conducted in-depth interviews with different companies. One interview was conducted with a plant engineering company and one with a plant operator. Each interview was conducted by two to three researchers and lasted between 80 and 120 minutes. The companies interviewed are described in table 1.

Table 1. Interview sample

Company	**Plant engineering company**	**Plant operator**
Company location	Germany	Germany
Annual turnover in 2011	1.42 bn. €	36.5 bn. €
Number of employees in 2011	5,600	111,800
Interview partner	Senior Project Manager; Product Manager Technical Services	Head of Engineering Process and Plant Layout

3.2 Status Quo in the Chemical Industry

The current situation in the chemical industry is driven by large plants that are built to optimize economies of scale [6, 7, 8]. Three main players are involved in the business starting with equipment manufacturers who produce components, which are then sold to the plant engineers that build the plants towards the customer's requirements, who in turn are the plant operators.

BM CHARACTER-RISTICS		ATTRIBUTES OF BUSINESS MODEL CHARACTERISTICS					
value	**customer value**	property of the physical product	use of the product	availability of the product	result of the use of the product	consumption of the product	
			including services				
organization	**operation responsibility**	customer					provider
	provider's life cycle activities	specification and installation	maintenance	upgrading	continuous improvement	manufacturing resources	operation
	customer's life cycle activities	operation	manufacturing resources	continuous improvement	upgrading	maintenance	specification
risk distribution	**risk sharing**	customer					provider
	provider's risk	risk up until product sale/invest	risk for life cycle activities	risks for the availability (e.g. preterm wear out)	risk for result of the use of the product	market risks	
	customer's risk	risk up until product sale/invest	risk for life cycle activities	risks for the availability (e.g. preterm wear out)	risk for result of the use of the product	market risks	
revenue	**revenue**	based on order (one time sale)	revenues over the life cycle				
			not based on unit		based on result (e.g. revenue per produced unit)		
			availability (in %, e.g. OEE; time)	utilization period			
PR	**ownership**	customer (buyer) gains ownership of product	product in ownership of a third party	product in ownership of the provider			

Fig. 1. Current business model in the chemical industry [1]

The interviewed plant engineering company outlined two ways on how to sell chemical plants. First, operators ask for turnkey plants, merely communicating their requirements in advance. The plant is built according to these requirements by the plant engineering company and sold in a onetime transaction for a lump sum. Second, some customers want to co-develop the plant with the engineering company. In this case the development is marked by a higher degree of interaction. Some customers even take over single engineering services themselves. The payment is characterized by single prices for parts and different reimbursable engineering services. Meanwhile, at the time when the plant is readily constructed, the operator takes over the whole responsibility. Hence, in both cases the plant is solely operated by the operation company. During the operation phase little interaction between the three parties occurs. Except for single spare-part businesses or process optimizing and upgrading, no further relationship evolves. In case of shortfalls the plant operator either contacts the engineering company or gets in touch with the equipment manufacturer. Plants are usually constructed for huge production volumes in order to reach economies of scale. The operators of these large plants possess great know-how which enables them to take over maintenance and repair services.

Thus, the business model applied in the current chemical industry is a transactional one. The specifications of the different characteristics of the business model described above are shown in figure 1).

The value that is delivered to the customer is the property of the chemical plant. The operator takes over the whole responsibility during the operation phase, whereas the supplier is only responsible for specification and installation. Hence, the risks that can occur during the operation phase lie on the customer's side as well. The provider only takes over risks until the plant is ready for operation. Nevertheless, in the case of huge chemical plants the investment risks on the supplier's side are high. Revenues are generated accordingly on a transactional basis. The customer either pays for single engineering services or a lump sum prior to operating the plant. Since the value delivered is the property of the plant, the customer gains the ownership.

3.3 New Technologies and Production Concepts in the Chemical Industry

The chemical industry still focuses on economies of scale and therefore builds its plants as large and as optimized as possible [6, 7]. But this industry faces more and more volatile, global customer demands, shortened product life-cycles and an increasing product variation which lead to uncertain forecasts [9, 10]. As large-scale plants are very inflexible regarding output numbers, assortment and local positions, modular, transformable production concepts emerge in order to increase flexibility [11, 12]. In this context a module is defined as a technical and organizational separated part of a chemical plant which represents a standardized, operational and autonomous unit [8]. Modularity is distinguished between serial and parallel modularity regarding different scale-levels. Serial modularity means the selection, order and substitution of single, standardized apparatus in order to gain different production lines. Whereas parallel modularity means numbering up the same production line as often as necessary in order to serve market demands. The combination of parallel and serial modularity leads to a modular multi-purpose plant as shown in figure 2.

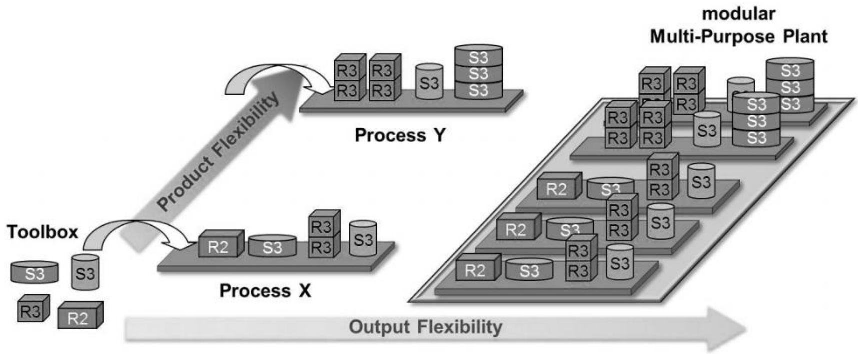


Fig. 2. Parallel and serial modularity [8]

Modular chemical plants owning one process line have got a fraction of the size of traditional plants. They consist of standardized and, depending on the requirements, process intensified apparatuses with homogenous interfaces, which are taken from a toolbox. Apparatus can be integrated in a given backbone-system that has the dimensions of an ISO-container [11]. This backbone system provides standardized interfaces to the environment and supplies the apparatus with the required energy and utilities. Figure 3 shows such a production container developed by the research center "invite" in Leverkusen. The production mode of a container module is preferably continuous. As the usage of ISO-containers offers mobility, the standardization of apparatuses provides product flexibility and short lead times. In addition output numbers can easily be adapted by adding or removing containers.

Fig. 3. Container module and backbone-system [13]

Hence, on the one hand the loss of economies of scale and no longer optimized, individual adapted process parameters display the disadvantages of modular production plants. On the other hand modular concepts offer flexibility and faster process development and plant construction in contrast to conventional plants. Furthermore modules are built more than once. Thus module investment costs are going to decrease because of experience and learning effects.

Regarding quantified economical terms Lier and Grünewald examined the net present value of a large-scale plant in contrast to a modular plant concept with the same capacity. Due to shorter time-to-market the modular plant gains earlier revenues and therefore obtains an earlier break-even point whereas the large-scale plant lags behind by years. But at a certain point, due to economies of scale, the large-scale plant overtakes the modular plant. The main influencing parameter on the net present value can be identified in the course of product demand (Lier & Grünewald 2011).

Modular production plants provide the possibility to relocate production directly at customers' sites. Thus product transportation can be reduced to a minimum while just-in-time concepts, which are not possible in conventional environments, can emerge. Additionally assembly and construction of modules can be performed at a manufacturer's home location, for modules are distributed afterwards to their specific destination. In case of shortfalls during operation either single apparatuses or the entire ISO-container can be substituted quickly. This scenario of a decentralized production requires new services such as maintenance or remote control because the staff at decentralized locations does not possess the same know-how about operating the container-module as at a central location. Furthermore new business models can emerge since operator models become attractive. The following section 3.4 describes these changes in services and business models in detail.

3.4 Changes in the Business Model

When modular production concepts emerge in the chemical industry new balances will result between the involved players. The reason for this is that probably a completely new player, the module manufacturer, occurs on the market. The first question is which current market player (the plant engineering company, the plant operator or the equipment manufacturer) is going to evolve to such a module manufacturer.

Considering the equipment manufacturer there is a lack of know-how and expertise about process development and management of the whole production process. Nowadays the communication between plant engineering companies and equipment manufacturers is reduced to a minimum due to intellectual property protection issues. The equipment manufacturer does not supply one customer exclusively. Therefore the company gets just as much information as needed from the engineering company in order to produce appropriate apparatuses.

The plant operator lacks engineering competences. This implies that this company is yet neither able to design and construct proper apparatuses nor to combine apparatuses and configure transportation and interface devices such as pipes for the desired process. Nevertheless, the operator possesses know-how of product development, process parameters and operation of the plant and has contacts to current product customers for selling the product. Thus operators know required product specifications and how to obtain them with chemical reactions and further unit operations.

The engineering plant company has no or only minimal experiences in adjustment of process operating parameters. In addition, due to intellectual protection issues, equipment manufacturers are sometimes restricted in their publication of experiences made with other plant engineering companies. This again shows the conflict of interests between the three main players on the market. Furthermore engineering companies do not possess enough human capacity to run several chemical plants in addition. Most engineering companies are specified in certain chemical products. They develop their specific technologies. This gives them unique selling points and strong market positions. Thus they probably do not have any interest in changing their business models, because there is no reason to do so.

After considering all current market players no one seems to be dedicated to evolve into a module manufacturer at the moment. Hence, either one of the current players has to develop into a module manufacturer or a fourth player will take this part. For example companies that are dealing with process intensified technologies possess the essential know-how and they combine necessary requirements such as an established network, manpower and technology knowledge. Therefore these companies have got the potential to become a module manufacturer.

Figure 4 gives an overview on how the market structure can be set up and how the players' interactions might change when modular production concepts emerge. The left part of figure 4 shows the traditional interactions of market players as earlier described in this paper. The right part shows a possible situation for modular systems.

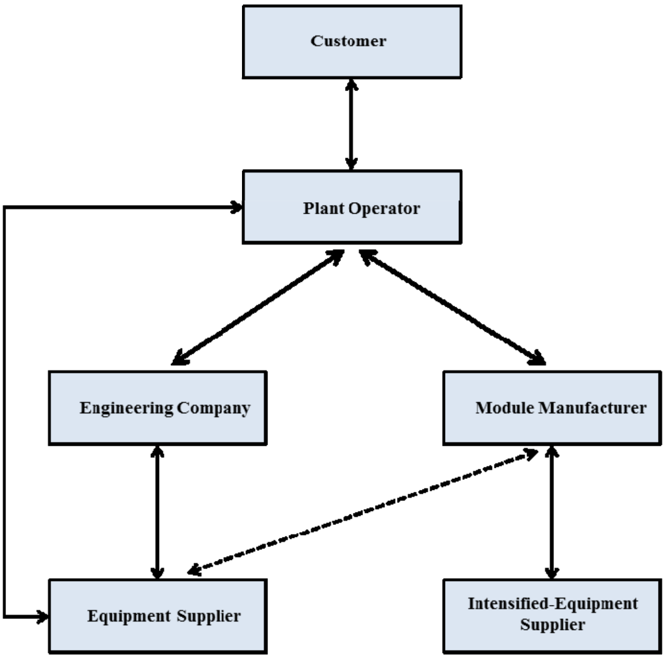


Fig. 4. Market overview with modular plants

The relationship between plant operator and customer will not be influenced by the production concept. The customers demand the product and its specification without any interests in the underlying production process as long as the product quality and price are appropriate. But they would probably prefer a production site in their surroundings.

The plant operating company gets the possibility to choose between the modular production concept and the traditional large scale production. The decision about the production concept depends on two product attributes. The first one is whether the product is a bulk-chemical or a fine-chemical product. Bulk-chemicals are defined by huge, steady customer demands, while fine-chemical demands are relatively small and volatile. On the one hand, in the case of bulk-chemicals, a traditional large-production concept can be preferred due to economies of scale. On the other hand a modular production concept will likely be chosen if the product is a fine-chemical due to low production volume and more flexibility.

The second product attribute which influences the production concept decision is the position of the production process in the value chain. If the process describes a core product conversion, which is followed by several further conversion steps, the preferred concept will likely be the large-scale plant. Vice versa, if the considered process is a finishing and conditioning step the modular production concept will come into consideration. Thus the traditional plant engineering company will compete with the module manufacturer depending on the production concept preferred by the plant operator.

The business models between plant operator and engineering company has been described and analyzed in chapter 3.2. The interactions between plant operator and module manufacturer are described henceforth. The module manufacturer will be mainly delivered by micro or milli equipment companies as process intensified technologies are preferably built into container modules. In addition further equipment manufacturers will supply the module manufacturer with comprehensive equipment such as pipes and instruments.

New services between plant operators and module manufacturers will emerge when container modules are located decentralized and not necessarily integrated in a chemical park. The module manufacturer is able to move modules to locations where they are needed. Thus, depending on the product lifecycle, modules are added or removed. During inspections apparatuses do not necessarily need to be repaired on site. Instead apparatus modules can be completely substituted. Thus value production time can be gained. Furthermore business models between operators and module manufacturers change in contrast to those of conventional plant engineering companies. For example leasing contracts become attractive as modules are not custom specified and are not fixed at dedicated locations. The following figure 5 illustrates an example for a likely business model between a plant operator and a module manufacturer. This business model describes only one possible scenario derived from the conducted industry interviews since container- modules are not on the market yet.

BM CHARACTER-RISTICS		ATTRIBUTES OF BUSINESS MODEL CHARACTERISTICS					
value	customer value	property of the physical product	use of the product	availability of the product	result of the use of the product	consumption of the product	
			including services				
organization	operation responsibility	customer				provider	
	provider's life cycle activities	specification and installation	maintenance	upgrading	continuous improvement	manufacturing resources	operation
	customer's life cycle activities	operation	manufacturing resources	continuous improvement	upgrading	maintenance	specification
risk distribution	risk sharing	customer				provider	
	provider's risk	risk up until product sale/invest	risk for life cycle activities	risks for the availability (e.g. preterm wear out)	risk for result of the use of the product	market risks	
	customer's risk	risk up until product sale/invest	risk for life cycle activities	risks for the availability (e.g. preterm wear out)	risk for result of the use of the product	market risks	
revenue	revenue	based on order (one time sale)	revenues over the life cycle				
			not based on unit		based on result (e.g. revenue per produced unit)		
			availability (in %, e.g. OEE; time)	utilization period			
PR	ownership	customer (buyer) gains ownership of product	product in ownership of a third party	product in ownership of the provider			

Fig. 5. Business model in the chemical industry involving modular plants [1]

Customer value is described by the use and/or the availability of the container module including appropriate services. Thus the value architecture is product-service-orientated. The module manufacturer takes over some operation responsibilities. He conducts maintenance, upgrading and improvements whereas the operator is responsible for running the module. The risks now mainly shift towards the provider's side. He now takes over the risks for modules life-cycle activities, for module availability and, together with the operator, the risks of results from the use of the product. Market risks lie on the operator's side. Considering revenues a wide range of interactions is possible. A sales model based on a utilization period is as appropriate as a revenue model based on availability or on results. That decision really depends on the involved companies and their preferences. The modules stay in the ownership of the module manufacturer who distributes and coordinates them to operators' locations. Owning a huge bulk of modules gives the module manufacturer the opportunity to react flexible and quickly to customers' demands. All in all the module manufacturer takes over more risks, offers a product-service orientated solution and gets paid over the life-cycle.

4 Conclusion

Based on the conducted interviews comprehensive product service systems over the entire product life cycle are not in demand within current production technologies in the chemical industry. But as new production concepts like modular production plants emerge dedicated services and thereby product service systems are indispensable for a successful establishment. Thus new production technologies are only attractive accompanied by new services and vice versa product service systems in the chemical industry become especially relevant with the introduction of modular production concepts.

Today the relationship between a plant engineering company and a plant operator in the chemical industry is very separated and restricted. In extreme cases the operator is purely investment orientated, not interested in any engineering processes. Vice versa, the plant engineering company does not offer any further services while the plant is in operation. Such a business model is characterized as transaction orientated. This is due to change when modular production concepts emerge on the market. As a result a new market player, the module manufacturer, might join the market. It is hypothesized that the module supplier will probably not evolve out of one of the existing players, mainly due to lack of know-how, capacities and intellectual protection issues. Instead new companies might take over this part and become competitors to conventional plant engineering companies. The operator receives the possibility to choose whether he wants to serve the market operating large-scale plants or container modules. The decision depends on the specifications of the product the operating company wants to sell. If the operator decides to use modular production concepts the company will be confronted with new business models. A shift towards providers' responsibilities and risk taking can be identified in this relationship. This is because the modular production concept requires different services in order to be attractive for operators. The module manufacturer takes care of the plant over the entire life-cycle. Services such as remote control, apparatuses substitution or moving modules to different locations will emerge and will be necessary in order to gain the full potential of modular chemical plants.

Acknowledgments. We extend our sincere thanks to the German Association of Research (DFG) for funding the research project TR29 and to all who contributed to preparing this paper.

References

1. Rese, M., Meier, H., Gesing, J., Boßlau, M.: An Ontology of Business Models for Industrial Product-Service Systems. In: Proceedings of the 4th CIRP International Conference on Industrial Product Service Systems, Tokyo, Japan (2012)
2. Teece, D.J.: Business Models, Business Strategy and Innovation. Long Range Planning 43(2-3), 172–194 (2010)
3. Osterwalder, A., Pigneur, Y.: Business Model Generation. John Wiley and Sons, New Jersey (2010)
4. Cova, B., Salle, R.: Introduction to the IMM special issue on 'Project marketing and the marketing of solutions' A comprehensive approach to project marketing and the marketing of solutions. Industrial Marketing Management 36(2), 138–146 (2007)
5. Link, P., Marxt, C.: Integration of Risk- and Chance Management in the Co-operation Process. International Journal of Production Economics 90(1), 71–78 (2004)
6. Kent, J., Riegel, E.: Handbook of Industrial Chemistry and Biotechnology. Springer, New York (2007)
7. Behr, A., Agar, D., Jörissen, J.: Einführung in die technische Chemie. Spektrum, Heidelberg (2003)
8. Lier, S., Grünewald, M.: Net Present Value Analysis of Modular Chemical Production Plants. Chemical & Engineering Technology 34(5), 809–816 (2011)
9. Ewers, C.L.J.: Pharma Supply Chain: Neue Wege zur effizienten Wertschöpfung. Der Pharmazeutische Betrieb, vol. 47. ECV, Aulendorf (2002)
10. Früh, K.F., Maier, U., Schaudel, D.: Handbuch der Prozessautomatisierung: Prozessleitechnik für verfahrenstechnische Anlagen, vol. 4. Oldenbourg Industrieverlag, München (2009)
11. Bott, T.: Flexibilität dank Modularität. Process 6, 8–9 (2010)
12. Drathen, H.: Haben Module im Anlagenbau Zukunft? Process 5 (2010)
13. Invite GmbH, `http://www.invite-research.com`

Strategies for Extended Product Business Models in Manufacturing Service Ecosystems

Stefan Wiesner[1], Marcus Winkler[2], Jens Eschenbächer[1], and Klaus-Dieter Thoben[1]

[1] Bremer Institut für Produktion und Logistik, Hochschulring 20, 28359 Bremen, Germany
{wie,esc,tho}@biba.uni-bremen.de
[2] DITF-MR, Koerschtalstrasse 26, 73770 Denkendorf, Germany
marcus.winkler@ditf-mr-denkendorf.de

Abstract. The growing demand for integrated solutions forces manufacturers of industrial goods to combine their products with service components to Product-Service Systems, or Extended Products (EP). The new value proposition of the EP and the required network of business partners are not included in the traditional business models of manufacturing companies. A business model represents the implementation of an industrial strategy in respect to its specific elements. The purpose of this paper is to investigate classic strategies in manufacturing and new strategic approaches to help manufacturers transform their business models for EP. A special focus is given to value innovation and collaboration in Manufacturing Service Ecosystems (MSE). In an MSE, different organizations and individuals can work together with common or complementary objectives on new value added combinations of manufactured products and product-related services. The approach is exemplified by the transformation of the business model of a machine tool manufacturer.

Keywords: Product-Service Systems, Manufacturing Service Ecosystem, Business Models, MSEE Integrated Project.

1 Introduction

The European manufacturing industry is currently in recession. Although Germany is still very successfully exporting goods and services, most of the other European countries see their industries declining. One potential way out of this critical situation might be the creation and operation of service ecosystems as an extension to the existing industrial districts. The paradigm shift towards a service dominant logic [1] is simple: Customers are more and more looking for solutions and benefits. In an attempt to understand and answer the customers' problems, manufacturers of industrial goods are increasingly adding services to their products to create holistic and individual solutions. While in the beginning the physical product has just been extended with some basic services, the value share of services is now increasing to parity with the product and beyond. Such an offering of complementary product and service components is viewed as a Product-Service System, or Extended Product (EP) [2].

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 239–250.
DOI: 10.1007/978-3-642-30820-8_21

However, this servitization of manufacturing from physical products to EP also requires innovation of business models [3]. Of course, the value proposition of the Extended Product to the customer has to be described. But furthermore a new infrastructure of business partners is needed, providing the right competencies and resources for realization of the value proposition. Also, new revenue streams have to be defined. While in the past revenue has been generated from selling the product, now additional types of revenue streams can be distinguished: In a function-oriented business model, the functionality of the solution is secured, e.g. through maintenance services. Availability-oriented business models additionally guarantee the usability of the solution. Finally, result-oriented business models sell only the benefits of the solution to the customer, while the responsibility for its operation remains with the provider [4].

A business model can be seen as an implementation of an industrial strategy in respect to the specific elements of the business model. Thus, the innovation of business models does require an investigation of the underlying strategic approaches. The paper will first present a theoretical background on the chosen business model definition and elements. The relationship between industrial strategy and business model is described. Following, classic strategies in manufacturing are identified and exemplified by the traditional business model of a machine tool manufacturer. On this basis, a new strategy of value innovation and collaboration in Manufacturing Service Ecosystems (MSE) is described, which has been developed in the European integrated project "Manufacturing SErvice Ecosystem" (MSEE) [5]. In this non-hierarchical form of collaboration, different organizations and individuals work together with common or complementary objectives on new value added combinations of manufactured products and product-related services. The example of the machine tool manufacturer is again used to show the transformation of the business model according to the new strategy.

2 Theoretical Background on Business Models

The following sections give a short overview on the definition of a business model, which is used in this paper and the relationship between industrial strategy and business model.

2.1 Definition of a Business Model

The origin of the term business model is still not settled [6] and is either assigned the 1950ies by Peter Drucker (using the term 'logic of business') or in the beginning of the 1970ties when the fields of information systems grew. There is a great amount of definitions and descriptions of business models, especially around the year 2000. They are either very short like the one from Baatz [7], who said this is the way *"how to create money"* or more sophisticated like the one from Rentmeister and Klein [8]: *"A business model is an abstract model that depicts the relevant and essential aspects of a business in an aggregated and clear form. The model is used by the business to check and rank ideas and concepts. Business models concentrate on the decision makers and potential investors, and also employees and clients. A business model* *should depict the performance and information stream of the business and consider other involved actors."* Timmers [9] specifies: *"An architecture for the product, service and information flows, including a description of the various business actors and their roles; and a description of the potential benefits for the various business actors; and a description of the sources of revenues."*

However, the above definitions are too vague to be applied in this paper. To analyze the impact of different industrial strategies to a business model, a concrete description of its elements is needed. Such a classification is offered by the Business Model Canvas as an approach for illustrating the building blocks of a business model [10]. The Business Model Canvas is a template that is often used within strategic management and offers the idea to describe how an organization creates, delivers and captures value. It divides a business model into four pillars with altogether nine building blocks that are intended to realize that claim. The pillars and building blocks of the Business Model Canvas are:

- Value proposition of the offering to the customer
- Customers
  - Customer Segments
  - Channels of delivery
  - Customer Relationship
- Infrastructure
  - Key Activities
  - Key Resources
  - Partner Network
- Finances
  - Cost Structure
  - Revenue Streams

The application of the Business Model Canvas, especially the nine building blocks, will deliver a holistic view on the changes new industrial strategies inflict on a business model. It will be used in the following chapter to describe the traditional business model of a machine tool manufacturer and in chapter 5 to give a hint on a new EP business model.

2.2 Relationship between Strategy and Business Model

Often the terms business model and strategy are mixed and put in different orders. Anyhow most of the management researchers agree that both are different concepts affecting different conceptual levels. Here we follow Bieger et.al. [6] stating that strategy gives the framework for the development and the design of a business model. In general, a company deduces strategies out of its corporate vision or mission, and establishes within the frame of these strategies an appropriate business model.

According to Casadesus-Masanell and Ricart [11], a strategy is a context specific plan that serves to reach goals. The given frame or limitations to reach the goals are the 'raw material' to create business models. The determination of a business model is part of the strategic process in order to reach the goals and so a business model is a reflection of a companies' realized strategy (see Fig. 1).

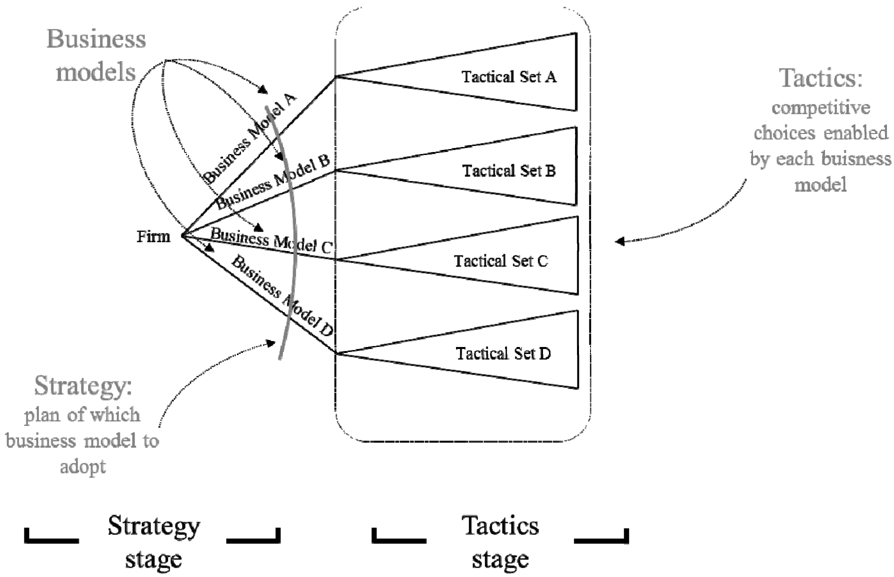


Fig. 1. Strategy, Business Model and Tactics [11]

Following this, the business model is not a simplified representation of the strategy but rather an implementation of the realized strategy in respect to specific elements of the business model. Hence the planning of strategy and business model(ing) must be combined in order the gain and protect competitive advantages [12]. Therefore, to deduce new business models, first the strategies of manufacturing companies have to be analyzed.

3 Classic Strategies and Business Models in Manufacturing

This chapter gives an overview of the classic strategies identified in manufacturing and the business models which have been derived from them by the example of a machine tool manufacturer.

3.1 Classic Strategies in Manufacturing

In the past 30 years, company strategies have been focusing on how to beat the competition and achieve a greater share of the existing demand. A widely used classification of the basic strategies is given by Porter. He describes two basic possibilities to gain competitive advantages in manufacturing: either by cost leadership or by differentiation. Porter called them generic strategies that are seen as useful *"…to characterize strategic positions at the simplest level."* [13]

The strategy of cost leadership focuses on low production costs to be able to offer low prices to the customer and to protect thereby own market positions. This could be reached by high capacities (economies of scale) and a strict view on cost aspects. Using this kind of strategy means to become the lowest cost producer in your industry or business. This kind is often used with large-scale businesses providing standard products with little differentiation and which are accepted by most of the clients.

Differentiation in contrast means to create a unique product or products with unique attributes (support etc.), that are perceived by the customers. It is often used with asking for a higher or even premium price, like brands do. Different options allow following this way, like superior product quality, branding, industry-wide distribution across all major channels and consistent promotional support.

Most companies will choose a path between these two extremes of cost leadership and differentiation. They might focus their concentration on a restricted number of market segments. An example of a business model derived from the Porter strategies is presented in the next section.

3.2 Classic Business Models in Manufacturing

From the Porter strategies a blueprint of a classic business model in manufacturing can be created. In order to complement the theoretical approach, a survey under MSEE end-users has been conducted, taking up a Business Model Canvas of the partners. The canvas of one of the end-users is shown below (see Fig. 2):

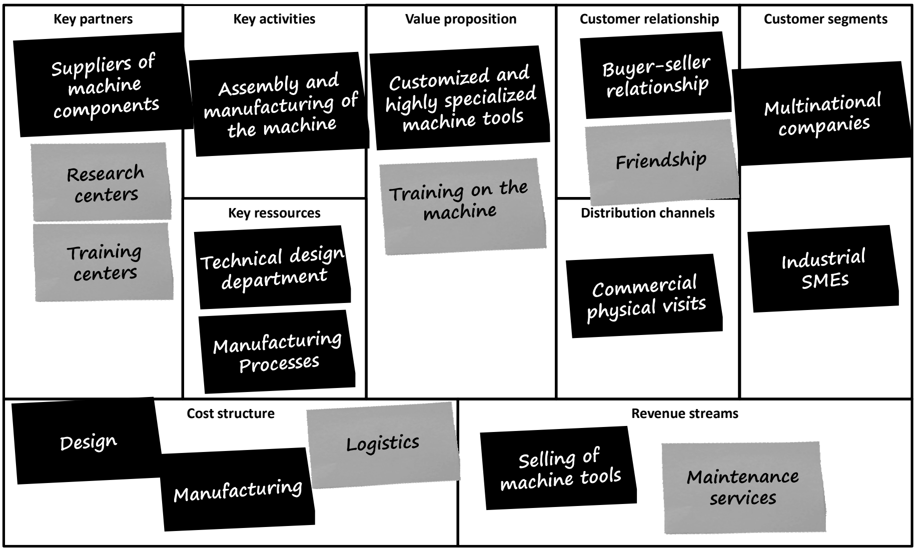


Fig. 2. Classic Business Model of a Machine Tool Manufacturer

The machine tool manufacturer is following a differentiation strategy. The high-price products are customized individually for each offer. In the figure above, the effects of this classic manufacturing strategy are marked black, while first attempts to break the boundaries of the manufacturing industry by adding services to the product are marked in dark grey. The separate building blocks characterizing a “classic” business model can be described as follows:

- Value proposition
  The value proposition to the customer are the functionalities the customized machine tool and to a certain extent training on its operation.
- Customers
  - Customer Segments
    Individual companies as customers in different size categories (differentiation).
  - Channels of distribution
    Physical visits of the selling department.
  - Customer Relationship
    Typically a buyer-seller relationship, sometimes long-term “friendship”.
- Infrastructure
  - Key Activities
    Manufacturing and assembly of the machine.
  - Key Resources
    Design and manufacturing departments.
  - Partner Network
    Suppliers of machine parts as well as training and research centers.
- Finances
  - Cost Structure
    Cost-driven for design, manufacturing and logistics.
  - Revenue Streams
    Most of the revenue comes from the sale of the product and basic maintenance.

4 New Strategic Approach in Manufacturing

Formerly, the boundaries of the manufacturing industry and its market space were defined and accepted. However, improved productivity generated through new technologies has led to a surplus of supply, while demand remains static. Furthermore, decreasing trade and information barriers increase the competition, leading to commoditization of products and shrinking profits. A new strategic approach is needed for manufacturing companies to sustain high performance, which is presented in the following sections.

4.1 Value Innovation through Extended Products

The classic approaches of cost leadership and differentiation are called the Red Ocean Strategy, as cutthroat competition turns the “ocean” of known market space red. As a solution, the creation of untapped market space with new demand and profitable growth through a Blue Ocean Strategy is proposed [14]. While the classic approaches call for a trade-off between differentiation and low cost to exploit existing demand, the creation of new demand in blue oceans breaks this value-cost trade-off.

An analysis of strategic moves has shown that blue oceans are formed by creating a leap in value for the company and their customers. This process is termed *value innovation*, in contrast to incremental *value creation* and purely *technological innovation*. Value innovation means to pursue differentiation and low cost at the same time: *"Value innovation is created in the region where a company's actions favorably affect both its cost structure and its value proposition to buyers. Cost savings are made by eliminating and reducing the factors an industry competes on. Buyer value is lifted by raising and creating elements the industry has never offered. Over time, costs are reduced further as scale economies kick in due to the high sales volumes that superior value generates."* [14]

Value innovation thus denotes a strategic element that concentrates on the value proposition to potential buyers. For manufacturing enterprises, this means to concentrate their strategy on innovating new value propositions for their customers to make competition of other companies irrelevant. The leap in value has to be achieved by breaking the boundaries of the manufacturing industry and creating a new offering that is hard to copy. At the same time, the key factors of manufacturing have to be improved and complemented with non-manufacturing factors from other industries.

The bundling of physical products with intangible components like services creates new options for value innovation, where the manufactured product is combined with services from other domains to an Extended Product, giving more value to the customer [2]. The Extended Product concept is illustrated in Fig. 3.

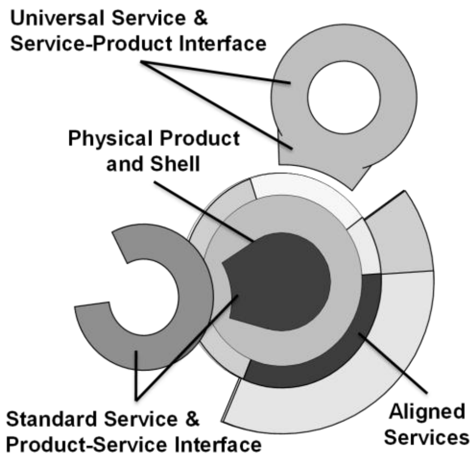


Fig. 3. Extended Product concept

The above figure shows the logic of the Extended Product concept, where the physical product in the center is surrounded by its shell (innermost ring) and different kinds of services (outer rings). While the product shell denotes tangible aspects like packaging, design etc., the services describe intangible additions to the product.

Aligned services are developed together with the physical product and are thus especially designed to be used with it (e.g. maintenance plans). Another possibility are standard services that are available on the market (e.g. logistics services), for which the physical product has to be equipped with a compatible interface. Finally, there may be universal services (e.g. remote monitoring), where the service itself is modified with an interface to work with the physical product.

The different options to configure Extended Products do also create a number of possibilities for value innovation. Therefore, it is necessary to further investigate the possible value propositions of Extended Products in more detail:

- **New combinations** of existing products with existing services
  Value may be innovated by recombining already existing products and services, maybe even from different domains. An example for this approach is the combination of the existing product bicycle with express mail service to bike couriers.
- **New services** for existing products
  If the product is already existing, the option might be to develop or adapt a new universal service with a service-product interface. A new remote monitoring service using the already existing sensors of a machine tool is an example for this approach.
- **New products** for existing services
  Another option for value innovation is to concentrate on already existing standard services and develop or adapt a product with a product-service interface. A fitting example is smart phones, integrating existing services from different domains like telephony, localization and internet.
- Combinations of **new products with new services**
  In this case, the products as well as the services are newly developed in an integrative approach. The integrated Apple approach of the iPod music player and the corresponding iTunes service can serve as an example for this.

4.2 Collaboration in Manufacturing Service Ecosystems

As value innovation typically requires breaking the boundaries of the industry, value itself has to be defined beyond the boundary of a particular company. It rather extends to other stakeholders involved and is not an isolated issue for individual companies. The innovation of Extended Products also requires additional competencies. New combinations of products and services require looking into branches which are not yet related to the product to discover opportunities. The development of services requires competencies in service engineering and in all cases it could be necessary to have competencies in developing product-service and service-product interfaces. These competencies could come from collaboration with service providers.

Therefore, collaboration is an important factor to be considered when defining new business models for Extended Products. To support collaboration for value innovation, companies have to be enabled to "work together". In previous papers, the Manufacturing Service Ecosystem (MSE) has been described as a suitable model to support the innovation of Extended Products: *"The MSE is a non-hierarchical form of* *collaboration where various different organizations and individuals work together with common or complementary objectives on new value added combinations of manufactured products and product-related services. This includes the promotion, the development and the provision of new ideas, new products, new processes or new markets. Future Internet architectures and platforms enable the active participation of all stakeholders in all the phases of the product and service life cycle."* [15]

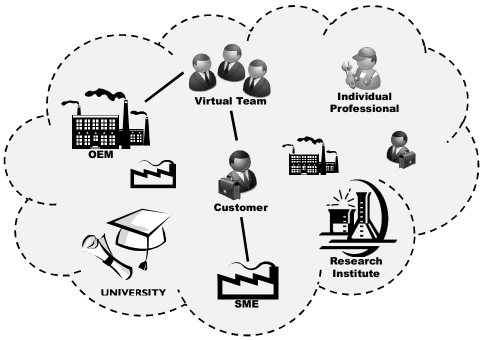


Fig. 4. The Manufacturing Service Ecosystem

Value Innovation is supported through the formation of a Virtual Manufacturing Enterprise (VME) structure, which is shown by the connection lines. The broad variety of the ecosystem supports the "look beyond the own backyard". Thus, an EP of interoperable products and services can be configured through the MSE members.

Being based on Future Internet architecture and platforms, MSE business models are heavily depending on drivers from this area. The FInES Cluster has recognized four major drivers for new business models [16]:

- Web 2.0 developments
- ICT market trends towards commoditization and utility
- New Key Enabling Technologies (KET)
- Globalization

Web 2.0 encompasses a range of services that are Internet based and involve the direct participation of end-users. As such, they capture new demand and create an ecosystem of relationships between business partners from different domains and the customer. Also, revenue is disconnected from selling a product towards service provision. Therefore Web 2.0 is an important enabler for value innovation.

Commoditization of ICT and interoperability as a utility support more high value added capabilities through online and real-time services. Standard basic tools from different platforms can be combined for co-creation of value based on the needs of the end-user. The relationship between suppliers and customers becomes more important than mere production. New business models have to balance the value between the provider and the customer.

As commoditization of existing technologies is on its way, the development of new Key Enabling Technologies for Enterprise Interoperability is critical for the success of new business models. Important aspects are e.g. Service oriented Architecture, business relations or enterprise modelling. A bottom-up approach of open, modular building blocks enables dynamic service creation, execution, discovery, composition and orchestration.

Finally, the broadly used term of globalization is also relevant for the development of new business models. Production is internationally distributed among specialized partners. This increasingly affects also the service business, enabled by ICT. This leads to new opportunities, but also to challenges for innovation. Dynamic business models are essential to respond quickly to changes. However, evolving value networks and ecosystems need new enterprise systems to manage them.

5 Extended Product Business Models

By mapping the new strategic approach of value innovation through EP by collaboration in MSE to the nine building blocks of the Business Model Canvas, ideas for new business models can be derived. Taking the recorded business models of the MSEE end-users as a basis, a transformation of these models towards EP and MSE has been conducted. In the following, the effects on the building blocks from Extended Products and Manufacturing Service Ecosystems are described according to the example from the machine tool manufacturer (see Fig. 5):

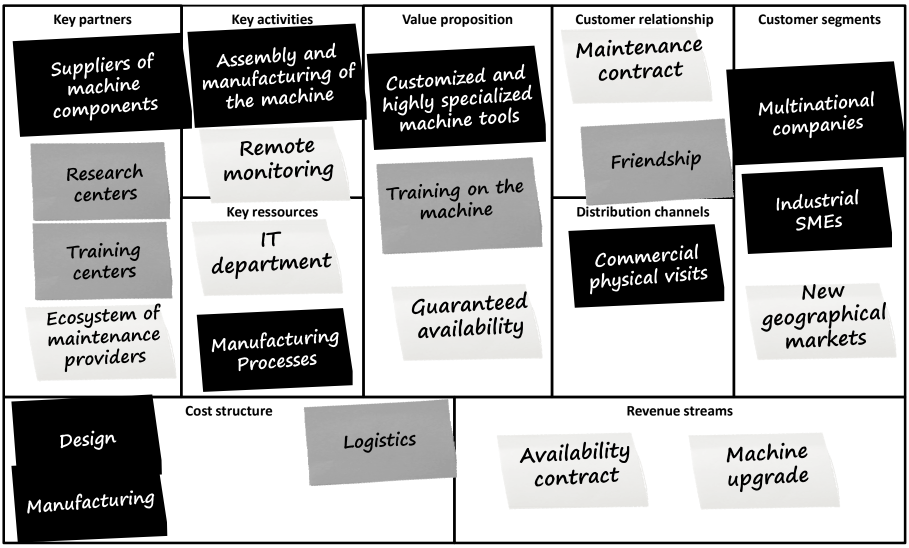


Fig. 5. EP Business Model of a Machine Tool Manufacturer

In the figure above, the similarities to the classic business model are marked black and dark grey, while changes based on the EP and MSE strategy are marked in light gray. The separate building blocks can be described as follows:

- Value Proposition
  The value proposition is the guaranteed availability of the machine tool.
- Customers
  - Customer Segments
    The customers addressed remain mainly unchanged, but new geographical areas can be targeted thanks to new business partner in the ecosystem.
  - Channels
    Recalling the growing importance of ICT and networking, new maintenance services will be delivered in real-time on-line.
  - Customer Relationship
    While selling is more or less a one-time activity, the new business model focuses on permanent interaction with the customer on the basis of a maintenance contract.
- Infrastructure
  - Key Activities
    Besides the production of the machine, remote monitoring of its health status is one of the main activities.
  - Key Resources
    To develop and implement the maintenance services, a IT department is a main resource.
  - Partner Network
    The partner network is extended to an ecosystem of local maintenance partners, who are able to repair a broken machine in a minimum of time.
- Finances
  - Cost Structure
    The maintenance activities are subcontracted to the local maintenance partners.
  - Revenue Streams
    The goal is to generate a constant revenue stream through the availability contract and machine upgrades.

6 Conclusion

This paper has analyzed the challenges to the classic business models in manufacturing, which are based on the strategies of cost leadership and differentiation. Using the Business Model Canvas, the effects of these strategies to the building blocks of a business model example from the machine tool sector have been illustrated. Extended Products and the Manufacturing Service Ecosystem are introduced as a new strategic approach for value innovation in manufacturing. A first analysis has shown how the building blocks of the Business Model Canvas for the machine tool example could be adapted to this new strategy. This preliminary analysis will be detailed in subsequent work and the results will be evaluated through implementation in the business cases of the end-users from the MSEE project.

Acknowledgements. This work has been partly funded by the European Commission through the FoF-ICT Project MSEE: Manufacturing SErvice Ecosystem (No. 284860), which is fostering the research in this area and will develop the final MSE concept and several practical implementations in the manufacturing industry until 2014. The authors wish to acknowledge the Commission and all the MSEE project partners for their contribution.

References

1. Vargo, S.L., Lusch, R.F.: Evolving to a New Dominant Logic for Marketing. Journal of Marketing 68(1), 1–17 (2004)
2. Seifert, M., Thoben, K.-D., Eschenbaecher, J.: Mechanisms to conduct Life Cycles of Extended Products. In: Hesselbach, J., Herrmann, C. (eds.) Functional Thinking for Value Creation, Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, pp. 39–43. Springer, Heidelberg (2011)
3. Chesborough, H.: Open Service Innovation: Rethinking your Business to Grow and Compete in a New Era, San Francisco (2012)
4. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems—IPS2. CIRP Annals – Manufacturing Technology 59, 607–627 (2010)
5. European Commission: Service Innovation Yearbook 2010-2011, `http://itemsweb.esade.edu/research/iik/files/service_innovation_20102011.pdf` (accessed on May 22, 2012)
6. Bieger, T., Bickhoff, N., Caspers, R., Knyphausen-Aufseß, D.Z., Reding, K. (eds.): Zukünftige Geschäftsmodelle – Konzepte und Anwendungen in der Netzökonomie, pp. 4–5. Springer, Heidelberg (2002)
7. Baatz, E.B.: Will your business model float? WebMaster Magazine (10) (1996), `http://www.cio.com/archive/webbusiness/100196_float.html` (accessed September 02, 2002)
8. Rentmeister, J., Klein, S.: Geschäftsmodelle in der New Economy. WISU – das Wirtschaftsstudium 3, 356 (2001)
9. Timmers, P.: Business Models for Electronic Markets. EM - Electronic Commerce in Europe, EM - Electronic Markets 8, 3–8 (1998)
10. Osterwalder, A., Pigneur, Y.: Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers, Switzerland, OSF (2010)
11. Casadesus-Masanell, R., Ricart, J.E.: From Strategy to Business Models and onto Tactics. Long Range Planning 43(2/3), 195–215 (2010)
12. Teece, D.J.: Business Models, Business Strategy and Innovation. Lange Range Planning 43(2/3), 172–194 (2010)
13. Porter, M.E.: On competition. The Harvard Business Review Book Series (1998)
14. Kim, Mauborgne: Blue Ocean Strategy: How to Create Uncontested Market Space and Make the Competition Irrelevant. Harvard Business School Press (2005)
15. Wiesner, S., Westphal, I., Hirsch, M., Thoben, K.-D.: Manufacturing Service Ecosystems - Towards a new model to support service innovation based on Extended Products. In: Conference on Advanced Production Management Systems, APMS 2012, Rhodos, Greece (2012)
16. Future Internet Enterprise Systems (FInES) Cluster: Cluster Book. In: ICT 2010, Event Version (2010)

Functional Products: Business Model Elements

John Lindström, Daria Plankina, Kent Nilsson, Vinit Parida, Håkan Ylinenpää, and Lennart Karlsson

Luleå University of Technology, 971 87 Luleå, Sweden
{john.lindstrom,daria.plankina,kent.nilsson,vinit.parida, hakan.ylinenpaa,lennart.karlsson}@ltu.se

Abstract. The paper explores business model elements that are vital when offering customers Functional Products. Based on in-depth empirical studies at four manufacturing corporations, a number of Functional Product business model elements are identified and discussed. The identified business model elements for Functional Products are found to have special requirements as compared to well-established generic business models. The results, including both academic and industrial contributions, can be used by corporations as input when modeling Functional Product business models on their own or together with customers, business partners or suppliers. Finally, factors and challenges that need to be addressed when modelling Functional Product business in corporations are further discussed.

Keywords: business model, business model elements, Functional Products (FP), Product-Service System (PSS).

1 Introduction

This explorative paper concerns elements that constitute a Functional Product (FP) business model. To facilitate successful development, marketing, sales and operation of FPs, manufacturing corporations need to revise their business model(s). Most business models aim to create value and sustainable competitive advantage in a defined market, and Chesbrough [1] posits that the choice of business model is crucial as "*a mediocre technology pursued within a great business model may be more valuable that a great technology exploited via a mediocre business model*" (p355). Thus, barriers to business model innovation, such as conflicts with existing assets and business models, understanding of these barriers, process of experimentation and effectuation, successful leadership of organizational change, etc., must be brought up and dealt with if they are to be overcome [1]. Casadesus-Masanell and Ricart [2] stress the need to understand how to innovate business models to improve the ability to create and capture value. Understanding the creation and capturing of value, i.e. how different inter-connected business model elements form the business logic or architecture required to do this, probably aids understanding of what is otherwise needed for a successful business model.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 251–261.
DOI: 10.1007/978-3-642-30820-8_22

Based on empirical data from four manufacturing corporations involved in FP innovation and research, our initial findings pertaining to FP business model elements are presented. The proposed set of business model elements can be used by corporations as input while modeling their own FP business models and customer offerings. An FP[1] comprises integrated developed hardware, software, a service support system and management of operation [10]. The software component grows as the requirements for monitoring, remote management and maintenance, as well as software upgradability become further sophisticated [11, 12]. The software is often integrated with the hardware and service support system and, depending on type of FP, can also be seen as a stand-alone entity providing its own value to the delivery of the function. The service support system is needed to keep the hardware and software operable, and the triad is combined to provide a complete function to customers [5, 13]. Alonso-Rasgado et al. [5] add that the service support system is much more than maintenance, often including decision-making, operations planning, remanufacture and education. Throughout the FP lifecycle, operation of the FP must be managed and developed [10].

Among many corporations, there is an increased interest in using the FP business model for transforming and selling products, services or combinations of products and services as FPs or parts of FPs. Moving into FP provision with a specified availability level requires identification of a future win-win situation with the customer, since the ownership of the FP is foreseen to remain with the provider/consortium providing the function. In line with Löfstrand et al. [14], Tan and McAloone [15] suggest that two lifecycle systems, i.e. the physical artefact and the activities in the relation in between the provider and customer, need to be considered. This challenge affects the FP business model, the planning of the FP lifecycle and its development, since the development is more complex than developing a product with services. Therefore, corporations need to further advance their understanding of FP business model elements and development to be able to critically craft such business models.

Prior research in the strategic management and management information systems domains, e.g. [16, 17, 18, 19], has highlighted generic business model elements. However, currently there is a lack of tangible research on the FP or closely related business models' elements (besides [20, 21, 22]). Focusing on business model elements in the context of FP, business development is important because the path through which corporations create value can differ significantly from prior knowledge gained from generic business modeling. Therefore, in this paper we aim to identify and propose a set of critical business model elements based on analysis of FP business model development in four corporations.

---

[1] The concept of FP has similarities with, for instance, Functional Sales [3], Extended Products [4], Total Care Product [5], Product-Service System (PSS) and Industrial Product-Service Systems (IPS[2]) [6], Servitization [7], or Service Engineering [8] in the sense of increasing the focus on soft parts such as services, knowledge and know-how etc., additionally offered. Tukker and Tischner [9] have identified three main PSS categories: product-oriented, use-oriented and result-oriented. The FP, originating from hardware aspects, has most commonalities with PSS/IPS[2], Total Care Products and Functional Sales, however adding additional complexity development-wise.

2 Research Approach

The research approach employed in this study has been based on in-depth empirical studies at four manufacturing corporations. The empirical studies were conducted using semi-structured open-ended interviews [23, 24] with fourteen respondents working for corporations active in the Faste Laboratory at Luleå University of Technology, Sweden, which is a VINNOVA[2] Excellence Centre concerned with FP Innovation. Thus, the respondents were well aware of and knowledgeable regarding FPs. The respondents were professionals responsible for marketing, services, research coordination, development and sales, at three global international corporations and one small Swedish-based corporation:

1. International manufacturing corporation (five respondents – marketing specialist, services specialist, responsible portal development, project leader research, research coordinator)
2. Hägglunds Drives Bosch Rexroth (three respondents – director services, manager design R&D motors, and manager development control systems)
3. Volvo CE (three respondents – R&D chief project manager, service marketing manager, advanced engineering engineer)
4. Infrafone AB (three respondents – founder, Director Engineering, and CEO)

The purpose of having multiple corporations with diverse focus was to ensure an advance in the understanding of how the FP business model and its elements can be embodied at a mainly strategic business unit level, considering the similarities and differences between the corporations [cf. 25]. Although the corporations have different offerings, they all face the common challenge of how to best develop, market, sell and operate FPs and/or similar concepts such as PSS/IPS[2], either as a provider in a partner consortium or as part of their own offerings. The corporations are all manufacturing corporations with roots in hardware development. However, additional components have been added to their customer offerings. What the additional components comprise and their weight or importance differs depending on industry and customer segments served. Some of the corporations aim to increase their revenue from soft parts, e.g. services, knowledge or know-how, as well as functions sold globally. The FPs planned or currently offered by the corporations differ and have differing emphasis on the composition of hardware, software, service support system and management of operation.

Initially, semi-structured interviews were used, with open questions [23, 24] allowing the respondents to give detailed answers and add extra information where deemed necessary [26]. The data collected were displayed using a projector during the interviews, allowing the respondents to immediately read and accept the collected data. The collected data were displayed and analysed using a matrix [27]. The analysed data were used to compile a table comprising elements that may be included in the FP business model and the number of corporations considering each element as part of their view of the FP business model (see Table 2 in section 4). For reasons of

[2] VINNOVA – The Swedish Governmental Agency for Innovation Systems.

confidentiality, only an aggregated view of the analysis is presented (and thus the individual corporations' FP business model elements are not presented).

3 Towards Functional Product Business Model Elements

Teece [18] asserts that the essence of a business model is how an enterprise delivers value to customers, what makes the customers pay for value, and how profit is made. Further, Teece [18] adds that when an enterprise is incepted, it implicitly or explicitly uses a business model describing the architecture for value creation, delivery and capture mechanisms used. A question raised by Teece [18] is how to build a sustainable competitive advantage with profit or super profit. The answer, according to Teece [18], is to not only excel at product innovation, but also at business model innovation, and understanding of customers and business design options. Thus, for an enterprise with a product development focus, business modeling and understanding of business models are necessary together with tight interaction with customers.

Business modeling is gaining more and more interest both in industry as well in academy, and business modeling concerning products, services and products combined with services have been well discussed by researchers, e.g. [28, 29]. However, for business models comprising additional complexity, such as: PSS, IPS[2], Functional sales or FP, there is still a lack of basic as well as specific research. To shed additional light on business models, the following sub-section highlights established/recent research on generic business models, and another sub-section concerns state-of-art in FP and closely related business models. Table 1 comprises a condensation of the business model elements found.

3.1 Generic Business Models

Recent research [17, 18, 19] indicates an interest in generic business models and what elements the generic business models comprise. Below, one established and three recently developed generic business models are defined by their elements (see further Table 1):

- **Johansson et al. [16]**: 1) Customer value proposition, 2) Profit formula (revenue model, cost structure, margin model resources velocity), 3) Key processes (processes, rules & metrics, norms) and, 4) Key resources (people, technology & products, equipment, information, channels, partnerships & alliances, brand).
- **Osterwalder and Pigneur [17]**: 1) Customer segments, 2) Value proposition, 3) Channels, 4) Customer relationship, 5) Revenue streams, 6) Key resources, 7) Key activities, 8) Key partnerships and, 9) Cost structure.
- **Teece [18]**: 1) Target segment, 2) Customer value, 3) Revenue stream, 4) Capture value and, 5) Technology selection.
- **Lindgren et al. [19]**: 1) Value proposition, 2) Target customers, 3) Value chain, 4) Competences, 5) Network partners, 6) Relations and, 7) Profit formula.

Table 1. Business model elements found in literature

Business Model type	Generic	Generic	Generic	Generic	PSS	IPS²	Servitization
Business Model Elements	**Johansson et al. [16]**	**Osterwalder and Pigneur [17]**	**Teece [18]**	**Lindgren et al. [19]**	**Schuh et al. [20]**	**Meier et al. [21]**	**Kindström [22]**
Customer		Customer segments	Target segment	Target customers	Marketing		Target market
Customer value	Value proposition	Value proposition	Customer value	Value proposition	Value proposition	Customer value	Value proposition
Profit	Profit formulae	Revenue streams, cost structure	Revenue stream	Profit formulae	Profit mechanism	Turn over model	Revenue mechanism
Value chain, processes, activities	Key processes	Key activities	Capture value	Value chain	Development/ production process	Architecture of value creation	Value chain
Resources	Key resources	Key resources				Product model	
Relationships	Key resources	Channels, customer relationship, key partnerships		Network partners, relations		Focus on network partners	Value network
Skills/ competence	Key resources			Competences			
Technology	Key resources		Technology selection				
Strategy							Competitive strategy

3.2 Functional Products and Closely Related Business Models

There is a lack of tangible research published on the FP and closely related business models and their respective elements. Schuh et al. [20], Meier et al. [21] and Kindström [22] provide through their proposed elements some further guidance (see Table 1). However, further empirical research is deemed necessary to specify the business models and their elements with an additional level of detail.

- **Schuh et al. [20]:** 1) Value proposition, 2) Marketing, 3) Profit mechanism, and 4) Development/production process
- **Meier et al. [21]**: 1) Customer value, 2) Architecture of value creation, 3) Product Models (processes, recourses, partners) and, 4) Turnover model
- **Kindström [22]**: 1) Value proposition, Revenue mechanism, 3) Value chain, 4) Value network, 5) Competitive strategy and, 6) Target market

Table 1 provides a structure (which will partly be used in Table 2) and can give ideas to discussions pertaining to existing or new business related to FPs as well as similar business models.

4 New Emerging Business Model Elements in Functional Products

The empirical findings regarding what elements the studied corporations perceive as vital when developing FP offerings are summarized in Table 2. Table 2 shows a set of

FP business model elements and, for each element, how many corporations (out of 4) favor these. The elements are further described below based on the data collected. Further, an analysis of why the composition of elements looks like it does follows at the end of this section.

4.1 Descriptions of the Elements

Below are descriptions for each of the elements found in Table 2. The descriptions are based on the empirical data collected and analyzed.

 # 1. Quality of external relations – in the distribution channel between the FP provider, suppliers, partners, distributors, and end-customers. Properties seen as important for the relation are:

- Relation distributor/dealer to end-customer should be *needs-oriented* focusing to learn and analyze the customer's process/needs.
- Having a global presence is important to attract some customers. Important as well for partners/customers requiring closeness to expertise.
- Identification of present and future win-win situation in between provider, partners and customer is essential for establishing trustful long-term relationships.
- The customer needs to be able to trust the provider of an FP, and the provider must also be able to trust the customer in terms of acting responsibly (in line with the operational parameters stated in the contract).
- An ability to reference existing customers is a further indication of a strong relation.
- Partners are important to provide, e.g. onsite support and installations, as well as act together with the provider in the distribution channel to build a complete FP offer. Examples of additional services provided by specialists are financial services and specialized consulting/advisory services.

 # 2. Brand and value chain position

- Brand is important or vital. The brand is particularly important if the provider does not have close or any end-customer interactions.
- Being positioned as a market leader enables increased sales.
- An FP provider needs to be situated as high (upstream) as possible in the value chain, as being situated low makes it hard to develop FP business.

 # 3. In-house organization

- Change management and business training are required inside of provider organizations to change organizations accustomed to selling products, services, etc. into offering FP, e.g. referring to: top level management mindset and courage relating to FP, more complex business models, organizational readiness for FP and related development processes, decision impacts from FP business, need for patience and long-term thinking, and need for internal communication between adequate decision levels to create unity.

Table 2. FP Business Model Elements

Reference #	FP Business Model Elements	# of corporations listing the element
# 1	Quality of external relations	3
# 2	Brand and value chain position	3
# 3	In-house organization	2
# 4	Risk level and availability	2
# 5	Customer involvement and commitment	2
# 6	Customer value and value carrier	2
# 7	Competence/knowhow and relevant information for decision-making	2
# 8	Contract	2
# 9	Recipe for profitability and financial sustainability	1

- Sales strategy and modeling – additional business models with higher complexity requires careful modeling and strategic thinking. New customer segmentation models may be required, as well as improved understanding of customer processes. Need to consider how to organize for selling a mix of products, services and solutions/total offers/FPs, etc. – as new business models in addition can introduce or cause changes in the power balance among the parties involved.
- FP sales require upstream and downstream thinking in the value chains.

 # 4. Risk level and availability

- Availability – need to adapt towards selling an FP with a specified/agreed upon availability level. Of great importance for the customer.
- Risk management – need to balance availability versus cost, where providers need to take a greater long-term responsibility built on trustful relations. Risk modeling, risk mitigation strategies (such as insurance modeling), revenue modeling on long-term basis, and cost/revenue sharing models need to be developed.

 # 5. Customer involvement and commitment

- FP requires more from customers, e.g. increased maturity, ability to specify needs/wants as functions rather than as technical specifications.
- Customer behavior – the customers need to apply changes needed according to business model requirements - such as customer buying behavior and operational behavior (i.e. to ensure operation within specified parameters).

 # 6. Customer value and value carrier

- Customer value - what is considered as value by the customers? What generates the customer value? Is the value perceived differently by different customer segments? Need to segment the customers according to value perceived.

- o Value carriers need to be clear to set prices and profitability targets.
- o Customer value record – what have the customers achieved over time?
- o Measurement of customer value using KPIs such as: achieved productivity/total cost, productivity increase, savings, and customer satisfaction.

 # 7. Competence/know-how and relevant information for decision-making

- o *Soft items*: problems/solutions, training, development of standards, knowledge/know-how, etc. must be available where/when needed to be given and retrieved back from customers/partners.
- o Providers need to increase knowledge on product/services/FP properties and how these are used in customer processes, i.e. need to learn more on targeted customer processes to understand open opportunities.
- o Distributors and dealers need to increase knowledge on *soft items* and improve service capability.
- o Information transparency/adequacy - adequate information for decision-making at different levels of control is needed.
- o Business management needs to increase focus on competence/knowhow and information adequacy. KPIs should be implemented for follow-up on business management level.
- o Requirement for project-oriented sales.

 # 8. Contract – what has been agreed upon between the main provider towards partners/distributors/suppliers/customers, etc. within the value chain?

- o What is promised and agreed upon from both ends – what is paid for?
- o Different types of contracts are required towards customers, partners, suppliers, financial partners, etc.

 # 9. Recipe for profitability and financial sustainability – sound financial calculations (if possible, together with the value chain) are needed to create a stable and sustainable situation for the provider, customer and the rest of the value chain over time. Important aspects, but profitability, capital and operational expenditures are also required for the parties involved. Transparency among those involved allows for strong long-term relations, as all or most are kept content.

In Table 2 the elements of a business model for FPs are highlighted and summarized. When comparing the proposed elements in Table 2 with the elements of conventional business models (see Table 1) it becomes obvious that FP development requires highly developed relations with customers and partners, and that a thorough strategy for risk management is needed. The **management of the risk level** can be seen as an **integrator** for the FP business model, and spans the closely related elements #1 (i.e. building and maintaining trust), #4 (i.e. risks related to cost versus availability ratio) and #9 (i.e. profitability and sustainability over time). Further, management of the risk level pertains to all corporations interviewed, albeit by somewhat different but closely related means, which is logical, since an FP is provided with an agreed upon level of availability, often in combination with long-term contracts and expected long life-cycles. While customer interaction has always been regarded as a success criterion, the development, marketing, sales and operation of FP offerings require an even better understanding of customer needs and wants and of the processes creating value in the customers' value chains. Consequently, this implies a need for new mindsets in managing the corporation on different levels[3], development of competence and know-how, and a decision-making system that recognizes the partly new parameters and factors involved in FP business development.

There are FP business model elements that are similar to the ones listed in Table 1, and it would be remarkable if all elements were different. However, the results contain elements with content that is specific to FP contexts, such as elements #3, 4, 5 and 7. Among other things, #7 provides information for decision-making to the other elements where such is required (see, e.g. [10, 11, 12, 14]). In all business models there are elements that assist in the creation and capturing of value. However, there are also elements that support one or more of the other elements in the creation/capturing of value. In the proposed set of FP business elements, elements #1, 2, 3, 4, 6 and 7 are considered as creative or capturing, while elements #5, 8 and 9 in an FP context can be considered as more supportive rather than creative or capturing.

As all corporations in the study target different industries and applications of FPs, it becomes clear that, for instance, corporate history/age/organization/size as well as target markets, geographical coverage, customer types and types of customer offerings affect what business model elements are needed to sustain the business logic required to create/capture and deliver value to the customers and remain competitive.

5 Discussion and Conclusions

The business model elements listed in Table 2 are described, adding specificity for the FP business model context as seen by four corporations. It is evident that FP business model elements which are not related to hardware and/or services grow in importance. This will be a challenge for corporations who have until now been focusing on business models mainly involving hardware and/or services. Further, Table 2 provides a comprehensive set of nine FP business model elements to consider and select from, as it is not likely that all nine elements are required for all FP contexts. The set of elements constitutes a mix of creative or capturing as well as supportive elements, whereof most affecting organizations are of a holistic character. Further, management of risk level is seen as the essential integrator for the FP business model - spanning at least three of the proposed elements.

We see a number of business model challenges in line with Chesbrough [1], and a need for change and innovation [2] for corporations providing FPs - adding further complexity. Many of these challenges and changes pertain to: organizational age, history, habits, size and agility, existing customer offers, customer agility and requirements for new development, customer base homogeneity/heterogeneity. The same goes for the business partners, distributors and suppliers that will be involved on the provider side. As pointed out in some of the business model elements in Table 2, the customers also need to adapt and consequently change their business to be able to get the full value and potential out of an FP. Otherwise, a win-win situation leading to sustainable competitive advantage and (super) profit [18] for all involved will not be achieved. Consequently, future research should explore the role and importance of FP business model elements.

[3] While developing FP business models, decisions may involve both top management at corporate and strategic business unit levels.

In addition, Chesbrough [1] posits that many corporations have more processes and a stronger sense of how to innovate technology than they do for business models and, further, that the choice of business model and overcoming related barriers are crucial. Thus, important too is the (top management) interest and ability to add new business models to an organization, which today performs well and sees no immediate need to change its business. A change to add one or more business models with additional complexity can be challenging, risky, daring and require new ways of thinking (among providers and customers) as well as organizational change and addition of competences and skills. However, as a provider should provide the customers with what they need – we foresee that most providers will continue to offer their existing business models and add new ones where suitable. Thus, a provider may not solely offer an FP to a customer, and the FP can be part of a large offer where products, services, hybrids of products and services, and FPs, are part of the whole solution. FP business can involve whole corporations or parts of them. Certainly, it is possible for a provider to use different FP business models. Further, Karlsson et al. [30] point out that being able to offer an FP can make the difference in closing a deal, and separate market leaders from followers. Therefore, development of FP business model(s) is essential for future success.

Acknowledgments. This work was conducted at the VINNOVA Excellence Centre the Faste Laboratory at Luleå University of Technology, Sweden. The authors wish to thank the respondents for their time and patience.

References

1. Chesbrough, H.: Business Model Innovation: Opportunities and Barriers. Long Range Planning 43, 354–363 (2010)
2. Casadesus-Masanell, R., Ricart, J.E.: From Strategy to Business Models and onto Tactics. Long Range Planning 43, 195–215 (2010)
3. Stahel, W.: The Functional Economy: Cultural and Organizational Change. In: Richards, D.J. (ed.) The Industrial Green Game: Implications for Environmental Design and Management. National Academy Press, Washington DC (1997)
4. Thoben, K.-D., Eschenbächer, J., Jagdev, H.: Extended Products: Evolving Traditional Product Concepts. In: Proceedings of 7th Int. Conference on Concurrent Enterprising, Bremen, Germany, June 27-29 (2001)
5. Alonso-Rasgado, T., Thompson, G., Elfstrom, B.-O.: The design of functional (total care) products. Journal of Engineering Design 15(6), 515–540 (2004)
6. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems – IPS2. CIRP Annals Manufacturing Technology, 1–24 (2008)
7. Vandermerwe, S., Rada, J.: Servitization of business: Adding value by adding services. European Management Journal 6(4), 314–324 (1988)
8. Tomiyama, T.: Service engineering to intensify service contents in product life cycles. In: Proceedings of EcoDesign 2001, 2nd Int. Symposium on Environmental Conscious Design and Inverse Manufacturing, Tokyo (2001)
9. Tukker, A., Tischner, U.: New Business for Old Europe – Product-Service Development, Competitiveness and Sustainability. Greenleaf Publishing, Sheffield (2005)

10. Lindström, J., Löfstand, M., Karlberg, M., Karlsson, L.: A Development Process for Functional Products: Hardware, Software, Service Support System and Management of Operation. International Journal of Product Development 16(3/4) (2012)
11. Alzghoul, A., Löfstrand, M.: Increasing availability of industrial systems through data stream mining. Computers & Industrial Engineering 60, 195–205 (2011)
12. Alzghoul, A., Löfstrand, M., Karlsson, L., Karlberg, M.: Data Stream Mining for Increased Functional Product Availability Awareness. In: Proceedings of 3rd International Conference on Industrial Product Service Systems, Braunschweig, Germany, May 5-6, pp. 237–241 (2011)
13. Li, J.-P., Thompson, G.: Simulation based Reliability Assessment of Services in the Context of Functional Products. Journal of the Safety and Reliability Society 29(4), 47–78 (2009)
14. Löfstrand, M., Karlberg, M., Andrews, J., Karlsson, L.: Functional Product system availability: simulation driven design and operation through coupled multi-objective optimization. International Journal of Product Development 13(2), 119–131 (2011)
15. Tan, A.R., McAloone, T.C.: Characteristics of strategies in product/service-system development. In: Proceedings of the International Design Conference – Design, Dubrovnik, Croatia, May 15-18 (2006)
16. Johansson, M.W., Christensen, C.M., Kagermann, H.: Reinventing Your Business Model. Harvard Business Review, 57–68 (November-December 1996)
17. Osterwalder, A., Pigneur, Y.: Business Model Generation. John Wiley & Sons Inc., New Jersey (2010)
18. Teece, D.J.: Business Models, Business Strategy and Innovation. Long Range Planning 43, 172–194 (2010)
19. Lindgren, P., Jörgensen, R., Taran, Y., Saghaug, K. F.: Baseline for Networked Innovation Models, D4.1 of the EU FP7 project NEFFICS (2011), `http://ebookbrowse.com/neffics-d4-1-v1-0-pdf-d225549766` (accessed on June 24, 2012)
20. Schuh, G., Klotzbach, C., Gaus, F.: Service provision as a sub-model of modern business. Production Engineering 2(1), 79–84 (2008)
21. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems—IPS2. CIRP Annals - Manufacturing Technology 59(2), 607–627 (2010)
22. Kindström, D.: Towards a service-based business model – Key aspects for future competitive advantage. European Management Journal 28, 479–490 (2010)
23. Patton, M.Q.: Qualitative evaluation and research methods. Sage Publ., London (1990)
24. Kvale, S., Brinkmann, S.: InterViews: learning the craft of qualitative research interviewing. Sage Publications, LA (2009)
25. Yin, R.K.: Case Study Research: Design and Methods. Sage Publ., Thousand Oaks (2003)
26. Fontana, A., Frey, J.: Interviewing. In: Denzin, N., Lincoln, Y. (eds.) Handbook of Qualitative Research. Sage Publ., Thousand Oaks (1994)
27. Miles, M., Huberman, M.: An expanded sourcebook – Qualitative Data Analysis, 2nd edn. Sage Publ., Thousand Oaks (1994)
28. Zott, C., Amit, R., Massa, L.: The Business Model: Recent Developments and Future Research. Journal of Management 37(4), 1019–1042 (2011)
29. Smith, W.K., Binns, A., Tushman, M.L.: Complex business models: Managing strategic paradoxes simultaneously. Long Range Planning 43, 448–461 (2010)
30. Karlsson, L., Lindström, J., Löfstrand, M.: Functional Products - Goodbye to the industrial age. Ericsson Business Review 18(2), 20–24 (2012)

Developing PSS Concepts from Traditional Product Sales Situation: The Use of Business Model Canvas

Johanna Wallin[1,2], Koteshwar Chirumalla[1], and Anthony Thompson[3]

[1] Division of Innovation and Design, Luleå University of Technology, Luleå, 97187, Sweden
[2] GKN Aerospace Engine Systems, Trollhättan, 46181, Sweden
[3] School of Engineering, Blekinge Institute of Technology, Karlskrona, 37136, Sweden
{johanna.wallin,koteshwar.chirumalla}@ltu.se,
johanna.wallin@gknaerospace.com,
anthony.thompson@bth.se

Abstract. In recent years there has been growing interest in utilizing a product-service system (PSS) approach when developing products and services in order to arrive at a business model focused on selling function or availability instead of physical products. However, the complex nature of PSS development has left many manufacturers still struggling to arrive at PSS concepts out of their traditional product sales situation in early design phases. The purpose of this paper is to propose an approach using the Business Model Canvas which could help manufacturers in the transition towards PSS development by articulating key business elements in developing and analyzing PSS concepts evolving from their traditional product sales situation. The paper presents preliminary findings from the aerospace industry and discusses the evolution of key business elements for PSS concepts from traditional product sales situation using the Business Model Canvas. Finally, the potential benefits of using the Business Model Canvas in a PSS context are discussed.

Keywords: Product-Service System, Business Model Canvas, Business Development, PSS design, Value Creation, Aerospace Industry.

1 Introduction

In recent years, many manufacturing firms are significantly generating major revenues in offering both products and services [1]. Hence, there has been growing interest in utilizing a product-service system (PSS) approach in developing products and services in order to arrive at a business model focused on selling function or availability instead of the physical product. Although adding services to their portfolios is not new (e.g. Levitt was writing about services from manufacturers in the 1970's [2]); what is relatively new is the shift from perceiving those services as a cost center to seeing them as part of a revenue-generating value proposition [3] [4]. Many researchers assert that PSS transition implies a major shift in the business operations, strategic thinking and management approaches that impacts the way products concepts are derived in the early phases [5] [6]. However, the complex nature of PSS development has left many manufacturers still struggling to design a PSS concept from their

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 263–274.
DOI: 10.1007/978-3-642-30820-8_23

traditional sales situation in the earliest phases of product development [7]. Common approaches to product design have kept product and service aspects separate, thus when either the product or the service dominates in a combined offer, the corresponding traditional product or service development approaches may be appropriate [8]. However, products and services that are tightly coupled must be designed in an integrated way [9]. With an underlying shift from business based on value from exchange of product ownership and responsibility toward business based on value through utility of the products/services [10], a fundamental reassessment of the core business is often necessary [11].

A substantial number of methods for PSS design appear in the literature; see Clayton et al. [8] for an evaluation of several of these methods as they relate to industrial practice. Clayton et al. [8] also note that there is some discrepancy regarding their case company's "articulate value proposition" phase and corresponding phases in the literature (e.g. "business case" and "client and suppliers business cases"). This suggests a need for a tool to support PSS-minded companies to identify and articulate the value proposition of the PSS they are designing.

Current research on PSS provides little guidance regarding the development of new business models for companies in the transition towards PSS development. Kindström [5] e.g. provides some insight into moving toward a service-based business model for manufacturing firms, but gives only minimal attention to PSS. One recent tool for developing new business models is "The Business Model Canvas" (here after referred as "BMC" in the text) [12] that can be used to systematically understand, design and implement a new business models. The reasons for choosing BMC for this study is that BMC is an intuitive and easy-to-use tool, covering different elements that have been identified as critical for a successful business model, providing an initial vision for companies that like to move towards PSS by viewing the business from a holistic standpoint. There has been little research conducted on using BMC for PSS design (e.g. [13-15]). This paper aims to fill this gap by answering the following research question: *How can the Business Model Canvas support a company in developing PSS concepts in the early phases of the transition towards PSS development?* This paper therefore proposes an approach using the BMC, which could help manufacturers in the transition towards PSS development by articulating the key business elements in developing and analyzing the PSS concepts (i.e. service/use-oriented PSSs) from their traditional sales situation (i.e. product-oriented PSS).

2 Theoretical Framework

2.1 Product-Service System (PSS)

In literature, researchers suggest different definitions and types of PSS based on their focus and perspective [1] [4] [8] [16]. For instance, Mont [17, p.71] defines PSS as: *"…A system of products, services, supporting networks and infrastructure that is designed to be competitive, satisfy customer's needs and have a lower environmental impact than traditional business models"*. Tukker and Tischner [16] divide PSS concepts into three main categories—product-oriented, use-oriented, and result-oriented. The type of value embedded in the business offering (mainly product- or service- related) is chosen as the main criterion for this classification. A product-oriented PSS, in general, represents the traditional sale of a product embracing some additional services, such as maintenance, repair, warranty, upgrades, reuse and recycling. Use-oriented PSS represents sale of the use or availability of a product to customers in different forms (e.g. leasing or sharing), but with the producer retaining ownership. The final category, result-oriented PSS, represents the sale of the result, function or capability of a product to customers, while retaining the ownership of the product. Three main categories of PSS are further elaborated and classified as eight types of PSS: product related service, product related advice/consultancy, product lease, product renting/sharing, product pooling, pay-per service unit, activity management, and functional result—depending upon the way value is created and offered to the customers [16]. Based on the extensive empirical data on 10,028 firms from 25 different countries, Neely [18] adds two new categories of PSS—integration-oriented and service-oriented—to the Tukker and Tischner classification. Integration-oriented PSS result when firms seek to add services by going downstream and vertically integrating (e.g. consulting services, financial services, retail and distribution, transportation and trucking services and property and real estate services) whereas service-oriented PSS result when firms incorporate services into the product itself (e.g. systems and solutions). Recently, Clayton et al. [8] present these five generic types of PSS within the product-service continuum to create a range of product-service offerings (Figure 1). Both models [8] [16] emphasize the continuum of PSS, but leave little guidance on how a company can place themselves on this continuum from a traditional situation.

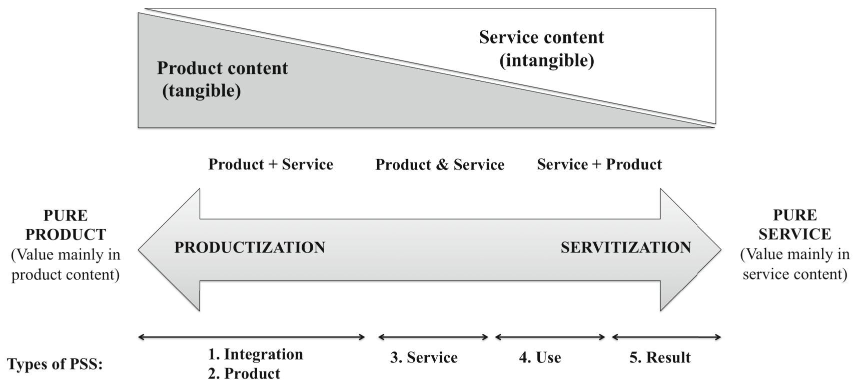


Fig. 1. Categorization of PSS types within the pure product-service continuum, adopted from Clayton et al [8] and Tukker and Tischner [16]

2.2 PSS in the Aerospace Industry

In the aerospace industry today, each aircraft engine is an opportunity to supply a stream of spare parts at high margins. Therefore the engines are often sold at reduced prices and the engine developers instead profit from maintenance and supply of spare parts, which typically represent product-oriented PSS business models [1]. There are also service-oriented PSS, where the engine is sold together with e.g. a monitoring system that keeps track of engine usage [19] and use-oriented PSS where the functionality of the engine is sold rather than the product itself, e.g. 'Power by the hour' or TotalCare® by Rolls Royce [20]. Commitment and availability is increasingly valued by the airlines, compared to the sale and purchase of the traditional product. Further, it is in the interest of the engine developer to control the risks that enable lowering ownership costs in order to enhance profitability for both parties [20].

2.3 Business Modeling for PSS

The shift towards a PSS offering alters the traditional view of value creation (e.g. [1], [16]). This triggers a transition from a '*transaction-based*' to a '*long-term relationship-based*' business connection [22], which necessitates redesigning the existing contractual and implicit relations and re-allocating risks and revenue structures. As a consequence, the successful implementation of a PSS solution needs to identify the supporting business models in order to address the organizational changes and operational strategies [21]. In this context, the business models that are traditionally product-based and short-term focused are not merely applicable [6]. A central virtue of the business model is that it takes into account different underlying business elements and puts them together to create a holistic and system-level picture of the business [12] [23]. Over the years, different authors have developed a number of business model frameworks with different underlying business elements. For instance, Chesbrough [24] uses six common business elements as a structuring and analytical framework-namely, (1) articulate the value proposition, (2) identify a target market, (3) define the structure of the value chain required by the firm, (4) specify the revenue generation mechanism(s) for the firm, (5) describe the position of the firm within the value network, and (6) formulate the competitive strategy. Related to the PSS context, Spring and Araujo [21] summarize the four common business elements, including: (1) a concern with network structure; (2) a focus on how transactions are made; (3) revenue models and incentives, and (4) how providers' capabilities are transferred or accessed – through products, services or combinations thereof. Kujala et al. [6] propose a typology of five solution-specific business models and suggest that business models in a PSS context should be analyzed at the level of individual solutions depending upon the maturity of customers, instead of only at the firm- or business unit-level. A recent work by Lee et al. [13] proposes a structured methodology for business model design for a PSS that consists of a design template with which companies can analyze their current business models or invent new ones in a systematic manner. The template defines strategies and protocols for all business elements, which represent basic building blocks of the business model.

2.4 The Business Model Canvas (BMC)

In recent years business model innovation has become an important tool to organizations for rethinking their value creation process and identifying new ways of creating value for their customers and themselves (e.g. [6], [23]). The Business Model Canvas proposed by Osterwalder and Pigneur [12] is one such tool for describing, visualizing the existing business models or developing new ones in a shared language. The visual canvas describes the business model through nine basic business elements as shown in Table 1, which covers the four core areas of a business: customers, offer, infrastructure, and financial viability. Table 1 summarizes the details of each business element. Barquet et al. [14] present the characteristics of business model elements according to the type of PSS (i.e. mainly [16] classification) using BMC. Kim et al. [15] elaborate the work of Lee et al. [13] and present a case analysis of PSS design using the category of the BMC together with strategies and protocols.

Table 1. Key business elements in the Business Model Canvas [12]

Business Elements	Description
Customer Segments	..defines the different groups of people or organizations an enterprise aims to reach and serve. E.g., mass market, niche market, segmented, diversified or multi-sided platforms.
Value Propositions	…describes the bundle of products and services that create value for a specific *customer segment*. E.g., Newness, performance, design, price, brand, cost/risk reduction, accessibility, or convenience/usability.
Channels	…describes how a company communicates with and reaches it's customer segments to deliver a *value proposition*. E.g., sales force, web sales, own stores, partner stores, or wholesaler.
Customer Relationships	…describes the types of relationships a company establishes with specific *customer segments*. E.g., dedicated personal assistance, self-service, automated services, communities, or co-creation.
Revenue Streams	…represents the cash a company generates from each *customer segment*. E.g., asset sale, usage fee, subscription fees, lending/renting/leasing, licensing, brokerage fees, or advertising.
Key Resources	…describes the most important assets required to make a business model work. E.g., physical, intellectual, human, or financial.
Key Activities	…describes the most important things a company must do to make it's business model work. E.g., production, or platform/network.
Key Partnerships	…describes the network of suppliers and partners that make the business model work. E.g., strategic alliances, or joint ventures.
Cost Structure	…describes all costs incurred to operate a business model. E.g., cost-driven, value-driven, fixed costs, or variable costs.

3 Methodology

This paper is based on a case study with a company that is an engine component and subsystem developer in the aerospace industry with a strong focus on traditional product development and additional maintenance services. The company has recently been transforming towards a PSS provider. On the military business side where the company is an engine OEM (Original Equipment Manufacturer), it has come far in service integration to the product offers and provides complete product-service systems. On the commercial business side where the company is a component developer, which requires close collaboration with the OEM, the company has recently increased the solution-based offers. This collaboration with the OEMs is described as a risk and revenue sharing partnership, where the partners shares development cost, risk and revenue throughout the engine program, which it is not in a ordinary customer-supplier relationship. Since the company is undergoing the transition towards PSS development, it is hence an ideal case for the purpose of this paper. Data has been collected through observations at the company and ten semi-structured interviews with stakeholders in PSS development and business development, which include engineers, project managers, process owners, business developers, and company specialists, where some also have used the BMC in their work. The data has been analyzed using a pattern matching technique to find coinciding (and non-coinciding) patterns [25]. The BMC has been used to summarize the data, deriving the key business elements to the PSS concepts from the traditional product sales situation. Furthermore, BMC elements have been used as a guiding tool for interviews.

4 Business Model Canvas for PSS Concepts: Empirical Findings

One of the main challenges to transition into PSS development is the creation of new business models. As a component developer the business case is dependent on the business case of the OEM. It is easier to imagine service integration in products as an OEM. Hence, methods to support PSS development are even more important for component developers: "*We cannot control the market, only how we do things, how we would like to do business*", described an interviewee. The company uses the term "soft products" to describe their servitization journey. Soft products represent all products and services sold to a customer that enhance the customer's experience and satisfaction other than the sale of new products, such as fleet management, product support and monitoring systems. While talking about his perception on PSS, one of the process owners said "*I would like to see our expansion of the area in soft products in the perspective of services, related to more efficient collaboration /…/ That says it is not necessarily part of the product portfolio. But that is part of our brand. That says we are the most easy to work with*".

Even though the company has developed traditional services such as maintenance and product support, the transition towards servitization has involved creation of software that tracks life consumption of the engine components, which was an unknown area for the company and involved risks. One challenge with entering unknown business areas is seeing the potential of new opportunities. The Business Model Canvas, in this context, is used to understand the potential benefits and challenges of entering unknown business areas as well as exploring related business elements around the unknown business area. At the case company the BMC is not a well-known tool, but it has been used in some groups for business development and PSS development groups. The tool has been used both as a workshop tool, where the group has performed a brainstorm activity for each section, as well as by individuals building a business case. The following paragraphs discuss each element of the BMC in detail. From the empirical discussion, Table 2 summarizes the evolution of business model elements for PSS concepts from the traditional product sales situation.

Customer Segments**:** As an engine component developer, the main customer is the engine OEM. However, this collaboration can be described as a risk and revenue sharing partnership rather than a customer-supplier relationship. In PSS development the company has the possibility to look further down the supply chain for potential customers. "*[The airlines] could be a customer. That scenario is also possible*". But reaching for customers segments further down the supply chain, such as aircraft manufacturer or airlines would be strengthened if made in partnership with OEM.

Value Proposition**:** In a traditional sales situation, value is primarily exchanged through the component itself. "*It's about making it clear what functions you are fulfilling with the product*", described a specialist. Another interviewee described the organizational culture as adding value: "*I think we are appreciated for our Swedish way, if we say something, that is the way it is, sincerity and loyalty"*. One of the project informants described the technology development as adding value: "*What technology can we bring to the table?; that is our value, in addition to the product development*". It is the same thing with the add-on maintenance service. In PSS business models, the value of the component is related more to the component in context, i.e. the value of the whole system: "*But the value the product generates is, of course, the same but we can add value in the form of services, since we are further into the process"*. Value is added through add-on services for increased product functionality, reduced risk, increased safety, and reduced cost. Being a partner and not only a supplier could be considered as a service since it involves e.g. the sharing of risk and perhaps other value-added activities: "*We might be offering services today that we do not know that we are offering*". Another interviewee added "*Service can also be the proactive way of living from [the company] side when we working with the OEMs regarding how we can improve our engineering support and how we can improve development methods in the prospective way of learning and feedback [those in] to the organization. That's the service that comes back internally as well as together with the OEM*".

Channels**:** The engine components are developed in close collaboration with the engine OEM. And the engine programs are one of the main channels with the OEM customer. One interviewee commented on this close collaboration: "*Our main distribution channel considering our value proposition is through product development (PD) projects. We also have business contacts and other channels and yes they're important too, but I think if you talk about building value and being a cog in the wheel, the PD projects are the most important thing, since we have straight communication [in PD projects]*". As the company transitions further along its PSS journey, other partnerships such as joint ventures could be possible in the future.

Customer Relationships**:** The company has strong ties with the closest customers (engine OEM for products, airlines for services). There are also (perhaps weaker) ties to other stakeholders in the industry. In PSS development, relationships become even more important, especially with partners in extended collaborations. Ties are strengthened with both upstream and downstream actors who are affected by the PSS, including aircraft manufacturer, process technology suppliers, service centers, engine OEMs partner companies, and engine OEM competitors (e.g. [22]). One experienced informant pointed out that, "*We work collaboratively early, we want to be even earlier, of course, to have a better plan. Let's say collaborating even earlier with the engine OEMs, aircraft OEMs, and systems OEMs would enable us to be better prepared from a technology prospective but also time-wise*".

***Revenue Streams*:** In the engine programs, revenue comes from selling the engine and, perhaps more importantly, the selling of spare parts: "*The company makes money on selling spare parts. If those revenues are decreased we are forced to think of other ways to make money*", described a project manager. But as a component developer the revenue streams are dependent on the business case of the OEM. "*When the OEM sold 'power by the hour' to their customers, they had no incentives to sell spare parts anymore"*, the same incentives are therefore needed in the whole value chain "*everyone would think of long product life, everyone would think of low lifecycle cost*" said a project manager. In a PSS situation there is also a possibility to increase revenue through availability contracts and selling of licensees.

***Key Resources*:** In the traditional sales situation the key resources are related to the structure of product development and the supply chain; the competences and knowledge of the product; and the production. Including service aspects in the product design space elevates the need to integrate an extended set of new competencies from many actors within the network, i.e. cross-functional cooperation: "*This business of system development, we have included many consultants*" said one interviewee. Another interviewee added: "*We simply had to bring in many consultants since there were no such resources at the company"*. Some consultants later became employees in order to keep the competence within the organization.

***Key activities*:** In traditional concepts product and service development activities are distinct. In this case, key activities involve e.g. assigning the positions that are responsible for development of the product. Key activities also involve infusing trust to the customer: "*We need to infuse trust to create value for the customer, come up with ideas, be proactive, show how we work and develop our methods*". In PSS concepts the products and services are co-developed in an integrated way to reduce risks, increase safety and reduce cost. The PSS concept can include activities such as calculating life consumption of the component and monitoring the environment where the product is used. PSS can also involve increased external collaboration: "*We know our application. So it is all about going out there and trying to find those pieces of puzzle that you need. We need to go outside our door, because if you only sit in your little team internally… of course you could come up with the world's best solution but the probability is quite low. If you constantly work with the world around you the probability is much greater*," described a project manager.

Key Partnerships**:** Key partners in traditional sales situations are the customer and suppliers in the aerospace industry. The company also has close collaboration with academia: "*We have a network of lots of customers that we work with, loads of suppliers that we interact with, a great number of universities and professors*" described an interviewee. In a PSS concept the partnerships may be even broader; here they can also include extended value chain actors as well as IT suppliers, e.g. because of the increased software development. However "*To handle and channel data that is not in our value proposition*" described an interviewee and therefore such a partner could be needed. "*But to establish the system infrastructure, I think that's our value proposition*".

Table 2. Evolution of business model elements for PSS concepts from traditional situation

Business Model Canvas Elements	**Traditional product sales situation (product-oriented)**	**PSS concepts (service-oriented/ use-oriented)**
Customer Segments	Engine OEM of the product supply chain in aerospace industry	Potentially new customers in aerospace industry. E.g. airlines, aircraft manufacturers.
Value Proposition	-The value of the product functionality and light weight technology -The value of the add-on services for product functionality	Added value from the component contribution to overall system performance service; value of risk reduction, safety increase, and cost reduction
Channels	Partner programs	Partner programs or Joint venture
Customer Relationship	Strong ties to closest customer (Engine OEM for products, airlines for services) and weak ties to other stakeholders in the network	-Strong ties to various stakeholders within the industry who are affected by the functionality of the product; Dedicated technical assistance and co-creation in early phases
Revenue Streams	-Percentage of engine revenue -Service contracts - Revenue on spare parts sales	Integrated product-service contracts, availability contracts and licensees
Key Resources	-Product and production knowledge -Patents -Financial -Contracts	Added key resources: -Cross-functional knowledge -Relationships with extended collaborators
Key Activities	-Development & manufacturing of product -Service development & provision -Assign responsible positions	-Integrated product-service system development; Calculating life consumption; Monitoring product environment
Key Partnerships	-Customer and suppliers in the aerospace industry -Academia	Extended stakeholder network through joint ventures, e.g. IT partners, service centers.
Cost Structures	Development; Material and production; Service provision; Entrance fee in the engine programs	Added cost of ensuring uptime, software development, monitoring costs and IT delivery.

Cost Structure: Costs in the traditional sales situations include product development, production, material and costs for maintenance services. In PSS situations the cost structure is not much different, but there could be added cost related to e.g. ensuring uptime, assuming additional risks, software development and monitoring costs. One interviewee described the additional costs of a monitoring system: "*When it is up and running then it's the infrastructure, servers and software, to keep it configured and updated so to speak*".

5 Discussion and Concluding Remarks

With the unprecedented speed at which customers' needs and behaviors are changing, a company's ability to rapidly adapt or generate innovative business models is critical to success. This study found that Business Model Canvas is a promising tool—with their intuitive and easy-to-use nature—for the companies to rapidly analyze and discuss their traditional product sales situation according to the nine business elements, thereby deriving the PSS concepts in the early phases. By having a value proposition as a central position, BMC provides an overall view of "what" and "how" the business would look like in the transition towards PSS development. Since PSS not only involves different organizational areas within the development organization but can also affect several organizational areas for the customer, this can challenge the marketing of the system and increases the importance of visualizing the value proposition in the business model. One interviewee described this challenge: "*The value is there. No doubt about that. The question is how to sell it … To be able to sell it [the PSS] you must find the economical buyer in each company, thus the person that can see the value. If you go through the traditional entrance, where you sell your product, perhaps the purchasing organization, they might close the door in front of you*".

The case company has realized the benefits of its PSS journey. As a company specialist put it: "*I think that the servitization, that is a trend that will last*". However, the challenge for manufacturers is to "take a mental break" from their product when exploring how to develop a PSS. History and attachment to the product may make it difficult for the company to see radical innovation opportunities that may or may not require significant changes to their core product. The BMC, with its initial emphasis on the value proposition, may aid companies in taking that mental break from their product and get a "PSS mindset". Furthermore, the BMC, through its structure, guides them in the next steps to help understand how to take the value proposition and build a business model around it, eventually linking back to the company's core product while adding significant context to the value offered by the product. By providing a level of abstraction related to the various business elements through qualitative assessment, the BMC can help the company's strategic plan (i.e. by defining overall mission and strategic goals) on an individual solution level [6] at a conceptual phase even before commencing business operations. Additionally, the BMC is a visual tool that is easy to use by both individuals and groups. One user described it: "*It is very fast. You get quickly into the business model. It is good to visualize the big picture, so to speak*". However, even though the users at the case company like it, one critical point was brought up by PSS developer: *"It doesn't bring up risks. But we added that, business risks"*.

This study suggests that the BMC is a promising tool to support modifying or creating new business models at a faster pace. But as a tool to support the transition towards PSS development, it needs to have a clearer focus on this change, and some modifications should therefore be added. First is the modification of questions in the BMC to emphasize a change in perspective and to widen the business scope. For example, instead of only asking: *What value do we deliver to the customer?* and *For whom are we creating value?* We should also ask: *Are there additional customer needs that we could be satisfying?* and *Who could be benefitting from the value we are creating?* Second is the addition of business risks, since the transition towards PSS development involves taking new risks. This could either be done by adding a new element of *Business Risks* to the BMC or with additional risk questions in each of the nine existing business elements. For instance, the questions such as: *What are our principal business risks in PSS transition? How do we integrate risks with the company's strategic direction? How effective is our process for managing risks?*

This study evaluated the use of the Business Model Canvas in developing PSS concepts especially with respect to manufacturing companies seeking to transition towards PSS. The paper provides the empirical basis in using BMC for an aerospace, business-to-business (B2B) context. This is especially important since the current PSS literature on BMC usage is mostly focused on business-to-consumer (B2C) situations. Moreover, a majority of PSS literature focuses on specific issues of PSS development separately such as cost, contracts, knowledge management, supply chain relationships etc. These issues may fall into one or two elements of business elements, which make it difficult for the companies to obtain a complete holistic view of the business challenges in PSS transition. BMC provides a visual platform for companies, which could allow them to consider all development issues related to various business elements very early in the process, thereby guiding them to develop a profitable PSS business model with effective strategic actions.

Acknowledgments. The authors would like to acknowledge the case company GKN Aerospace Sweden AB, which allowed the authors to conduct this research. Further, the authors wish to extend the gratitude to the participants and teaching staff in the "PV18 Product-Service Systems" doctoral course at Luleå University of Technology and Blekinge Institute of Technology during 2011-2012.

References

1. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems—IPS22. CIRP Annals-Manufacturing Technology 59, 607–627 (2010)
2. Levitt, T.: Production-line approach to service. Harvard Business Review 50(5), 41–52 (1972)
3. Wise, R., Baumgartner, P.: Go Downstream: the New Profit Imperative in Manufacturing. Harvard Business Review 77(5), 133–141 (1999)
4. Wang, P.P., Ming, X.G., Li, D., Kong, F.B., Wang, L., Wu, Z.Y.: Status review and research strategies on product-service systems. J. Production Research 49(22), 6863–6883 (2011)
5. Kindström, D.: Towards a service-based business model – Key aspects for future competitive advantage. European Management Journal 28(6), 479–490 (2010)

6. Kujala, S., Artto, K., Aaltonen, P., Turkulainen, V.: Business models in project-based firms – towards a typology of solution-specific business models. Int. J. Project Management 28(2), 96–106 (2009)
7. Isaksson, O., Larsson, T.C., Rönnbäck, A.Ö.: Development of product-service systems: challenges and opportunities for the manufacturing firm. J. Engineering Design 20(4), 329–348 (2009)
8. Clayton, R.J., Backhouse, C.J., Dani, S.: Evaluating existing approaches to product-service system design: A comparison with industrial practice. J. Manufacturing Technology Management 23(3), 272–298 (2012)
9. Cavalieri, S., Pezzotta, G.: Product-Service Systems Engineering: State of the art and research challenges. Computers in Industry 63, 278–288 (2012)
10. Tan, A.R., McAloone, T.C.: Characteristics of strategies in product/service system development. In: 9th International Design Conference, Dubrovnik, pp. 1435–1442 (2006)
11. Sakao, T., McAloone, T.C.: Product with Service, Technology with Business Model: Expanding Engineering Design. In: 18th International Conference on Engineering Design, Copenhagen, vol. 4, pp. 449–460 (2011)
12. Osterwalder, A., Pigneur, Y.: Business Model Generation. John Wiley, NJ (2010)
13. Lee, J.H., Shin, D.I., Hong, Y.S., Kim, Y.S.: Business Model Design Methodology for Innovative Product-Service Systems: A Strategic and Structured Approach. In: 18th International Conference on Engineering Design, Copenhagen, vol. 3, pp. 221–232 (2011)
14. Barquet, A.P.B., Cunha, V.P., Oliveira, M.G., Rozenfeld, H.: Business Model Elements for Product-Service System. In: 3rd CIRP International Conference on Industrial Product-Service Systems, Braunschweig, pp. 332–337 (2011)
15. Kim, Y.S., Lee, S.W., Kim, J.H., Do, S.H.: A Design Case of Product-Service Systems—Urban umbrella rental PSS. In: 12th International Design Conference, Dubrovnik, pp. 213–222 (2012)
16. Tukker, A., Tischner, U.: New Business for Old Europe: Product-Service Development, Competitiveness and Sustainability. Greenleaf Publishing Ltd., Sheffield (2006)
17. Mont, O.: Product-Service Systems: Panacea or Myth? PhD Thesis, Lund University, p. 140 (2004)
18. Neely, A.: Exploring the financial consequences of the servitization of manufacturing. Operations Management Research 1(2), 103–118 (2008)
19. Ward, Y., Graves, A.: Through-life management: The provision of total customer solutions in the aerospace industry. J. Services Technology Management 8(6), 455–477 (2007)
20. Harrison, A.: Design for service - Harmonising product design with a services strategy. In: The ASME Turbo Expo 2006, Barcelona, May 6-11, vol. 2, pp. 135–143 (2006)
21. Spring, M., Araujo, L.: Service, services and products: rethinking operations strategy. Int. J. Operations & Production Management 29(5), 444–467 (2009)
22. Chirumalla, K., Bertoni, A., Ericson, Å., Isaksson, O.: Knowledge-Sharing Network for Product-Service System Development: Is it atypical? In: 4th CIRP International Conference on Industrial Product-Service Systems, Japan, pp. 109–114 (2012)
23. Zott, C., Amit, R., Massa, L.: The Business Model: Recent Developments and Future Research. J. Management 37(4), 1019–1042 (2011)
24. Chesbrough, H.: Business model innovation: It's not just about technology anymore. Strategy and Leadership 35(6), 12–17 (2007)
25. Yin, R.K.: Case Study Research: Design and Methods. Sage Publications, CA (2009)

Challenges for PSS Implementation: Identification and Classification

Caio Di Francisco Kurak, Ana Paula B. Barquet, and Henrique Rozenfeld

Industrial Engineering Department, University of São Paulo, Address,
São Carlos, São Paulo, Brazil
{caiokurak,anabarquet}@gmail.com, roz@sc.usp.br

Abstract. New business approaches have been created as a way of differentiation for enterprises, such as Product-Service System (PSS). However, there are many challenges companies face while implementing PSS. Aiming to identify these challenges a systematic literature review was done. A classification of the identified challenges was performed based on Canvas Business Model. In addition, a case study in which a Brazilian company failed to implement PSS is presented. This case differs from the ones reported in the existing literature, which show successful examples of PSS implementation. An analysis and discussion regarding the practical challenges found in the case study and the challenges found in literature are reported and possible motives for the failure on PSS implementation are pointed out. The knowledge of PSS challenges can assist companies which want to adopt PSS since it can proactively support the development of actions to prevent difficulties during the PSS transition.

Keywords: Product-Service System, Challenges, Business Model, Implementation, Case Study.

1 Introduction

In an increasingly dynamic business environment in which competition is becoming more intense, companies are seeking to reinvent the ways they do business, looking for concepts that change their traditional business models. One of the new approaches is the product-service system (PSS), which is defined as the result of a strategy that shifts the focus of a business away from simply designing and selling physical products to providing a system that integrates products and services capable of meeting specific customer needs [1-2]. Currently, most companies focus their business strategies on product development or the provision of services. However, with this new concept, the focus of the innovation changes from designing only products or services to a strategy of designing integrated products and services [3].

Despite the benefits gained through the adoption of PSS, certain difficulties are encountered in relation to its practical application [1] [4-5]. These difficulties, challenges, or barriers are described in specific situation or single cases, hindering organizations to a have a broader awareness of them, which could assist organizations in preventing the occurrence of such challenges.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 275–285.
DOI: 10.1007/978-3-642-30820-8_24

The main objective of this research is the identification and systematization of the barriers and challenges companies encounter during the implementation of the PSS. Section 2 presents the method of this research. Section 3 includes a review of the literature on PSS and identifies barriers to its adoption. Section 4 discusses the proposed systematization of the challenges and barriers to PSS. Section 5 presents a case study on a company that faced challenges to implement PSS and Section 6 details the considerations about the study.

2 Methodology

The methodology used in this research was divided in two parts: a systematic literature review and a case study.

The systematic review of the literature had the objective of identifying the barriers and challenges of implementing PSS addressed in existent literature. According to Biolchini et al. [6], a systematic literature review (SLR) is a method developed to standardize and evaluate evidence on a particular topic. The main steps of the literature review are formulation of the problem, data collection, data evaluation, analysis and interpretation of data, and completion and presentation.

In a first moment, the formulation of the problem was written. The topics within this step were defining the objective of the SLR, contextualize PSS, mention the benefited areas by the research and elicit the expected results.

After that, data was collected by retrieving papers from the following databases: ISI/Web of Science, Scopus, and Compendex. The databases were chosen based on Beuren's [29] research that points the mentioned databases as the most relevant ones in PSS field. The keywords used in the SLR take into account the terms used by various authors [7-10], aiming for a more complete search on the subject. Thus, the keywords used were as follows: "functional sales" OR "soft product" OR "integrated solution" OR "industrial service" OR "integrated product and service offering" OR "product-service system" OR "servitization" OR "functional product" OR "integrated product service engineering" OR "integrated product service offering." Added to these keywords were strings and keywords related to challenges and barriers: "challenge" OR "barrier" OR "problem" OR "difficulty."

The assessment of the studies found in the last step was accomplished through three filters. The main criterion behind all filters was to reach the researches that were directly or close related to the challenges, difficulties or barriers within the adoption and implementation of PSS. The following steps of the SLR (i.e. analysis, interpretation and presentation) are presented in sections 3 and 4, and were used to generate the proposed systematization of PSS challenges.

Regarding the case study, the main objectives were to find the challenges the company faced while the attempt of PSS implementation, and compare it with the challenges found in literature, summarized in the classification propose.

To perform the case study, guidelines were taken from Voss [11], who list three key activities for case studies, namely, definition of a protocol for collecting data, data collection and data analysis. The research protocol contains the criteria used to select the company and the questionnaire utilized to conduct the case

As secondary objectives and part of the criteria selection, the authors aimed to present a case in which a company did not have success in the attempt to adopt PSS, a situation that has not been approached in many studies in literature. Also, the case was performed in a company that is present inside the Brazilian business environment, which differs from the majority of case studies published.

To perform the case, a semi-structure questionnaire was used to guide the interview. The questionnaire was developed based on the PSS challenges found in the Systematic Literature Review, summarized in section 4.

3 Literature Review

The term Product-Service System emerged in 1999, introduced in the literature by Goedkoop et al. [8], through a study entitled "Product-Service Systems – Ecological and Economic Basics." In that study, PSS was defined as a system of products, services, infrastructure, and support networks that continually strive to be competitive, satisfy customer needs, and result in a lower environmental impact than traditional business models. Subsequent to this study by Goedkoop et al. [8], other authors emphasized the importance and need for more research on the subject, such as [1] [8] [12-13]. The definitions that appeared later are similar and generally interpret PSS as a product and service combined in a system to provide the necessary functionalities to the user in a way that reduces environmental impact [7]. Regardless of whether or not environmental issues are considered, companies that adopt this new concept seek financial benefits.

Although there are many benefits of the adoption of PSS, challenges and barriers emerge for companies during the implementation of such a system. According to Baines et al. [4], some of the main challenges are related to the language of services, the value dimensions of integrated products and services, the development process of products and services, and the provision of PSS. The PSS also requires the development of new relationships and forms of partnerships between all stakeholders in the value chain; for example, new customer interactions are necessary, and new partnerships with producers/suppliers are required [1].

Targeting researches related to PSS challenges, the data collection step of SLR resulted on a bundle of studies, which were analyzed and scanned with the objective of gathering possible challenges, difficulties and barriers.

During the analysis process some classifications for the challenges were found. One example is Brax [14], which addresses the challenges into the following dimensions: Marketing, Production, Supply, Product Design, Communication, Relationship. Another example of classification is proposed by Kuo et al. [5], who proposes 4 dimensions, External, Internal, Maintenance and Remanufacture. In addition, Martinez et al. (2010) [15] came out with a classification which embraces Culture PSS, Offer Integrated Supply, Internal Processes and Capacity, Strategic Alignment, and Customer Relationship.

Besides all the value and importance of the specified studies for the PSS research field, such classifications are considered too specific, since they are restricted to just one area of application, based on a single case or focused on a specific process. Brax [14] conducted a single case study with a primary focus on managing the maintenance of PSS offerings. Kuo et al. [5] also addressed challenges related to maintenance. Moreover, the classification proposed by Martinez et al. [15] is based on a single case study in a traditional manufacturing company that has succeeded in implementing

PSS. Although the authors emphasize key challenges, they do not cover issues such as cost structure and market segments, which were identified as important dimensions to be considered in the adoption of PSS business models.

Thus, this study proposes a classification model for PSS challenges with the intention of providing a holistic view of the challenges associated with the development of PSS. Section 4 explains the proposed classification.

4 Systematization of PSS Challenges

The classification model for PSS challenges was drawn from an analysis of the challenges identified in the systematic literature review. In this analysis, it was found that the challenges have a holistic character and are associated with various dimensions of business. In addition to these broader characteristics, the fact that PSS requires new processes and activities within its business models (Kuo et al., 2009; Sakao, Sandström and Matzen, 2009), compared to traditional ones, is another relevant point that was taken into account. Therefore, it was considered appropriate to classify the barriers and challenges identified in the literature according to the elements of a business model, since it might help in the design of the new PSS model.

According to Osterwalder, Pigneur, and Tucci [18], a business model is a conceptual tool that provides a simplified description and representation of the logic behind the business model of a firm. It provides the business with a holistic vision of the enterprise while focusing on the important relationships and questions.

Osterwalder and Pigneur [19] developed The Canvas business model, a tool that can be used to decipher, analyze and design business models. Canvas creation was based on extensive research of the literature dealing with concepts and elements of different business models and the interplay between them. The elements that comprise the business model are written out in detail in Figure 1, and the methodology was tested and applied successfully across many organizations (e.g., IBM and Ericsson). Thus, this study adopted the business model canvas as a reference tool to classify PSS-related challenges.

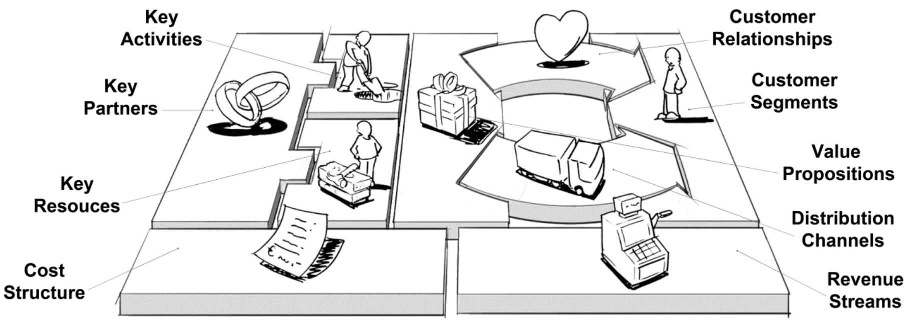


Fig. 1. Elements of the business model canvas [19]

During the classification of challenges in the elements of the business model, some additional sub-categories were added to the *Resources* element due to the tremendous amount of challenges related to this element. The new sub-categories created were *Knowledge*, *Technology*, and *Human Resources*.

Moreover, the information and data for *Market Segmentation* and *Value Proposition* were blended into one, and the same was done for *Cost Structure* and *Revenue Model*. In both cases it was considered appropriate to blend dimensions together due to the difficulty of categorizing the challenges found in any of the dimensions. The proposal for classification is found in Figure 2. The challenges allocated to each of the dimension are described below.

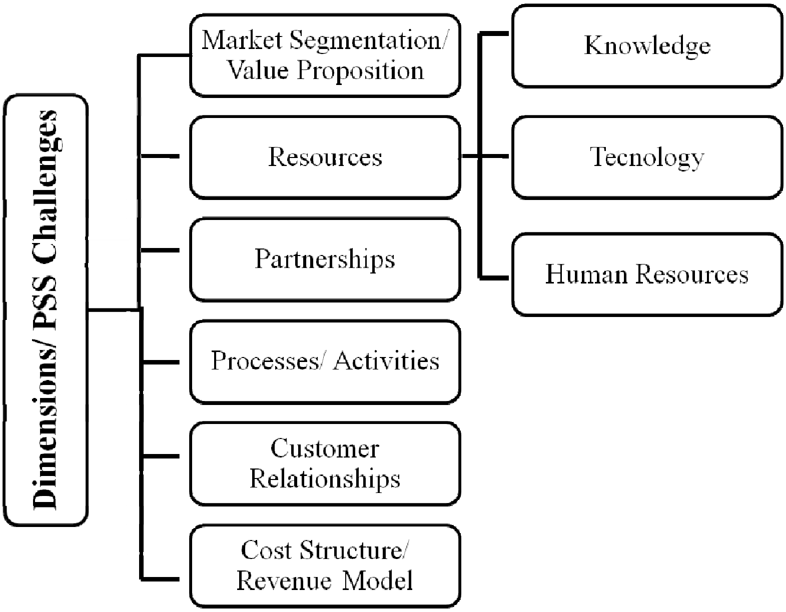


Fig. 2. Proposed classification of PSS challenges

The challenges related to *Market Segmentation* and *Value Proposition* reflect the lack of client acceptance of PSS. They have difficulty to realize the value of PSS offer, which increases their resistance to acquiring PSS and results in a lack of demand for it. One factor that increases this resistance is the fact that customers do not have ownership of the product [5] [7] [12] [14] [20-21].

In the dimension *Resources*, we see many challenges related to *Knowledge and Competences* levels towards PSS. There is an overall lack of trained personnel capable of dealing with the wide range of PSS business models [2] [5] [14] [16] [22]. For example, Ojanen et al. [22] mentioned the general lack of information and know-how about adapting the cost structure and revenue model for PSS, as well as the specific accounting methods. Further, a lack of appropriate tools and techniques to support the evaluation of an organization's internal resources for developing and offering integrated solutions of products and services is reported by Martinez et al. [5]. Uchihira et al. [23] affirmed that the adoption of PSS requires new skills not demanded in traditional business models.

Moreover, previous research has identified difficulties in acquiring and combining knowledge of the different functional areas necessary to develop PSS, showing flaws in the management of PSS information and knowledge [16] [24]. Because it is a new approach, many companies do not have expertise in PSS [14] [16] [23]. Several authors mentioned the fact that the people involved in a PSS project tend to have different backgrounds, skills, and styles of communication, which increases the difficulty of communication and information exchange between the actors involved in PSS throughout the entire value chain [9] [15] [17] [24].

Furthermore, issues have been raised relating to the reuse of information from previous projects, since this information is often stored in different databases, which hinders its accessibility [17] [24]. In addition, PSS providers lack a standardized language service and a shared format for the communication of information and transmission of knowledge for all actors in the value chain, such as suppliers, partners, and customers [7] [24]. There is also the issue of customer knowledge and skill in dealing with PSS. For example, Brax [14] commented that customers do not have enough knowledge to deal with planned computerized maintenance.

The challenges specific to *Technology* placed under the *Resources* dimension show a limitation in relation to the suitability and selection of information systems to support the lifecycle of PSS [5] [12] [14] [16], which is also linked to the acquisition and management of knowledge and information about PSS.

The *Resources* dimension also includes many challenges related to *Human Resources.* There is a lack of support from senior management in the adoption of PSS [5] [7] [22] [25]. One of the reasons for such challenges is the organizational culture, which is oriented toward developing and commercializing products in the traditional way [9] [12] [14-15] [20-21] [23] [26].

With respect to the *Partnerships* dimension, several papers mention the fear that organizations have of conflicts with partners due to difficulties in the division of responsibilities and the coordination of the actors in the value chain [4] [16] [23-25] [27]. In relation to the *Processes and Activities* dimension, some challenges are more critical for the implementation of PSS, including reverse logistics [5], project management [16-17], maintenance management [5] [14] [25] [28], and performance management using performance measures that reflect the functioning of PSS [15]. The need to integrate and configure processes of product development and services has been mentioned by several authors [4] [9] [14-16] [23] [25-27].

The *Customer Relationships* dimension reflects the challenges related to the relationship between the PSS provider and the client. A close relationship and trust are paramount to the successful implementation of PSS. However, there are still challenges when it comes to this relationship. Defining the responsibilities of each part [16] and defining when to interact with the customer are some examples [15]. Furthermore, communication problems with the client, in the sense of clarifying expectations [15-16] [28] and a lack of understanding by the PSS provider in terms of the process and technologies used by customers, and therefore their needs, have also been reported [16]. This also impacts the development of contracts and negotiations that satisfy both parts [15].

Dealing with financial issues is a challenge for companies. It is unclear how much they should charge and how they should price PSS offerings [7] [16]. Likewise, it is unclear how to share profits and coordinate costs [9] [23] [25]. These are issues that still cause businesses to doubt if PSS will be beneficial. Furthermore, the high initial investment and financial risk necessary to implement PSS is also a cause for concern for companies [12] [20-21]. These challenges are within the *Cost Structure* and *Revenue Model* dimension.

5 Case Study

This section describes the company business, the development of the case study and the results drawn by the authors.

5.1 Company Profile

The case study occurred in a Brazilian company of the optoelectronic industry, which operates on the following sectors: Medical, Anti-glare, Aerospace and Optical Components. The company had recently won a prize of innovation on the medium companies category. The study was performed on the Ophthalmic Medical sector, responsible for the development of diagnosis and treatment equipments for various diseases of the human eye.

The attempt of PSS implementation was considered for an equipment already developed and commercialized by the company, which is a retinographer. This equipment is used for examination by ophthalmologists, e.g. capturing images of the retina. The product development team responsible for this equipment has eleven employees and the interview was made with the manager of the team.

5.2 Case Description

The decision to implement and offer PSS was made because of the opportunities to increase the revenue and relationship intensity with clients, which is the medical market. The company would be responsible for maintenance, upgrade and collection of the equipment on the end of life or contract. Clients would buy credits to use the equipment, which would be available to buy in the website of the company. Therefore, clients would pay for quantity of utilization.

Pilot projects were developed and presented in a Medical Trade Fair. During this occasion, some clients showed to accept and acquire PSS offers. However, the medical market considers this equipment relatively cheap. The reason for this sense is that the only people allowed to operate the machine in Brazil are doctors, who are a class of high purchase power. Also, the idea of not owning the product resulted in a negative aspect for the doctors, since there is a "status" factor related to the ownership. Another factor, now linked with product characteristics, is the low level of maintenance and product upgrade, decreasing the interesting of clients to pay for a offer that include services supply during the usage phase of the equipment. Thereby, the company decided not to offer PSS and to continue to sell the equipment in the traditional manner.

Despite of the fact mentioned, the respondent highlighted an interesting point. This equipment had been developed in partnership with a company in USA, which commercializes it successfully by a PSS offer. This success, in the opinion of the respondent, is strongly related to the market segment the USA Company reaches. In USA, not only ophthalmologists can operate retinographers, but also optometrists. The latter has minor purchasing power then the former, which can be one of the reasons that they acquire PSS offers. In Brazil, the legislation allows just ophthalmologists to operate retinographers.

5.3 PSS Challenges

The analysis of the data collect on the interview pointed out some factors that hindered PSS implementation, mainly in *Market Segment* and *Value Proposition* dimensions.

Regarding *Market Segment*, the fact that ophthalmologists resist the idea of not having the ownership of the equipment is in accordance with many authors [5] [7] [12] [14] [20-21]. In this same dimension, the market conditions were also seen as a challenge.

However, the search made on the literature did not find *Value Proposition* challenges specifically related to product characteristics. Some characteristics of the equipment, such as low level of maintenance and upgrade could have hampered success on PSS implementation. Services supply is considered important in cases of frequently maintenance and upgrade. In addition, some clients can be attracted to adopt PSS when they consider the product expensive. Then, they can make low investments by using the product and paying a fee periodically.

Considering the facts mentioned, some characteristics that could have hindered success on PSS implementation are:

- Low price of product for the market segment;
- Lack of willingness about not owning the product
- The market environment and conditions where the company considered to launch the product
- Low level of breaking, failure and product upgrade;
- High durability of the parts and life cycle of the product.

As the company had decided to give up PSS implementation after the prototype development, they did not commercialize PSS offers. Therefore, challenges on others business model dimensions, such as *Cost Structure, Revenue Model, Distribution Channel,* had not occurred.

6 Conclusions

One of the major contribution of the present study is the identification and classification of the challenges related to the implementation of PSS. The proposed classification has a holistic character and can be of great value to companies because it can support the proactive development of actions to prevent difficulties, challenges, and barriers in developing a business model for PSS.

The results emphasize the higher number of challenges found in terms of overall PSS knowledge and ease of use. This could be an indication that the overall maturity level of knowledge on PSS of the companies is still quite low, and implies a need for more research to adequately evaluate the capacity of these companies to successfully adopt and implement PSS methods.

Human Resources was another dimension that had many challenges. It is clear that issues related to organization culture and design in PSS is a recurrent situation, and currently one of the research fields of highly importance.

Regarding the case study, it was noticed the importance of the proper choose of the market segment in which PSS will be offered. An investigation of aspects that increase the interest on PSS, such as product price, could be explored in future researches. Some product characteristics also demonstrate to be fundamental when it comes to PSS implementation. In addition, this research showed a case that face barriers during PSS implementation, differently from the cases registered in the literature, which show the best practices and success factors.

Comparing the results of the SLR and the case study, it was possible to prove that issues related to the dimensions of the proposed classification actually occur, e.g. *Market Segment and Value Proposition*. However, some of he challenges faced by the company were not specifically found in the SLR. They are the ones directly linked with product characteristics within *Value Proposition* dimension, and market environment in which the company will commercialize its products. This issues highlight the importance of taking into account new perspectives in research projects, (e.g. diversify the countries where studies are performed; considering failure cases as well), aiming more solid and complete knowledge about PSS.

The next step of this study includes the proposition of practices for the challenges encountered. These practices will be defined based on literature and by using case studies to identify the challenges experienced by companies while adopting PSS and the practices used to overcome them.

Acknowledgments. The authors would like to extend sincere thanks to CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) for supporting this research topic.

References

1. Manzini, E., Vezzoli, C.: Product-Service Systems e Sustainability - Opportunities for Sustainable Solutions. UNEP, Paris (2002)
2. Mont, O.: Product-Service Systems: Panacea or Myth? Thesis, p. 254. The International Institute for Industrial Environmental Economics, Lund University, Lund (2004)
3. Tischner, U., Verkuijl, M.: SUSPRONET Report: First draft report of PSS review. SUSPRONET (2002)
4. Baines, T.S., Lightfoot, H.W., Kay, J.M.: Servitized Manufacture: Practical Challenges of Delivering Integrated Products and Services. Proc. IMechE, Part B: J. Eng. Manufacture 223, 1207–1215 (2009)

5. Kuo, T.C., et al.: Barrier Analysis for Product Service System Using Interpretive Structural model. Int. J. Adv. Manuf. Technol. 49, 407–417 (2009)
6. Biolchini, J., et al.: Systematic Review in Software Engineering. Technical Report RT – ES 679/05, Systems Engineering e Computer Science Department, UFRJ (2005)
7. Baines, T.S., et al.: State-of-the-art in product-service systems. Proc. IMechE. Part B: J. of Eng. Manufacture 221, 1543–1552 (2007)
8. Goedkoop, M., et al.: Product Service-Systems, Ecological and Economic Basics. Pricewater- house Coopers N.V., Netherlands (1999)
9. Isaksson, O., Larsson, T.C., Rönnbäck, Ö.: Development of Product-Service Systems: Challenges and Opportunities for the Manufacturing Firm. J. Eng. Des. 20, 327–328 (2009)
10. Lindahl, M., Sundin, E., Rönnbäck, A., Ölundh, G., Östlin, J.: Integrated Product and Service Engineering – the IPSE project. In: Proceedings for Changes to Sustainable Consumption, Copenhagen, Denmark (2006)
11. Voss, C., Tsikriktsis, N., Frohlich, M.: Case Research in Operations Management. Int. J. Oper. & Prod. Manag. 22, 195–219 (2002)
12. Mont, O.: Clarifying the Concept of Product Service- Systems. J. Clean. Prod. 10, 237–245 (2002)
13. Morelli, N.: Developing New Product Service Systems (PSS): Methodologies and Operational Tools. J. Clean. Prod. 14, 1495–1501 (2006)
14. Brax, S.: A Manufacturer Becoming Service Provider – Challenges and a Paradox. Manag. Serv. Qual. 15, 142–155 (2005)
15. Martinez, V., Bastl, M., Kingston, J., Evans, S.: Challenges in Transforming Manufacturing Organisations into Product-Service Providers. J. Manuf. Technol. Manag. 21, 449–469 (2010)
16. Ojanen, V., Lanne, M., Ahonen, T., Tuominen, M.: The Customer-Centric Development of New Industrial Services: Antecedents, Risks and their Management. In: Proceedings of the 1st ISPIM Innovation Symposium. ISPIM, Singapore (2009)
17. Amberg, M., Holm, T., Dencovski, K., Maurmaier, M.: Generic Service Information System Architecture - A Reference Model Based Approach for Evaluating Information Systems in Industrial Service. In: 13th IEEE International Conference on Emerging Technologies and Factory Automation, pp. 608–615. IEEE Press, Hamburg (2008)
18. Osterwalder, A., Pigneur, Y., Tucci, C.L.: Clarifying Business Models: Origins, Present, Future of the Concept. Commun. Assoc. Inf. Syst. 15 (2005)
19. Osterwalder, A., Pigneur, Y.: Business Model Generation: A Handbook for Visionaries, Game Changers and Challengers. Modderman Drukwerk, Amsterdam (2009)
20. Besch, K.: Product-Service Systems for Office Furniture: Barriers and Opportunities on the European Market. J. Clean. Prod. 13, 1083–1094 (2005)
21. Gebauer, H., Fleisch, E., Friedli, T.: Overcoming the Service Paradox in Manufacturing Companies. Eur. Manag. J. 23, 14–26 (2005)
22. Micklethwaite, P.: BFM DTI Zero Emissions: Task 1.2—PSS: Alternative Models. Kingston University, Kingston upon Thames (2008)
23. Uchihira, N., Yuji, K., Sun, K.K., Maeda, K., Ozawa, M., Ishii, K.: Analysis and Design Methodology for Recognizing Opportunities and Difficulties for Product-based Services. In: Proceedings of Portland International Center for Management and Engineering Technology, PICMET, Portland, USA (2007)
24. BertoniI, M., Larsson, A.: Coping with the Knowledge Sharing Barriers in Product Service Systems Design. In: 8th International Symposium on Tools and Methods of Competitive Engineering, Ancona, Italy (2010)

25. Kowalkowski, C., Kindström, D., Witell, L.: Internalisation or Externalisation?: Examining Organisational Arrangements for Industrial Services. Manag. Serv. Quality 21, 373–391 (2011)
26. Nuutinen, M., IlomäkI, S.: Developing Industrial Service Capability: Towards Service-Oriented Organisation Culture. In: VTT Symposium on Service Science, Technology and Business, Espoo, Finland (2008)
27. Shen, J., Wang, L.: A Methodology Based on Fuzzy Extended Quality Function Deployment for Determining Optimal Engineering Characteristics in Product-Service System Design. In: Proceedings of 2008 IEEE International Conference on Service Operations and Logistics, and Informatics, pp. 331–336. IEEE Intelligent Transport System Society, Beijing (2008)
28. Datta, P.P., Roy, R.: Cost Modelling Techniques for Availability Type Service Support Contracts: a Literature Review and Empirical Study. In: 1st CIRP Industrial Product-Service Systems (IPS2) Conference, p. 216. Cranfield University, Cranfield (2009)
29. Beuren, F.H., Ferreira, M.G.G., Miguel, P.A.C.: Atualização da Literatura Vigente sobre Sistemas Produto-Serviço (PSS): Uma Análise da Produção Qualificada entre 2006 e 2010. In: 18th Production Engineering Symposium. SIMPEP, Bauru (2011)

What Makes a PSS Supplier Successful – An Analysis of the Drivers

Mario Rese and Judith Gesing

Marketing Department, Ruhr-University Bochum
Universitätsstr. 150, D – 44801 Bochum, Germany
{marketing,judith.gesing}@rub.de

Abstract. Providing Product Service Systems (PSS) calls for companies to react flexibly and individually to their customers' requirements and to be able to engage with them in the co-creation of value. In order to meet these changing requirements companies need to adjust their business models accordingly. Research on business models for PSS is limited. Therefore this paper analyzes the antecedents and outcomes of PSS conducting an empirical analysis, building on a questionnaire survey among 29 PSS suppliers. Results indicate that the value proposition is the essential part of the PSS business model, from which other characteristics can be derived. Companies providing PSS can generate higher revenues when they react flexibly towards their value propositions, are service-oriented and able to engage in co-design with their customers.

Keywords: business models, flexibility, capabilities of PSS suppliers.

1 Introduction

Providing Product Service Systems (PSS) is a current strategy of many companies in industrial countries. In doing so, companies react to fierce competition on globalized markets and growing product conformity [1]. PSS are regarded as the future on B-to-B markets in high wage countries, offering differentiation from competitors [2] as well as added value to customers and thus generating customer loyalty [3]. Additionally, profits from introducing services compensate for declining revenues in the product business [4] and stabilize cash flows.

Nevertheless, selling PSS does not offer benefits per se. Companies are required to adjust their business models and acquire special capabilities. One major characteristic inherent to PSS is the intense collaboration and co-creation of value between customer and supplier. This initiates a long lasting customer- supplier relationship covering the whole PSS life-cycle. Employing a business model characterizes this relationship in terms of delivering value, sharing responsibilities, generating revenues, sharing risks, and property rights [5]. In order to adapt this business model towards customer's needs, the PSS supplier should be able to flexibly react to the requirements of their customers during the whole life cycle. This also calls for new relationship capabilities, as the ability to co-design together with the customer as well as for a high service-orientation of the supplier.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 287–298.
DOI: 10.1007/978-3-642-30820-8_25

Up to now research on business models for PSS is still mainly theoretical or based on case studies. Rese, Meier, Gesing and Boßlau (2012) for example define business models for PSS as well as their characteristics using a morphological approach and elaborate three main types of business models for PSS. Other authors have described the special capabilities needed to offer PSS [6]. Nevertheless, no empirical analyses have been conducted to analyze drivers and outcomes of PSS provision.

In order to take this next step the paper at hand builds on a questionnaire survey among 29 PSS suppliers. The authors assess how much flexibility is needed within a PSS business model and what the major capabilities a PSS supplier needs to possess are. Furthermore, the paper analyzes what the outcomes of providing PSS for the supplier and the customer are. Hence, the authors can conclude how flexibility and the different capabilities influence the performance of PSS provision.

The reminder of the paper is structured as follows. First the potential drivers of PSS success are identified from literature. It is discussed whether they should have a positive or negative influence. Further, outcome variables on customer's and supplier's side are addressed. Afterwards the empirical setting is described. Finally the results of statistical analysis are shown and their implications for PSS provision are discussed.

2 Business Models for PSS – Definition and Characteristics

Business models for PSS are "characterizing the relationship between a customer and a provider (network)" [5]. More precisely they settle the value creation and delivery for customers, as well as how customers pay for the value delivered and profits are derived. In addition they contain operational and value chain elements [7]. In case of PSS a customer-provider relationship is characterized by one specific business model.

One major difference between business models lies in the degree of collaboration between customer and supplier. In traditional business models suppliers sell single products or services during one-time transactions, these models are labeled as transaction-based models. The degree of collaboration between customer and supplier is low. Meanwhile PSS business models mostly induce a high degree of collaboration, described by the co-creation of value between customer and supplier.

Each business model is composed of different parts. Rese, Meier, Gesing, Boßlau (2012) identified five characteristics that comprise a business model. The *value proposition* characterizes the value that is delivered to the customer [8]. In general this value can be a product, service, or a combination of both [9]. In the case of a PSS the value consists of a customized and integrated bundle of products and services [10] and the value is co-created [11]. Automatically derived from the value proposition of a PSS is the division of labor. The providence of services (as part of a PSS) is automatically to some degree connected with the division of labor [12]. The *organization model* describes the responsibility during utilization and thus the degree of co-creation. In agreeing on a PSS, customer and supplier automatically have to agree on *risk sharing* issues [13]. For example if the supplier guarantees a contractual performance, the risk of early wear out of physical parts or obsolescence shifts to his side in comparison to a transaction-oriented model where the risk remains on the customer's side. Additional risks also arise in cooperative agreements due to interdependencies between the partners [14]. The delivery of value and risk sharing is always connected to some kind of compensation, which is analyzed in the *revenue model* [15]. When selling products or services in transaction-based business models, the compensation is mostly a one-off payment. In the case of PSS revenue structure changes, the revenues are most often split into multiple payments distributed over the whole life cycle of the PSS. The *property rights* determine who owns the rights to the physical part (e.g. machines) of the PSS. The different characteristics of PSS business models opposed to transactional models are displayed in table 1:

Table 1. Business model characteristics **(according to [5])**

business model characteristics	**differences in business model characteristics**	
	transaction based business models	**PSS business models**
value proposition	sale of physical product or service	integrated and individualized bundle of products and services
organization model	processes are conducted by the customer	co-creation of value between customer and supplier
risk sharing	customer bears risks	risk sharing between customer and supplier
revenue model	transaction based (one-time sale of product or service)	revenues split into multiple payments over the PSS life cycle
property rights	customer owns physical parts	customer or supplier owns physical parts

3 Drivers and Outcomes of Successful PSS Provision

3.1 Supplier's Flexibility in PSS

In todays globalized markets suppliers are confronted with fast changing technologies and thus also with changing customer requirements. The possibility to adapt a PSS towards changing customers' needs is one of its central characteristics [16]. Hence, suppliers including his value chain have to react flexibly. This implies the need for changing the business model according to the changes in the PSS. Thus the supplier has to exhibit flexibility towards the different characteristics of a business model.

Nonetheless flexibility, involving changes in the PSS and thus the business model, can cause costs such as for new assets, training of staff towards the new requirements or procurement costs [17]. Moreover both partners have to renegotiate the PSS conditions. Thus, suppliers have to balance flexibility to fulfill customer's demands against keeping the costs low in order to remain profitable. They face a dilemma between flexibility and stability [18]. Hence, one major challenge for PSS suppliers lies in handling flexible business models [18]. To address this challenge suppliers have to flexibly react within the different characteristics of the business model described above. This flexibility spans the whole life cycle, which means that suppliers might have to adapt the characteristics during the operation of the PSS. To react flexibly within the risk sharing model the capability of risk handling is necessary. The supplier has to assess different kinds of risks and follow a diverse risk portfolio. Also concerning the revenue sharing the ability to structure revenue streams is essential. Hence, as suppliers face a trade off between flexibility and stability, it might not be necessary to show flexibility towards each of the characteristics.

3.2 Supplier's Capabilities for Offering PSS

Offering PSS differs from offering mere products or single services. Hence, suppliers need new capabilities and skills to be able to tailor PSS towards individual customer's needs [19]. In addition to traditional skills such as technical knowhow, research and development, service and relationship based capabilities are needed.

One of the most important capabilities is the service orientation of the supplier. It has to be implemented in the organizational structure as well as in the corporate culture and mindset of people [20]. Traditional production oriented companies have to recognize that services are not merely a necessary evil and can be given away for free [19]. Service orientation implies solving customers' problems, giving advice to customers, as well as developing a relationship with the customer to deliver complex services [20]. Showing service orientation is associated with having a positive performance effect. On the one hand services have to be produced together with the customer with a high degree of interaction, forming sustainable supplier-customer relationships [21]. On the other hand services, if not given away for free, offer higher margins than products [22]. Thus, service orientation should be of utmost importance for PSS suppliers. Yet many manufacturing companies are still struggling to implement service orientation into their company [21].

Another important capability is being able to co-design products and services with customers. PSS are designed to meet customers' *individual* needs [13]. Therefore it is of utmost importance to integrate the customer during the development stage of the PSS. By this means the supplier should be able to obtain his customer`s demands and wishes for the PSS and convert them into technical specifications. As customers often have problems at the beginning with articulating their needs and lack insight into the complex domain of PSS a continuous feedback from both sides is necessary to design the PSS for the customer. Otherwise, the PSS might not meet true customer's requirements. In this case the supplier has to redesign the PSS, which in turn causes costs. Hence, the ability to co-develop the PSS with the customer from the beginning of the development stage should be an important capability for PSS suppliers.

A further advantage linked to PSS is the continuous improvement of products and services due to the information gathered during PSS operation [3]. In PSS the supplier establishes a relationship to his customer and thus can gather feedback concerning the performance of the PSS. This is not possible in transaction based business models where the supplier sells a product based on a one-time exchange, without building a relationship. However, continuous improvement can only work if the supplier has the ability to gather and use the information in a systematic way. He has to listen to customer's feedback and pass it on to the development department. Meanwhile the development department has to be open to feedback and new ideas and not caught up in their routines and habits. Thus, the ability to use customer feedback should be another important capability of PSS suppliers.

3.3 Outcomes of Offering PSS

PSS are supposed to offer benefits not only to the supplier but also to the customer.

For suppliers PSS offer the ability to differentiate themselves from the growing conformity on product markets [2]. Profits from selling products are more and more declining due to this conformity whereas services offer higher margins which can counterbalance this decline [4]. Furthermore, services offer stable revenues along the whole life cycle and are thus able to reduce the volatility of fluctuating revenues from products. Additionally, services offer the ability to build sustainable supplier customer relationships, which can be used for cross-selling and in turn for additional revenues. Thus, providing product service bundles is perceived as being able to establish a more sustainable source of competitiveness [23]. It should positively influence the overall performance of the company, having a positive influence on its revenues.

Customers also benefit from PSS in multiple ways. First, they can benefit from the know-how and expertise of the supplier [24]. The experience of the supplier and having multiple customers whom he offers PSS can lead to economies of scales. Further, due to the co-development between customer and supplier the PSS solution fits the customer's needs better than a standalone product and thus leads to higher performance. Purchasing a turn-key solution which the supplier has already tested additionally lowers the performance risks for the customers [25]. Due to these reasons, product service strategies influence the overall client satisfaction [23] as it offers superior value. Thus, providing PSS should have a positive effect on customer's benefit.

3.4 Research Model

To conclude, PSS suppliers need to balance flexibility and stability as well as acquire new capabilities to deliver PSS successfully in a way so that both parties profit from it. The described capabilities should influence PSS provision in a positive way. Meanwhile it might not be necessary to show flexibility regarding each of the characteristics of the business model, as suppliers face a trade off between costs and benefits of flexibility. There are no assumptions up to now as to how the flexibility regarding the different characteristics influences the PSS provision.

Concerning the outcomes, providing PSS should have a positive effect on suppliers' revenues as well as on customers' benefit. These relationships are shown in figure 1.

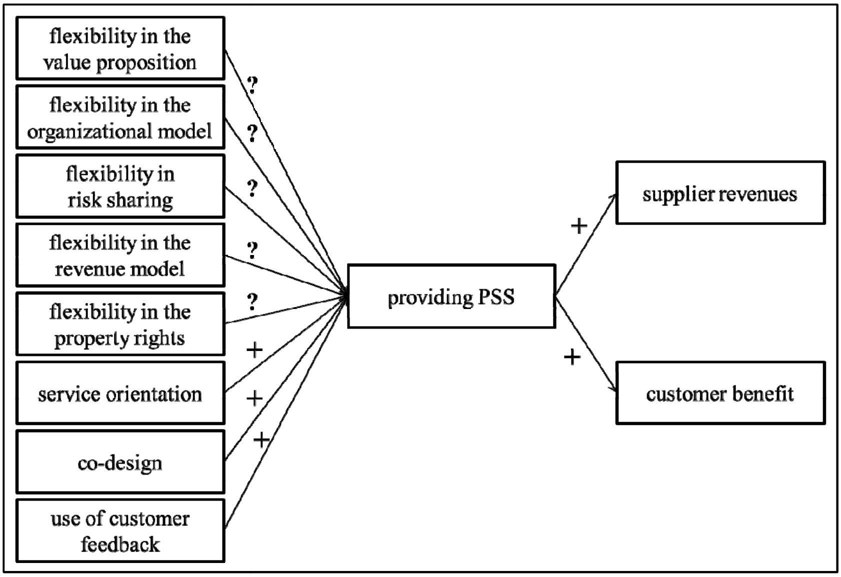


Fig. 1. Premises and outcomes of PSS provision

4 Empirical Study

4.1 Sample and Measurement

To test the framework of PSS provision a survey study was conducted in June 2012. A questionnaire was sent out to 200 German companies selling PSS. 29 valid questionnaires were sent back, i.e. a response rate of 14.5%. This response rate is in line with previous reported studies in B-to-B markets.

The dependent variables were measured using a scale approach. The operationalization of companies' service orientation draws on items by Gebauer, Edvardsson and Bjurko 2010. Indicators of co-design were taken from Ittner, Larcker 1997 and use of customer feedback was measured by drawing on items from a scale by Christensen, Germain, Birou 2005 concerning applied customer supply chain knowledge. The flexibility within the different characteristics of the business model was measured by two items each shown below.

To what extent a company provides PSS was measured using 3 items. PSS are characterized by integrated and mutually determined planning, development, provision, and use of product and service shares [18]. Thus the first item measures the interdependence between product and service components. Further PSS have a high degree of variety in elements [28] which is measured by item 2. The last characteristic describes PSS as being individualized for every customer [13], asked for in item 3.

For each scale an exploratory factor analysis was conducted and Cronbachs Alpha was calculated to test the construct's reliability. All values were above 0.6 and thus acceptable, most scales reached values above 0.7 which indicates high internal consistency of the scales. The items used are shown in table 2. Factor scores were generated calculating the mean between the items' scores.

Table 2. Items used in empirical analysis

Construct	**Items**	**Cronbach's Alpha**
Flexibility in the value proposition	Concerning the value proposition we are flexible regarding which value proposition we offer to our customers.	0.698
	Concerning the value proposition we attend individually to our customers' wishes.	
Flexibility in the organiza-tional model	Concerning the division of labor we are flexible regarding which customers' tasks we undertake.	0.650
	Concerning the division of labor we attend individually to our customers' wishes.	
Flexibility in risk sharing	Concerning the acceptance of risks we are flexible regarding which risks of our customers we assume.	0.721
	Concerning the acceptance of risks we attend individually to our customers' wishes.	
Flexibility in the revenue model	Concerning the revenue mechanisms we are flexible regarding which revenue mechanisms we agree to.	0.882
	Concerning the revenue mechanisms we individually attend to our customers' wishes.	
Flexibility in property rights	Concerning the property relations we are flexible regarding which property relations we approve of.	0.685
	Concerning the property relations we attend individually to our customers' wishes.	
Service orientation	Our company considers service as a lasting differentiation strategy.	0.828
	Our company considers the combination of products and services as a potential way to improve profitability.	
	Our company uses services to reduce comparability with other organizations.	
	Our company aims to exploit financial potential of services.	
	Our company sees services to compensate product sales.	
	Our company considers services as highly profitable.	
Co-design	How often are customer expectations translated into design specifications for a new product/service by a cross-functional team including the customer?	0.882
	How often are meetings with customers employed to identify product or service features that go beyond meeting customer requirements and add performance excitement?	
	How often are customer representatives on the review team used to verify that the products/services meet customer requirements?	
	How often are customer pilot runs used to verify that design of your products/services meet your customer requirements?	
	How often are design reviews by customers used to verify that design of your products/services meet your customer requirements?	
	How important are the customer visits to the development of new products/services?	
	How important are feedback offered by current customers?	

Table 2. (*continued*)

Use of customer feedback	We use information from customers on their future production plans.	0.754
	We use information from customers to improve our product quality.	
	We use information from customers that improves our outbound delivery and inventory management.	
Providing PSS	The offer consists of combined and integrated product and service components.	0.612
	The offer to a customer consists of many different allowance in kind and service components. (1=few, meaning 1-5 components; 7=many, meaning more than 20 components).	
	Targets of our company are individualized bundles consisting of products, services and consulting.	

Outcome variables were measured using single items on a 7 point scale asking for the supplier's revenue and the provision of customers' benefit in comparison to competitors (1= much worse than competitors; 7= much better than competitors).

Table 3 shows descriptive statistics for all variables used in the study.

Table 3. Descriptive statistics

Variable	Mean	S.D.	Min.	Max.
providing PSS	5.00	1.24	2.00	7.00
supplier revenue	4.79	1.37	2	7
customer benefit	5.61	0.72	4	7
flexibility in the value prop.	5.14	1.19	1.50	7.00
flexibility in the org. model	4.72	1.42	1.00	7.00
flexibility in risk sharing	3.93	1.39	2.00	7.00
flexibility in the revenue model	3.38	1.72	1.00	7.00
flexibility in the property rights	3.19	1.40	1.00	7.00
service orientation	4.53	1.15	1.83	6.67
co-design	4.65	1.01	2.75	6.50
use of customer feedback	5.16	1.06	1.00	7.00

4.2 Model Results

In a second step the framework was tested using structural equation modeling. Fit values were calculated which indicate an acceptable model fit (CFI = 0.82; RMSEA = 0.10; SRMR = 0.07). Only the RMSEA is slightly above the recommended value of 0.085. Model results are shown in figure 2.

Model results indicate that providing PSS has a significant positive influence on suppliers' revenues. Further concerning the customers' side PSS also positively influences customers' benefits. Addressing what abilities suppliers need to offer PSS flexibility in the value proposition, service orientation, as well as co-design have a significant positive effect, whereas flexibility in the organizational model, in risk sharing and property rights have a negative but not significant effect. The use of customer feedback has no significant effect on PSS provision.

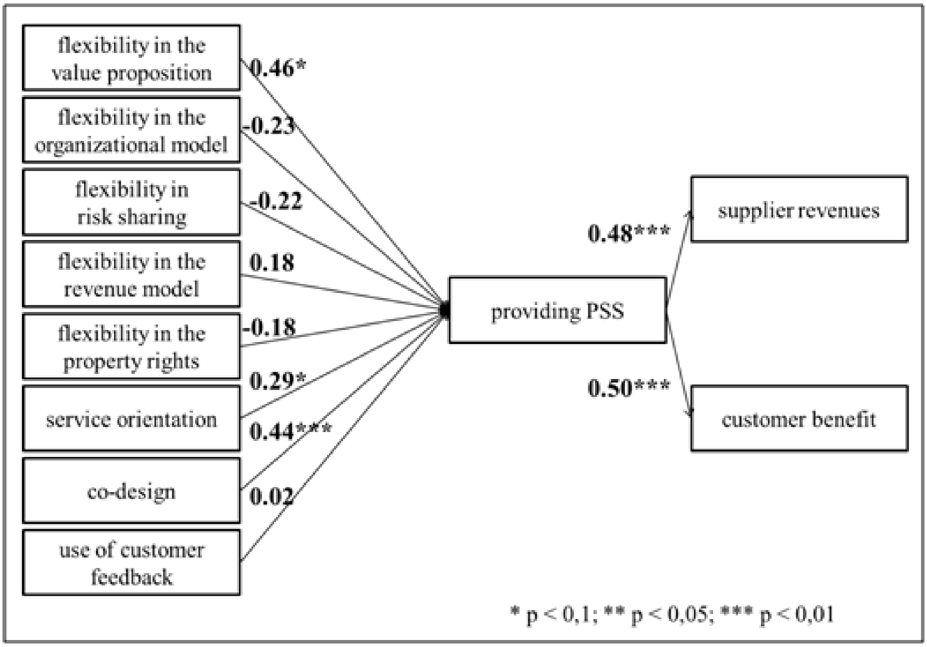


Fig. 2. Model results

4.3 Discussion of Results

The value proposition of a business model has been identified as its central part from which all other characteristics can be derived [5]. Thus, showing flexibility regarding this characteristic seems to be of greater strategic priority for PSS suppliers. Meanwhile flexibility within the organizational model, risk sharing and the property rights show a negative effect on PSS success. Hence, too much flexibility might have a negative effect. Additionally showing flexibility within the risk sharing model needs the ability to assess all risks correctly as well as having a balanced risk portfolio. These might be a major challenge for PSS suppliers. Facing the trade-off between flexibility and stability, suppliers should be most flexible within the value propositions they offer to their customers. Afterwards they can negotiate about the other elements of the business model.

Further, being service oriented appears to be one highly important capability for PSS suppliers. They have to regard services as a major strategy to compete against other companies. If services are merely seen as an add-on for products, the emphasis will still be on product businesses. As a result, services may be given away for free by sales employees or executed poorly. The first most probably leads to a decline in the supplier's revenues, because he does not earn anything with the services. The latter will lead to unsatisfied customers, which in turn might prompt them to change the supplier and hence, again leads to lower profits. Thus, we can conclude that service orientation is highly important for PSS suppliers.

Moreover co-design has a positive effect on PSS provision. Co-design results in a PSS that truly meets customers' needs. If suppliers fail to do so, customers will not be satisfied with the PSS provided. The supplier may have to readjust the PSS, which causes additional costs. Further the customer might choose another supplier the next time and perform negative word of mouth. All these consequences lead to a decline in supplier's profits. Consequently we can identify co-design as an important capability for PSS suppliers.

Meanwhile the use of customer feedback has no significant effect in our study. One reason could be the individualized adaption of PSS for the single customer. If PSS are designed very differently for every customer it might be difficult to learn from previous projects. In this case the ability to co-design is even more important. Another reason could be the small sample size. These effects are discussed within the limitation section.

Concerning the outcomes PSS provision has positive effects for the supplier and for the customer. Providing PSS positively influences supplier's revenues. Hence, by offering PSS suppliers can generate higher margins and compete against their competitors. On the customer's side, PSS positively influences the perceived benefit. Consequently, by integrating products and services suppliers can offer higher values to customers and solve their problems better.

4.4 Limitations

The empirical study reveals interesting results, nevertheless there are some limitations. First of all the sample only contains 29 companies, which is quite a small sample size. Small sample sizes can lead to type II errors. This means that test results indicate non-significant effects, although they might exist. Hence, some effects in the data may not be recognized. To overcome this limitation a follow up study with a larger sample size is necessary.

Second the outcome variable on the customer's side (customer benefit) was measured using the information provided by the supplier. Thus, there can be a discrepancy between the customer's and supplier's perception. In PSS provision this discrepancy should be lower than in transaction based business models, due to the close interaction between customer and supplier. Nevertheless, a follow up study should match suppliers' and customers' perceptions.

5 Conclusion

The study at hand conducted a survey study about the drivers and outcomes of PSS provision. Up to know no empirical studies in this area exist, hence, this study is the first survey among PSS suppliers.

Our study reveals that providing PSS instead of products has a positive effect on supplier's revenues as well as on customers' perceived benefits. Thus, providing PSS seems to be beneficial for companies. Nevertheless, companies have to obtain certain capabilities to provide PSS successfully. They have to be service-oriented, be able to co-design with the customer and show high flexibility with regard to the value proposition. Thus companies willing to enter the PSS business should place a high importance on these capabilities in addition to delivering superior products and services. If suppliers succeed in doing so PSS offers high advantages to them.

Acknowledgment. We extend our sincere thanks to the German Association of Research (DFG) for funding the research project TR29 and to all who contributed to preparing this paper.

References

1. Evanschitzky, H., Wangenheim, F.V., Woisetschläger, D.M.: Service and Solution Innovation: Overview and Research Agenda. Industrial Marketing Management 40(5), 657–660 (2011)
2. Wise, R., Baumgartner, P.: Go Downstream: The new Profit Imperative in Manufacturing. Harvard Business Review 77(5), 133–141 (1999)
3. Mont, O.K.: Clarifying the Concept of Product-Service System. Journal of Cleaner Production 10, 237–245 (2002)
4. Reinartz, W.J., Ulaga, W.: How to sell Services more profitably. Harvard Business Review 86(5), 90–96 (2008)
5. Rese, M., Meier, H., Gesing, J., Boßlau, M.: An Ontology of Business Models for Industrial Product-Service Systems. In: Proceedings of the 4th CIRP International Conference on Industrial Product Service Systems, Tokyo, Japan (2012)
6. Storbacka, K.: A solution business model: Capabilities and management practices for integrated solutions. Industrial Marketing Management 40(5), 699–711 (2011)
7. Teece, D.J.: Business Models, Business Strategy and Innovation. Long Range Planning 43(2-3), 172–194 (2010)
8. Osterwalder, A., Pigneur, Y.: Business Model Generation. John Wiley and Sons, New Jersey (2010)
9. Morris, M., Schindehutte, M., Allen, J.: The Entrepreneur's Business Model: Toward a unified Perspective. Journal of Business Research 58(6), 726–735 (2005)
10. Tuli, K.R., Kohli, A.K., Bharadwaj, S.G.: Rethinking Customer Solutions: From Product Bundles to Relational Processes. Journal of Marketing 71(3), 1–17 (2007)
11. Cova, B., Salle, R.: Marketing Solutions in Accordance with the S-D Logic: Co-creating Value with Customer Network Actors. Industrial Marketing Management 37(3), 270–277 (2008)
12. Ehret, M., Wirtz, J.: Division of Labor between Firms: Business Services, Non-Ownership-Value and the Rise of the Service Economy. Service Science 2(3), 136–145 (2011)
13. Cova, B., Salle, R.: Introduction to the IMM special issue on 'Project marketing and the marketing of solutions' A comprehensive approach to project marketing and the marketing of solutions. Industrial Marketing Management 36(2), 138–146 (2007)
14. Link, P., Marxt, C.: Integration of Risk- and Chance Management in the Co-operation Process. International Journal of Production Economics 90(1), 71–78 (2004)
15. Petrovic, O., Kittl, C., Teksten, R.D.: Developing Business Models for eBusiness. In: International Conference on Electronic, Vienna, Austria (2001)
16. Meier, H., Funke, B., Boßlau, M.: Flexible Resource Planning in the Context of Dynamic IPS^2 Business Models Functional Thinking for Value Creation. In: Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, pp. 165–170. Springer (2011)

17. Steven, M., Alevifard, S., Keine genannt Schulte, J.: Economic Relevance of IPS^2 Flexibility. In: Hesselbach, J., Herrmann, C. (eds.) Functional Thinking for Value Creation. Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, Heidelberg, pp. 261–265 (2011)
18. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems - IPS^2. CIRP Annals - Manufacturing Technology 59, 607–627 (2010)
19. Ulaga, W., Reinartz, W.J.: Hybrid Offerings: How Manufacturing Firms combine Goods and Services successfully. Journal of Marketing 75(6), 5–23 (2011)
20. Gebauer, H., Edvardsson, B., Bjurko, M.: The impact of service orientation in corporate culture on business performance in manufacturing companies. Journal of Service Management 21(2), 237–259 (2010)
21. Gebauer, H.: An Attention-Based View on Service Orientation in the Business Strategy of Manufacturing Companies. Journal of Managerial Psychology 24(1), 79–98 (2009)
22. Oliva, R., Kallenberg, R.: Managing the Transition from Products to Services. International Journal of Service Industry Management 14(2), 160–172 (2003)
23. Salonen, A.: Service transition strategies of industrial manufacturers. Industrial Marketing Management 40(5), 683–690 (2011)
24. Macdonald, E.K., Wilson, H., Martinez, V., Toossi, A.: Assessing value in-use: A conceptual framework and exploratory study. Industrial Marketing Management 40(5), 671–682 (2011)
25. Bharadwaj, N., Naylor, R.W., Hofstede, F.: Consumer response to and choice of customized versus standardized systems. International Journal of Research in Marketing 26(3), 216–227 (2009)
26. Ittner, C.D., Larcker, D.F.: The Performance Effects of Process Management Techniques. Management Science 43(4), 522–534 (1997)
27. Christensen, W.J., Germain, R., Birou, L.: Build-to-Order and Just-in-Time as Predictors of Applied Supply Chain Knowledge and Market Performance. Journal of Operations Management 23(5), 470–481 (2005)
28. Galbraith, J.R.: Designing the Customer-Centric Organization. Jossey Bass, San Francisco (2005)

Deciding on PSS: A Framework for PSS Strategies

Line Neugebauer, Krestine Mougaard, Jakob Axel Bejbro Andersen, and Tim C. McAloone

Department of Mechanical Engineering,
Section for Engineering Design and Product Development,
Technical University of Denmark (DTU), Building 426, 2800 Kgs. Lyngby, Denmark
lmne@mek.dtu.dk

Abstract. Product/Service-Systems (PSS) are a strategic approach wherein the value proposition covers the performance of a system throughout the whole life cycle. Many industrial companies are challenged on many levels in the transition process towards a PSS oriented approach. Much of the literature has until now focused on PSS from a design object perspective, and less focus has been on how the business model of the company must be designed simultaneously with the offering, covering topics as organisational restructuring, value chain collaboration plus a change management focus. This paper presents a *PSS strategy topic matrix*, as a boundary object for the company, aimed at creating a shared understanding of important factors in the organisation while evaluating, developing, implementing and operating a PSS strategy. This is done through an empirical foundation of twelve companies representing a whole branch industry, together with three cases of industrial best-practice.

Keywords: Product/Service-System, business model strategies, organisational change, value-chain collaboration.

1 Introduction

Across sectors, industrial companies are increasingly moving toward strengthening their after-sales activities through introduction or improvement of service provisions. The notion of Product/Service-System (PSS) as an emerging business concept is increasingly being adapted by practitioners in industry. In doing so many of the companies are facing a complex transition phase as the design object is changed from a *physical product*, to *the performance of the system throughout the whole life cycle* [1], when designing a PSS, the company takes decisions that creates a direct and disposed effect on many aspects of the value chain and require an understanding of the life cycle. This creates demands for change in the organisation, ranging from an operational level to a strategic management, and business model creation perspective. A PSS strategy therefore requires decisions and actions regarding changes in the network, development processes, and alternative cash flows [1]. When looking at PSS at a strategic level there is a need to develop normative methods that can be shared across departments in the organisation and across organisations to enable the PSS strategy evaluation, development, implementation and operation.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 299–310.
DOI: 10.1007/978-3-642-30820-8_26

Looking into other research fields as business management, many tools and methods have been created for general management and business model creation. Over time, the complexity created by accumulation of tools will impede the company's ability to find the right tools or method for the task at hand. For this reason recent research within this field, attempts to provide easy accessible overview tools. This paper attempts to establish a tool with the same aim, directed specifically against the PSS field, for use in evaluating, developing, implementing and operating new PSS strategies.

PSS literature has long focused on defining what constitutes a PSS, together with the goal of a PSS approach, research is currently focused on how to develop a PSS, which is focusing to a large extend solely on the development task, on different levels in the organization. Besides this research also focus on evaluating how companies deal with the implemented business model, but little research has been on the overall considerations of whether a company should move towards a PSS approach or not.

Researches on industrial cases investigating, what parameters influences a PSS and therefore are important to take into account in all phases, from evaluating to operating a PSS, are therefore sparse. This paper presents three best-practice cases of PSS oriented companies, together with twelve companies representing a whole branch industry, which are all in the transition process towards a PSS approach.

The proposition for this paper is:

When staging the transition process towards a PSS approach, the decision to change, as well as the process of change itself, demands an inherent awareness in the company of what topics are important to consider, internally as well as externally to the company.

The proposition will be investigated through the following questions:

1. What topics are important to take into consideration when developing and maintaining a PSS approach?
2. How can this list of topics be made manageable for an organisation when navigating the change process?

2 Methodology

The research design of this study follows a case study design [2], [3] which for this study builds upon the following sources of data and evidence:

- Literature study
- Empirical findings from the PROTEUS innovation consortium consisting of twelve case companies
- Three best-practise cases from other industries than that of PROTEUS

2.1 Research Cases

The main source of empirical evidence for this study is the PROTEUS innovation consortium, which consists of twelve companies from the maritime industry, a branch organisation, a technical service partner (consultancy), and international university partners. All involved companies are interested in normative methods to bridge the challenge of effectively and systematically integrating service development into their product development and business creation process. The companies are all international, ranging in size of 30-3000+ employees and have different levels and years of experience in approaching the PSS transition challenge. Secondarily empirical insights have been gathered from case studies conducted across three industries different from that of PROTEUS: Aerospace, automotive and land transport. All three case companies have successfully managed the transition to a profitable PSS business model. The last mentioned cases are used as validating and improving the established framework, created within the context of the PROTEUS companies.

2.2 Data Gathering and Analysis

The empirical insights have been gathered over a period of 24 months, covering multiple research phases in the consortium. The data have been collected through approximately 30 interviews (2-4 hours), two site visit at each company, four workshops gathering the consortium, and two in-depth case studies; one in the context of a single company, and one covering a case of two companies. Besides the companies of the consortia multiple interactions have taken place with various stakeholders of the industry. The best-practice cases were identified through PSS networks and were explored through an extensive desktop research and an in-depth interview with each company, through a semi-structured interview approach, covering the topics as: motivation, PSS offerings, change process, challenges, and business model. All empirical insights have been documented through, personal field notes, reports, and audio recordings. The analysis have been build upon an adaptive-research approach using the pattern matching strategy where information collection have been conducted in parallel with the process of analysis. Comparing findings with literature have aided the creation of new themes emerging from the empirical insights. Validation of empirical insights has been done in collaboration with the companies, either through report verification or presentation and feedback.

3 Literature Review

PSS as a business strategy is described in literature as a phenomena, but little is written on how to aid a company in the transition towards it. Prior work [1] has indicated the following multiple areas besides PSS should be included when looking at this; Change management, Business management, Value network management, and Relationship marketing.

3.1 Product/Service-System Approaches

Within the field of PSS, attention is focused on different levels. This paper focus lies on PSS as a business strategy, and also touches upon PSS as value creation, where the design process perspective is in focus. Despite PSS being a relatively new field in management and engineering design research, a mass of useful tools and frameworks have emerged from the PSS area, whereof many are still in the process of validation and refinement within industry. A proposed model of PSS business development shows the link between development activities and business strategy, illustrating that a PSS as a design object, needs a broad focus in the organisation [4]. A tool directed towards the PSS designers are a so-called PSS morphology where in different PSS strategic characteristics and PSS dimensions can be designed, to mention a few are: *Availability of offering* (ownership), *Revenue mechanism* (cost structure), *Partner or collaborators* (external view) [9]. Besides this model can be mentioned the model PSS typology [5] which can aid in the choice of what service degree the company would prefer, as e.g. *product related advice*, and *product sharing* and *activity management*. These frameworks are uncovering many important elements to take into consideration when considering a transition from a product-oriented company to a service oriented business, but still lack a compilation to use on a strategic level. When looking at the organisational structure different possibilities of organising the service development can be carried out through different strategies; the service operation can be integrated in all levels within the company, and it can be dedicated to a business unit, or outsourced by partnering with external service entities. [4], or a mix of all three, they all have different network structure, ranging in nature of internal towards external network.

A recent PSS study created through an extensive empirical study focus to a large extend on the stage where the company have established itself in a constellation of a PSS business model, and how their approach has changed over time, and what challenges it had brought with it (the study looks retrospectively at the PSS strategy development), and do not focus on the early stages where to evaluate whether the company are suited a PSS approach or not, which by the authors are seen as vital and an area for future focus.

3.2 The Network as a Catalyst for Exploration and Transformation

Companies' competitiveness should be evaluated through a holistic network perspective, as it is the totality of the value chain, or "value system" that represents the true competiveness. A trend is moving towards competition being based on value systems against value systems, it is therefore vital to be able to diagnose and manage the external network of the company. [6]. When looking at PSS research, the literature points towards PSS being strengthened if a collaborative approach is taken when conceptualising, implementing and/or operating the system, to be able to sustain and enhance the utility of the offering throughout its lifetime, which demands a more advanced customer and supplier relationship management, recognised by the new field of relationship marketing [7], as the value creation process to a larger extend is not held solely by one company, but should be seen on a system-solution level, [7].

When changing from a product supplier to a product/service supplier different relationships are needed (both internal and external) following the advancement in the PSS approach [8]. The network structure is important to navigate when designing the business strategy of a company, as all relationship together carry opportunities for new constellations of revenue, information, and resources, needed for innovation and the possibility to sustain this [9]. This network approach is yelling for new business models, wherein a shared value system can be reached, here the value proposition can be created by a cluster of companies; therefore revenue streams among other becomes crucial topics.

3.3 Approaching Business Model Creation

The field of business model research is rather new (with actual beginnings in the late nineties) and still quite divergent with regard to the interpretation of central terms such as "business model" and "strategy". [10]. Osterwalder et al have done an extensive study into business models, and on basis of this developed a framework termed *business model canvas*. The business model canvas can be used as a boundary object from the initial conceptual stages of planning a new strategy to the execution phases. Its contents are static, but the interpretation and focus of each dimension evolves as the change process unfolds. This depiction of the business model research field is reminiscent of the PSS research field, where central terms are also interpreted in a divergent manner.

In the context of this paper, a distinction is made between business model and strategy. As stated by Magretta [11], *"Business models describe, as a system, how the pieces of a business fit together. But they don't factor in one critical dimension of performance: competition..."* Osterwalder et al adds to this distinction by stating:*"... strategy includes execution and implementation, while the business model is more about how a business works as a system.* Having identified competitors and other external actors as key influencers in forming and executing a PSS based strategy and realizing the importance of capturing the temporal dimensions of the process, the authors have chosen to place the frameworks presented in this paper in the strategy category.

3.4 Understanding Change in Organisations

For decades, the field of change management has sought to describe and understand the process of strategic planning and execution in companies.

This paper seeks to elucidate the process of strategic implementation of PSSs by incorporating the widely adopted and proven theories for managing change. Several authors provide generic processes describing the different phases of strategic change. In this paper, the authors have opted for the *BPR Project Stage Activity Framework* described by Kettinger et al [12]. The framework deals with the following stages for change: *Envision – Initiate – Diagnose – Redesign – Reconstruct – Evaluate.* Supplementary to this the authors is Kotter's change model "*Eight steps to Transforming Your Organisation"* [13]. Here Kotter primarily focus on the implementation stages of the change process, contributing several organisational and political dimensions. For instance, in his initial phase "*Establishing a sense of urgency"* he emphasises the significance of creating a common understanding of the need for change.

4 Empirical Insights

This section will present the findings, through three empirical cases of companies that have successfully transitioned from manufacturing companies to PSS providing companies.

4.1 Case A

Company A develops and produces integral engine components for the aviation industry. The aviation industry was one of the first to implement PSS offerings in the form of change in product ownership and a fixed engine maintenance cost over an extended period of time which has become a market trend. A contributor to this trend has been the high regulations on engine maintenance. With a development time of 3 to 5 years and an aftermarket life of 30 to 50, company A has to plan and align its offerings to support the engine manufacturer throughout the product life phases. As its components are an integral part of the engine, company A has to align their development process with its customers. Company A´s development process need to be agile and flexible to meet the ever changing requirements to the changes made in other components that affects the design, dimensions, and location of the component. Design for maintenance becomes complex as minor alterations of the surrounding components can have great effects on the accessibility and serviceability of Company A's components. To enable the provision of the needed PSS solutions a change in the solution development was required. The strategic decision to commit to the market demand created high demands on the financial part of the business. With an extended product life the potential revenues in the aftermarket are substantial. As the aircraft owners essentially lease the engine, the engine manufacturer has high up-front expenses but also high aftermarket revenues. To manage the high up-front cost the engine manufacturers and suppliers enter a financial partnership agreeing to split costs and earnings through the product life cycle.

Company A already had a long history with business models based on revenues throughout the product life cycle in other customer segments, so when the market and customer demand in the commercial customer segment arose, they were ready to act upon it. Along with the change in strategy a different set of competences was needed. Where the company developers had always had a high technical level the developers needed to be agile when co-developing with the customers and potentially also other partners, as well be able to incorporate demands from the aftermarket (as repair activities, welding etc.) into the product development. One way the competence and knowledge level was raised within the company was by entering into collaboration with research institutions. Thereby the company had access to the latest research on the subject as well as research projects focusing on their company and its challenges. The collaboration with the knowledge institutions is also part of a human resource strategy. By hiring the candidates when they finished their studies, they also had access to a workforce that already knew the inner workings of the company and that already had acquired many of the competences needed.

4.2 Case B

Company B has a long history of producing and selling coating for automotive refinish workshops. Company B was one of five market-leading companies to compete on products that were becoming a commodity. To be able to compete and differentiate themselves from their competitor they made the strategic decision to change.

Company B went from what they describe as being "can-kickers" to a business partner that offers holistic workshop solutions to their customers; including workshop audit and design, profit management, and business educations. Company B's customers have a high technical knowledge, but many are small start-up companies that had grown larger but had not been trained in the operation and growth of a paint shop. The customers were already loyal and trusting to the company which created the foundation for a close collaboration throughout the expansion of their own and Company B's business.

To sell the new holistic solutions a comprehensive set of new competences was needed inside the organisation. Instead of merely selling coatings the sales personnel representative should be able to consult on and sell workshop design, machinery and business thinking. For this the company created a three-year education programme for a selected number of suitable employees. With the new offer of workshop design they increased their offer portfolio to include equipment for the workshop, so the customer was able to order the equipment directly when deciding on the design. Expanding the offerings in this way also meant creating a new supply network as well as planning the logistic between suppliers and customers aligning this to the process of executing the workshop design. In the effort of developing business courses for their customers they hired in external experts in business coaching and organisational development, to integrate the company's expertise and customer knowledge into a set of tailor-made courses for their customers.

It was challenging to alter the culture within Company B. If a sales person is going to sell integrated workshop solutions and supporting business solutions instead of coatings, the sales person has to be able see the benefits for the customer of these new offerings. In this the communication from management to the different departments proved essential. The language, with which the alterations were communicated to the workers, was too academic for the workers to relate to their day-to-day practises. First when the communication problems were cleared, the workers were able to successfully sell the PSS solution.

4.3 Case C

Company C develops, produce and sell *transport solutions* and has through ten years transformed its business to a holistic PSS provider. It changed its role from a manufacture and component supplier to a financial partner and consultancy in transport solutions. By this company B also changed its business model as new revenue streams was created, as its customers could choose between different financial solutions, all with different level of ownership of the products.

Important here for company C was its training of its sales personnel to be consultants, a change in competence level. Besides this the process of the sales procedure was changed as it in a sales situation would use a tool for calculating and configure the Total Cost of Ownership (TCO) in collaboration with the customer, the customer culture was to a high extend reflecting a market change, as they possess a changed mental mindset. Besides this a change was also created in the internal processes and the organisational structure, as the companies new approach linked together new-sales and after-sales creating a customer lock-on.

To be able to extend its service network and hereby company reach, company C, made a close collaboration with its dealer network, a change in the external network constellation. The dealer was changed from being both a service workshop and a sales house, to be only a service workshop, which was done through an educational programme, changing the external network capabilities and creating a direct sales force internal the company instead of a mix of external and internal. Company C, had through a customer focus created a set of KPI´s for the dealers to be measured against, and hereof be rewarded. The dealers had an increased profit based on this new relationship, illustrating a new network structure.

The internal culture was a source of barrier in the company and a large change in employee force all the way up to management, was created as many was stuck in the old culture of being a manufacture company. The company made a cultural check list wherein: Capacity, competence and commitment where three important elements.

Company C made a total redesign of its value proposition, which was done through a company strategy ranging ten years. Company C sell: *A guaranteed cost per km*, this was among other things made possible due to the change in the product as it became more digital, whereof the company could make proactive and preventive maintenance, together with statistically planned maintenance schedules. This also changed the information of which to base service on. Information sharing and communication was increased between company C, its dealers and its customers. The transparency of the cost throughout the products lifetime was made more transparent, causing a relationship wherein trust could be created.

5 Generel Findings: The PSS Strategy Topic Matrix

Based on the pattern matching strategy, where an iterative process of relating theory and empirical insights, reveal new knowledge, a set of topics of importance emerged, topics of importance when dealing with the transition towards a PSS strategy, the authors have compiled this into a framework doubt: *PSS strategy topic matrix*, see Figure **1**

Figure **1** shows the framework and the empirical foundation, it gives a holistic view of the framework and how it is grounded in each of the companies. The table illustrates how topics have been identified as important in each company. Whereof the mark in the table should be understood as; (i) observed by the researcher (implicitly referred to by the interviewee), (ii) mentioned explicitly by interviewee, or (iii) in the iteration of the two mentioned with literature.

The framework was developed by categorising all the topics into six main categories, which are mirrored in what a company would consider as internal (departments, organisational culture etc.) and external elements (suppliers, competitors etc.). The categories that emerged was: "Stakeholders and stakeholder processes", "Capabilities", "Influencers", "Network" and "Offering".

	Findings		Empirical data												
	Category	Topics	A	B	C	D	E	F	G	H	I	J	K	L	M
Internal	Stakeholders and stakeholder processes	Finance	•	•	•	•			•				•		
		Marketing		•	•	•		•	•		•		•	•	
		Solution development	•	•		•	•	•	•	•	•	•		•	•
		Management	•	•	•	•	•	•	•	•		•			
		Human resources	•	•	•			•	•				•	•	
		Logistics		•		•					•		•	•	
		Sales channels			•	•	•			•		•		•	
		Operation & processes	•	•	•	•	•	•	•	•	•		•	•	
		Strategy development	•	•	•	•		•	•	•		•	•	•	
	Physical assets	Physical facilities			•	•						•	•		
		Company Reach			•	•		•			•	•	•	•	•
	Capabilities	Competence level	•	•	•			•	•				•	•	•
		Information & Comm.	•	•	•	•			•		•	•	•		•
	Influencers	Organisational culture	•	•	•			•	•			•	•		
		Current strategy	•	•	•				•						
	Network	Organisational structure	•				•		•						
	Offering	tangible, intangible	•	•	•	•	•	•	•	•	•	•	•	•	•
External	Stakeholders and stakeholder processes	Customers & segments	•	•	•	•		•	•	•	•		•	•	
		Suppliers			•	•		•						•	
		Competitors		•	•					•			•	•	
		Sales channels			•	•			•	•	•		•	•	
		Knowledge institutions	•	•		•									
		Financial partners	•		•	•									
		Other partners	•			•							•	•	
	Physical assets	Customer locations			•	•		•	•	•	•		•		
		Supplier locations	•		•	•	•		•				•		
	Capabilities	Customer competence	•	•	•	•				•					
		Competitors competence	•		•										
	Influencers	Mega trends	•	•	•	•	•	•		•			•	•	
		Influencing bodies			•								•		
		Regulating bodies	•		•	•	•		•					•	
		Customer culture	•	•	•	•		•			•		•		•
		Supplier culture			•										•
	Network	Network constellation	•	•	•	•	•	•					•		
	Offering	tangible, intangible	•	•	•	•		•		•	•	•		•	

Fig. 1. The PSS Strategy Topic Matrix (PSTM) to the left and the empirical foundation on the right, A-C are the case companies in this paper. D-M is the PROTEUS companies.

6 Discussion and Implication

This section will elaborate the findings and implication for each of the two research questions. The first objective of the research has been to identify a list of important topics that should be considered when developing and maintaining a PSS approach. The second objective was to make the topics manageable for an organization. The PSS Strategy Topic Matrix (PSTM) is an attempt to present the identified topics in a manageable way. Many of these topics have diverse implications and adopt different meanings depending on the context, company dynamics as well as semantics under-standings. E.g. Communication can regard communicating the need for change by management to the employees, but it also refers to communication between relevant stakeholders in the development process. The nature of the topic change in according to context. This also apply over time. When discussing the topics with the case companies it was clear that the topics transcended the change phases; from Envision to Evaluate in Kettinger's framework.

For instance, in case company B, the topic of *competencies* was recognized throughout the change phases. In the early *envision* phase, the company realized that it could benefit from training its sales personnel. From here, the change process went into the *initiate* phase where a collaboration with a knowledge partner was established. In the *diagnosis* phase, the company realized that the training program had to be altered to meet the needs of the sales personnel. This led to the *reconstruction* phase, where the company implemented an updated version of its training program. Lastly, it is clear that the topic of *competencies* is still relevant in the final change phase, *evaluate,* as the company is now constantly monitoring the training program and adjusting it in order to establish the competencies needed in the market.

In some cases the topics revealed themselves to be tightly related. In the case of Company C, the internal topic of *finance* has clear links to the external dimension of *financial partners* as the internal processes and roles of the finance department will inevitably have to change to accommodate the interaction with an external stakeholder.

A similar argument is valid for the changed revenue streams in Company C that have implications for both *customer and customer segments* topic and internal topics such as *finance* and *information and communication.*

The ability of the topics to work in different contextual setting is a great strength, but also one of the main limitations of the matrix. Companies looking to quantify and model business processes, relations etc. will fall short if trying to use the framework presented herein. Here, one must remember the analogies between Osterwalder's business model concept and the PSS strategy matrix; the former was never intended as a detail planning tool – rather, it is a boundary object for gaining an overview. Having established an overview, literature offers a mass of excellent tools for going into the details. The same thing can be stated for the role of the *PSS Strategy Topic Matrix* and its relation to tools available in the field.

In evaluating the general validity of the topics presented, one has to bear in mind the origins of the framework. The main empirical basis lies in the PROTEUS research project which is exclusively focused on the maritime sector. This attribute could pose a problem with regard to general applicability of the framework. It is important to underline this point in relation to; firstly, the inclusion of three in depth cases from outside the maritime sector has ensured a wider spread in the empirical data. Secondly, it is not the claim of the authors, that the framework presented should be seen as completed – indeed, more topics are likely to emerge as the framework migrates into other industries with unique attributes. Also, the case companies all work on a business to business (B2B) basis. Moving from B2B to B2C (business to consumer) would most likely require additions to the framework.

To further touch upon the validity and limitations of the PSTM, the authors have not been able to validate the results with the case companies before formulating the framework. Ideally, the framework should go through, at least, one iteration before it is widely adopted. For this reason, the coming period will be spent on doing just that.

Finally, we revisit the assumption made in the literature review section, that the framework presented herein is best described as a strategic one (as opposed to a business model framework); we have found clear indications in the empirical studies of the case companies, that external factors such as competitors as well as considerations regarding implementation are of great importance to the companies. For that reason, the assumption is seen as validated in accordance with the definitions by Magretta and Osterwalder.

7 Conclusions and Future Work

RQ1: The list of important topics has been presented in the PSS Strategy Topic Matrix. As the presented cases verify, the topics have all been considered by companies that have moved toward a PSS approach.

RQ2: Presenting the topics in matrix form, where the topics are divided into categories which are mirrored in internal and external considerations are the authors attempt to enable organisations to overview and use the topics in the change process. This is a first attempt that has not yet been tested, and thereby verified in industry. The list is not total and will most change when applied in other industries.

Approaching the transition towards a product/service-oriented business a need for an overall framework for aiding this process has been recognised. This paper presents a matrix that uncovers the topics a company should to be aware of when considering a PSS strategy. The framework (matrix) currently consists of 35 topics, which are divided into six categories seen through the lenses of internal and external perspectives. The matrix is intended to act as a boundary object between stakeholders across functional areas within the company. It is meant to create a shared awareness of what is important for a company to take into account while e.g. developing, marketing, or selling the offering.

It is found that building a business strategy for PSS can be done with help of existing tools as e.g. the business Model Canvas, where certain perspectives are added.

The authors plan to further explore, revise, and validate the matrix together with industry and PSS design students. It has already been identified that the different topics have different importance and influence in different phase of the change process, further research should explore the nature and extend of this.

Acknowledgement. The authors would like to thank the companies participating in the empirical work and the Funding bodies, (Danish Agency for Science and Technology & Danish Maritime Foundation) for their support of this research.

References

[1] McAloone, T.C., Mougaard, K., Neugrbauer, L., Nielsen, A.T., Bey, N.: Orthogonal views on product service system design in an entire industry branch. Presented at the Internaional Conference on Engineering Design, ICED 2011, Denmark, Copenhagen (2010)

[2] Eisenhardt, K.M.: Building theories from case study research. Academy of Management Review, 532–550 (1989)

[3] Yin, R.K.: Case study research: Design and methods, vol. 5. Sage Publications, Inc. (2009)

[4] Tan, A.R.: Service-Oriented product development strategies. PhD thesis, DTU Management Technical University of Denmark, DTU Management (2010)

[5] Tukker, A., Tischner, U.: New business for old Europe: product-service development, competitiveness and sustainability. Greenleaf Pubns (2006)

[6] Möller, K., Rajala, A.: Rise of strategic nets — New modes of value creation. Industrial Marketing Management, 36, 895–908 (2007)

[7] Payne, S.H.A.: Diagnosing Customer Value: Integrating the value process and relationship Marketing. British Journal of Management 12, 24 (2001)

[8] Mougaard, K.H., McAloone, T., Neugebauer, T., Bey, N.: Establishing collaborative networks for conceptualising PSS. Presented at the 11th International Design Conference, Design 2012, Croatia, Dubrovinik (2012)

[9] Tan, A., McAloone, T.C.: Characteristics of strategies in product/service-system development. In: 9th International Conference on Design: DESIGN 2006, pp. 1435–1442 (2006)

[10] Osterwalder, Y.P.A., Tucci, C.L.: Clarifying business models, origins present, and future of the concept. Communication of the Association for Information Systems 16, 25 (2005)

[11] Magretta, J.: Why business models matter. Harvard Business Review 80, 86–93 (2002)

[12] Kettinger, W.J., Teng, J.T.C., Guha, S.: Business process change: a study of methodologies, techniques, and tools. MIS Quarterly 21, 55–80 (1997)

[13] Kotter, J.P.: Leading change: Why transformation efforts fail. Harvard Business Review 73, 59–67 (1995)

An Indicator Framework for Monitoring IPS² in the Use Phase

Michael Abramovici, Feng Jin, and Hoang Bao Dang

Chair of IT in Mechanical Engineering (ITM), Ruhr-University Bochum,
Universitätstr. 150, 44801, Bochum, Germany
{michael.abramovici,feng.jin,bao.dang}@itm.rub.de

Abstract. An Industrial Product Service System (IPS²) in the use-oriented business model is delivered to customers with the guarantee of high performance. Due to dynamic changes and uncertainties in the IPS² use phase, suppliers carry risks when trying to achieve the expected high performance or keeping the budget. In order to reduce these risks and to keep the balance between IPS² performance and cost, suppliers have to improve IPS² based on the decisions taken on its management level. These decisions can only be made, when an accurate monitoring of IPS² has been achieved. This paper introduces an indicator framework for decision-makers of IPS² suppliers to monitor IPS² in the use-oriented business model in the use phase. Indicators are defined with regard to IPS² performance, IPS² lifecycle cost and influencing factors. A monitoring method with early risk warning against risks using indicator corridors will also be introduced.

Keywords: IPS² Monitoring, Indicator, Decision-Maker, IPS² Performance, IPS² Lifecycle Cost.

1 Introduction

An IPS² is viewed as an integrated bundle of key industrial product (e.g. a micro-machining tool) and related services [1]. In the use-oriented business model, an IPS² is delivered to the customer with the guarantee of high performance and is usually integrated as a production unit into a customer production process [1], [2]. Because of dynamic changes and uncertainties in the IPS² use phase, IPS² suppliers have to improve their IPS² during its use phase [3]. The IPS² improvement processes requirement a lot of management decisions [4]. Right decisions can only be made based on an exact monitoring of IPS² and an analysis of IPS² risks.

Generally, from the supplier's view, IPS² risks can be lower IPS² performance than expected and higher cost than budget [5], [6]. The prerequisite for detecting these two risks is the monitoring of IPS². Although IPS² has been exhaustively researched by international academics, the topic of IPS² monitoring for decision-makers has not yet been sufficiently focused (cf. chapter 2).

This paper introduces an indicator framework for decision-makers of IPS² suppliers to monitor IPS² in the use-oriented business model in the use phase. That way,

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 311–322.
DOI: 10.1007/978-3-642-30820-8_27

related indicators are defined primarily for IPS² performance, IPS² lifecycle cost and related major influencing factors. Later, they are bunched together into a systematic indicator framework. A method for monitoring IPS² and for early warning IPS² risks will be introduced towards the end of the paper.

2 Related Work

Present research can be classified into the measurement and monitoring of IPS² in the development and the use phase.

An important IPS² decision is the configuration of IPS² and the selection of the best IPS² variant in the IPS² early development phase. [7] introduces an approach to simulate IPS² performance. [8] and [9] both adopt lifecycle costing (LCC) methods to predict the overall IPS² cost for the selection of an economical IPS² variant. Moreover, an indicator system is introduced in [10] to configure IPS² with an adjustable goal. These approaches can support decision-makers to select the potentially best IPS² variant. As the actual IPS² environment in the use phase is quite different from its prediction in the early development phase, it is inevitable to improve the developed IPS² during the use phase based on a continuous monitoring of IPS². Related methods for monitoring IPS² have not been introduced in these works.

Some works introduce methods to measure and evaluate IPS² in its use phase. [11] introduces an evaluation scheme for IPS² with a focus on sustainability and customer value. In [12] an indicator system is developed based on balanced scorecard (BSC) to monitor IPS². [13] describes an approach to evaluate customer satisfaction for IPS² design. Due to various customer requirements on IPS², IPS² can be offered in different business models. Different criteria are required to measure IPS² in different business models (function-oriented, use-oriented and result-oriented) [1]. The approaches introduced in these works disregard different IPS² business models, so that they can only measure IPS² very abstractly and cannot be used to measure and monitor IPS² in the use-oriented business model in detail.

3 Requirements

3.1 Requirements for an Indicator Framework

In order to measure and to monitor IPS² in the use-oriented business model in the use phase, an indicator framework should be developed as a foundation. Three major aspects have been identified for the indicator framework.

IPS² Performance: In the use-oriented business model, IPS² is a customer-specific problem solution with the guarantee of high performance. Thus, IPS² performance must be considered within the indicator framework.

IPS² Lifecycle Cost: From the supplier's perspective, the development and marketing of IPS² is associated with the improvement of its competitive abilities and with upgrading its value-added chain in the end [15]. Low cost in the whole IPS² lifecycle should be a concrete and measurable goal of IPS² suppliers. Hence, IPS² lifecycle cost should be monitored by decision-makers and considered within the indicator framework. Due to the complexity of the IPS² lifecycle cost [10], a simplified model should be developed to compute IPS² lifecycle cost.

Influencing Factors: To jointly analyze and predict IPS² performance and lifecycle cost, their influencing factors cannot be ignored. Due to the complexity and the wide distribution of the influencing factors with different importance levels, only most important ones should be considered by the development of this indicator framework.

3.2 Requirements for a Monitoring of IPS²

Upon its development, the indicator framework must be used to monitor IPS². In addition to an appropriate visualization of indicators, the early warning against risks is also required. Only if risks are identified in time, decision-makers can make decisions to improve IPS² against the risks. Instead of simple comparisons between limits and actual values of indicators, the different features and development tendencies of indicators should be considered in the development of this method.

4 Concept Model of the Indicator Framework

Based on the requirements of the decision-makers, a concept model has been developed for the indicator framework (cf. Fig. 1). It specifies the structure of the indicator framework and the relationship between indicators.

The IPS² goal system of IPS² suppliers from the decision makers' perspective has a hierarchical structure with three levels. The strategic IPS² goal can be defined as successful IPS² on the top level. This main goal can be realized by two concrete goals on the second level: high IPS² performance and acceptable profit.

High performance in the IPS² use phase raises customer satisfaction and further enhances the competitiveness of IPS² suppliers. While availability and flexibility are the two essential significances for the IPS² [14], high performance can be achieved with two sub aspects, availability and flexibility, on the third level.

Acceptable profit can ensure the economic sustainability of IPS² suppliers. As the price of IPS² is fixed in the IPS² contract signed in the IPS² development phase, low lifecycle cost ensure an acceptable profit. Thus, the goal of an acceptable profit can be achieved with a sub aspect, lifecycle cost, on the third level.

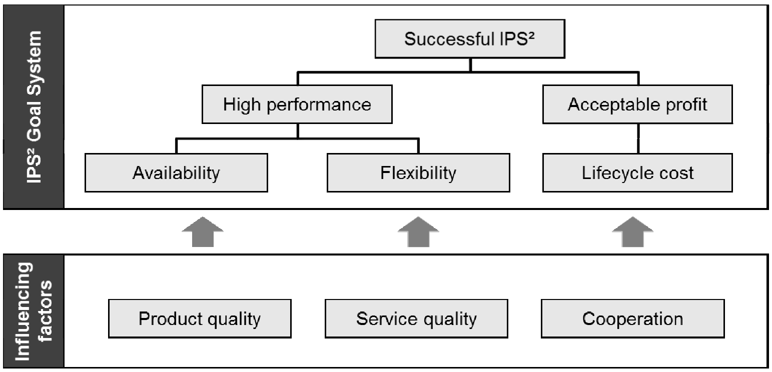


Fig. 1. Concept model of the indicator framework

In addition to the main measured IPS² goals, some metrics for the most important quality influencing factors must be developed. As IPS² is a combination of products and services in the use phase, product and service quality are two essential influencing factors. In the whole IPS² lifecycle, customers and suppliers must work together. The cooperation between IPS² customers and suppliers can largely influence the operation and use of IPS² [4], [16]. Thus, the cooperation quality is the third important influencing factor. With the aim of facilitating the analysis and prediction of IPS² performance and lifecycle cost, these three influencing factors have been specified as follows:

- Product quality: the quality of key industrial products, e.g. micromachining tools.
- Service quality: the quality of services associated with key industrial products, e.g. operational training, repair, maintenance.
- Cooperation quality: the quality of cooperation and communication between customers and suppliers.

Based on this concept model, detailed indicators should be defined for IPS². The categories of indicators are availability, flexibility and lifecycle cost, as well as produce quality, service quality and cooperation quality.

5 Detailed Indicator Framework for Monitoring IPS²

In order to define indicators for the indicator framework, relevant references (standards, books, papers, and dissertations) have been reviewed. Regarding the requirements for IPS² monitoring, suitable indicators have been identified and adjusted by using brainstorm or Delphi method. Generally, all indicators have been defined in accordance with the S.M.A.R.T. principle [17]. According to this principle, all indicators must be specific, measurable, attainable, realistic, and timely.

Figure 2 shows the structure of the developed indicator framework. All indicators including their definitions and calculation methods will be described in this chapter.

5.1 Availability Indicators

In the use phase, IPS² availability equals to the availability of its key industrial product from the customer's perspective. Indicators about equipment availability could be adopted. With regard to the different criteria of equipment availability, three sub-indicators are defined for the overall indicator *IPS² availability*.

Technical availability: It describes the largest possibility for an IPS² customer to use IPS² [18]. It is calculated as the ratio of available production time (key industrial product without technical failure) to planned production time within a certain time period.

OEE (Overall Equipment Effectiveness): An essential expectation for IPS² is high productivity. OEE is used to measure the loss of IPS² productivity [19]. OEE has three sub indicators: *availability rate*, *performance rate*, and *quality rate (of the IPS² output)*. Its calculation process is introduced by [19].

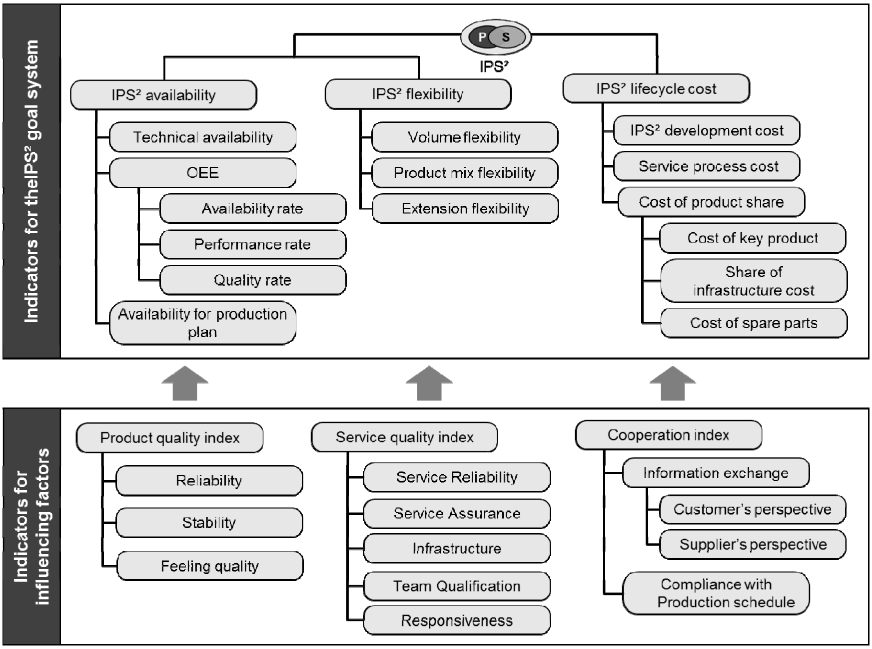


Fig. 2. Structure of the indicator framework

Availability for production plan: It measures whether IPS² availability is consistent with the customers' production plans. It is calculated as the ratio of the production tasks, which are started as planned, to all production tasks within a given time period. Here, only IPS²-related reasons should be considered, e.g. equipment in maintenance and long tooling time.

5.2 Flexibility Indicators

Flexibility is an important characteristic of any production systems. As a production unit in the customer's production system, IPS² should have high flexibility to meet the high dynamic changes of customer production. As the IPS² suppliers' responsibility of services has a big impact on flexibility [20], IPS² flexibility must be measured and continuously monitored in the IPS² use phase.

The flexibility of a production system is classified as short-term (process, routing, product, and volume flexibility) and long-term flexibility (expansion flexibility) [21]. As process and routing flexibility describe the ability to adjust the process among production units to manufacture different products [21], they do not match the character of IPS². The other three flexibilities are suitable for measuring IPS² flexibility.

Volume flexibility and *product flexibility*: They are used to measure if and to what degree IPS² can fulfill the dynamic customer production requirements in a short term. The reference to quantify these two indicators can be found in [22].

Expansion flexibility: It has been introduced to measure the long-term flexibility. During the whole use phase, IPS² should be as flexible as to adapt to meet new customer requirements [23]. This indicator should be qualitatively measured based on several criteria, such as reaction speed, degree of fulfillment, and customer satisfaction.

5.3 Lifecycle Cost Indicators

IPS² lifecycle cost is the cumulated costs of IPS² throughout its whole lifecycle. Due to the complexity of the IPS² lifecycle, it is almost impossible to calculate IPS² lifecycle cost [10]. Thus, a simplified model (cf. Fig. 3) has been designed to approximate IPS² lifecycle cost regarding major cost factors for the IPS² lifecycle.

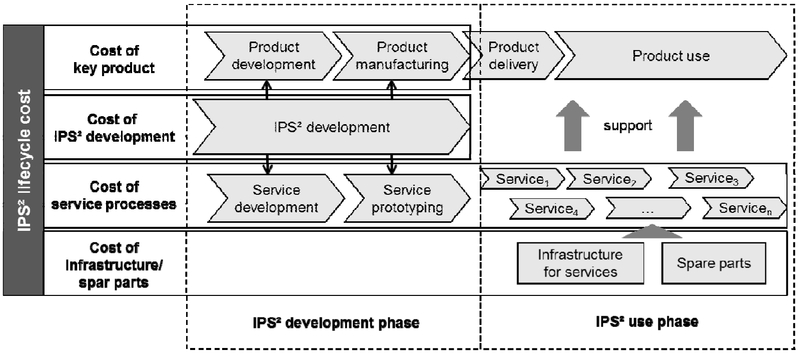


Fig. 3. Simplified model of IPS² lifecycle

The major activities in the IPS² development phase are the overall IPS² development, the related product development, and manufacturing, as well as related service development and prototyping.

In the IPS² use phase, different services are operated to support the delivery and the use of the key industrial product of IPS², i.e. training, maintenance and repair. In order to simply the structure of IPS² lifecycle, IPS² improvement processes in the use phase are viewed as service processes. Certain infrastructures should be invested for some services, e.g. expensive inspection equipment. Spare parts are also needed by some services, such as repair.

Based on the simplified IPS² lifecycle, IPS² lifecycle cost can be divided into four cost components:

- Cost of IPS² development: It includes all costs from first customer contact to the end of the overall IPS² development.
- Cost of key product: The cost of the development and manufacturing of key industrial product of IPS², as well as the related material cost.

- Cost of service processes: It is the cost of all service processes operated by suppliers, including IPS² improvement processes. Without the consideration of their infrastructure and spare parts, the cost of these service processes can be simplified as the cost of staff and travel. If the cost of service development and prototyping should not be ignored, a share of the whole cost should be added to this cost.
- Cost of infrastructure and spare parts: The cost of infrastructure is the share of the cost of the service-related infrastructure for an IPS². The cost of spare parts includes the cost of any part used to replace damaged parts or to improve IPS² performance.

Based on this model, three indicators for computing *IPS² lifecycle cost* have been selected: *IPS² development cost*, *service process cost*, and *cost of product share*, which can be divided into three sub indicators: *cost of key product*, *share of infrastructure cost* and *cost of spare parts*.

5.4 Product Quality Indicators

Generally, indicators should be defined to measure the quality of the key industrial product of IPS². Function-related quality parameters (e.g. work range, processing speed, etc.) are prerequisites to IPS². They must be ignored in the indicator framework. The quality parameters that influence IPS² performance and cost should be considered. Hence, three indicators have been defined as the *product quality index*:

Reliability: It is the most important quality attribute of the product, which influences the availability of IPS² directly. Three sub indicators have been defined to describe machine reliability: *TFF (Time to First Failure)*, *MTBF (Mean Time between failures)*, and *failure rate* [24].

Stability: With a highly stable product, IPS² can reach high productivity and generate more qualified output. The indicator can be calculated using the statistical process controlling (SPC) method.

Feeling quality: It is a qualitative indicator to describe the user's feeling about the product. A user-friendly operation can lead to an easy and safe use of IPS². Several criteria can be used to sum up this indicator, e.g. product appearance, ergonomic and comfort designing, and safe devices [25].

5.5 Service Quality Indicators

In the use phase, different services should be offered by IPS² suppliers to improve the use of key produce and further to improve IPS² performance. High service quality is crucial to achieve the expected high IPS² performance. The SERVQUAL method and its five criteria are suitable for the measurement of the service quality of IPS² [26]. Instead of original full qualitative measurement, quantitative methods should be adopted. These five indicators are:

- *Service Reliability*: It measures the relationship of the planned and the actual time of a service process [27].
- *Service Assurance*: It is a qualitative indicator used to compare the expected and the actual result of a service process.
- *Infrastructure*: It is defined as to evaluate the invested service infrastructure to improve service quality.
- *Team Qualification*: It is used to evaluate the qualification of the service teams of IPS² suppliers.
- *Responsiveness*: It measures the reaction time from the appearance of a service requirement to the start of the service process.

The indicator *service quality index* can be estimated based on the above five sub-indicators. The overall service quality over a given time period is the weighted average quality of all services operated in that time.

5.6 Cooperation Quality Indicators

A successful IPS² requires a closed cooperation between suppliers and customers. To quantify the cooperation, two indicators have been defined:

Degree of information exchange: Cooperation among companies is exchange of information. This indicator can be measured from the customer's and supplier's perspective [28].

Compliance with production schedule: Due to competition on the market, IPS² customers face challenges to meet an accelerated production schedule. In this case, IPS² suppliers should work together with IPS² customers to raise IPS² productivity. The cooperation in this situation should be measured. This indicator describes the ratio of tasks finished as planned to all production tasks in a given time period.

6 A Method for Monitoring IPS²

For IPS² monitoring, a dashboard should be developed to visualize indicators with suitable forms, e.g. tables, trend charts, distribution curves, or visualized traffic lights. Going beyond the mere visualization of indicators, risks should be warned as early as possible during the IPS² monitoring.

Generally, risks are considered the appearance of unexpected actual values of indicators in the monitoring process. In order to compare actual and expected values of indicators, indicator corridors are used to set expected values visually. A corridor consists of the target value, the lower specification limit (LSL), and/or the upper specification limit (USL). Figure 4 shows different types of corridors. Once the actual value crosses the LSL or USL, automated risk warning should ensue. Figure 5 shows an example dashboard for the IPS² monitoring by a pilot IPS² supplier. Indicators are structurally visualized in the framework of a virtual balance. A traffic light is illustrated to alarm identified risks.

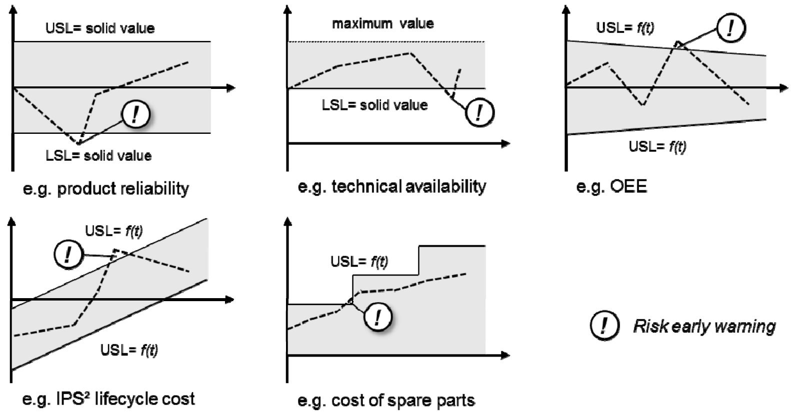


Fig. 4. Types of indicator corridors (adapted from [29])

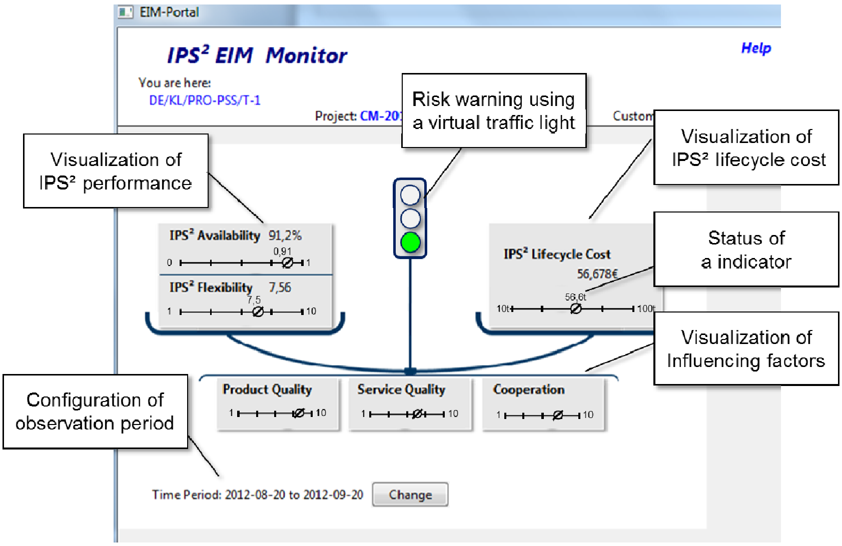


Fig. 5. An example dashboard for the IPS² monitoring

7 Conclusion and Outlook

This paper has introduced an indicator framework for decision-makers of IPS² suppliers to monitor IPS² in the use-oriented business model in the use phase. In order to warn the risks for IPS² performance and cost during the IPS² monitoring, three major aspects, i.e. IPS² performance, IPS² lifecycle cost and influencing factors (product quality, service quality, and cooperation quality) have been considered in the indicator framework. Based on the developed indicator framework, a monitoring method using indicator corridors has been introduced. With the help of early warning of risks during the IPS² monitoring, decision-makers can analyze risks and make decisions for IPS² improvement.

In the next months, an evaluation of the developed indicator framework will be done at a manufacturer of agricultural machines in Germany. This company has begun to offer their machines and related services in the use-oriented IPS² business model. By applying this indicator framework, the company could monitor their offerings and compare the results with his IPS²-related strategies. All objective and subjective feedback on this indicator framework will be collected from its users during the entire evaluation period. By using of experience and empirical analysis, this indicator framework will be evaluated upon the collected feedback. The structure and indicators of this indicator framework could be improved with the focus on the evaluation results.

Setting up the indicator corridors proposed in the paper could be very difficult and time-consuming. Thus, risk warning should be made without indicator corridors, when corridors cannot be easily defined. A more intelligent risk warning method could be developed in the further, i.e. by using SPC (Statistical process controlling) or DEA (Data envelopment analysis).

In order to allow an easy use of the developed approach to the IPS² monitoring, a web-based application, even an app for smart phones or tablets could be developed in the future, so that decision-makers can monitor IPS² any place at any time.

Acknowledgements. We express our sincere thanks to the German Research Foundation (DFG) for financing this research within the Collaborative Research Project SFB/TR29 on Industrial Product-Service Systems – dynamic interdependency of products and services in the production area.

References

1. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems – IPS2. CIRP Annals – Manufacturing Technology 59(2), 407–627 (2010)
2. Lanza, G., Behmann, B., Werner, P., Vöhringer, S.: Simulation of Life Cycle Costs of a Product Service System. In: Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, Braunschweig, Germany, pp. 159–164 (2011)
3. Abramovici, M., Bellalouna, F., Göbel, J.C.: Adaptive Change Management for Industrial Produkt-Service Systems. In: Proceedings of the TMCE 2010, Ancona, Italy (2010)
4. Oliva, R., Kallenberg, R.: Managing the transition from products to services. International Journal of Service Industry Management 14(2), 160–172 (2003)
5. gen. Schulte, J.K., Steven, M.: Risk Management of Industrial Product-Service Systems (IPS2) – How to Consider Risk and Uncertainty over the IPS2 Lifecycle? In: Proceedings of the 19th CIRP Conference on Life Cycle Engineering, Berkeley, USA, pp. 37–42 (2012)
6. Ng, I., Yip, N.: Identifying Risk and its Impact on Contracting through a Benefit Based-Model Framework in Business contracting: Case of the defense industry. In: Proceedings of the 1st CIRP Industrial Product-Service Systems (IPS2) Conference, Cranfield, UK, pp. 207–216 (2009)

7. Komoto, H.: Computer aided product service systems design: Service CAD and its integration with life cycle simulation, dissertation, Delft (2009)
8. Mannweiler, C., Siener, M., Aurich, J.: Lifecycle Cost oriented Evaluation and Selection of Product-Service System Variants. In: Proceedings of the 2nd CIRP IPS2 Conference, Linköping, pp. 21–28 (2010)
9. Panarotto, M., Larsson, T.C.: Towards Value Driven Simulation of Product-Service Systems: A Conceptual Scenario. In: Proceeding of International Design Conference-Design 2012, Dubrovnik-Croatia, pp. 279–288 (2012)
10. Aurich, J.C., Schweitzer, E., Mannweiler, C., Wolf, N.: Kennzahlen als Hilfe zur Konfiguration und Bewertung von Produkt-Service Systemen: Ein Ansatz zur Bewertung der Leistungsfähigkeit investiver PSS. Industrie Management 24(5), 57–60 (2008)
11. Kim, K.-J., Lee, D.-H., Lim, C.-H., Heo, J.-Y., Hong, Y.-S., Park, K.-T.: Development of an Evaluation Scheme for Product-Service Systems. In: Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, Braunschweig, Germany, pp. 255–260 (2011)
12. Abramovici, M., Jin, F.: A New Method for Monitoring Industrial Product-service Systems based on BSC and AHP. In: Proceedings of ICEIS, Beijing, pp. 190–196 (2011)
13. Kimita, K., Shimomura, Y., Arai, T.: Evaluation of customer satisfaction for PSS design. Journal of Manufacturing Technology Management 20(5), 654–673 (2009)
14. Richter, A., Sadek, T., Steven, M., Welp, E.: Use-oriented Business Models and Flexbility in Industrial Product-Service Systems. In: Proceedings of the 1st CIRP Industrial product-Service Systems (IPS2) Conference, Cranfield, UK, pp. 186–193 (2009)
15. Meier, H., Uhlmann, E. (eds.): Integrierte Industrielle Sach Und Dienstleistungen: Vermarktung, Entwicklung Und Erbringung Hybrider Leistungsbundel. Springer, Berlin (2012)
16. Brax, S.: A manufacturer becoming service provider – challenges and a paradox. Managing Service Quality 15(2), 142–155 (2005)
17. Doran, G.T.: There's a S.M.A.R.T. way to write management's goals and objectives. Management Review 70(11), 35–36 (1981)
18. VDI3423: Verfügbarkeit von Maschinen und Anlagen. Beuth Verlag, Berlin (2002)
19. Koch, A.: OEE für das Produktionsteam: Das vollständige OEE-Benutzerhandbuch oder wie Sie die verborgene Maschine entdecken. CETPM Publ., Ansbach (2011)
20. Nili, M., Shekarchizadeh, A., Reza, S.: Outsourcing of Mantenance Activities In oil industry of Iran: Benefits, Risks and Success Factors. Business and Management Review 25(2), 20–36 (2012)
21. Sethi, A.K., Sethi, S.P.: Flexibility in Manufacturing: A Survey. The International Journal of Flexible Manufacturing Systems 2, 289–328 (1990)
22. Rogalski, S.: Entwicklung einer Methodik zur Flexibilitätsbewertung von Produktionssystemen. Univ.-Verl. Karlsruhe, Karlsruhe (2009)
23. Richter, A.: Planung, Steuerung und Kooradination industrieller Produkt-Service-Systeme, dissertation, Bochum (2010)
24. O'Connor, P.D.T.: Practical Reliability Engineering. John Wiley and Sons Ltd., Chicester (2012)
25. Lai, H.-H., Chang, Y.-M., Chang, H.-C.: A robust design approach for enhancing the feeling quality of a product: a car profile case study. International Journal of Industrial Ergonomics 35(5), 445–460 (2005)
26. Udo, G.J., Bagchi, K.K., Kirs, P.J.: Using SERVQUAL to assess the quality of e-learning experience. Computers in Human Behavior 27(3), 1272–1283 (2011)

27. Li, J.P., Alonso, R.M.T., Thompson, G.: Simulation Based Reliability Assessment of Services in the Context of Functional Products. Journal of the Safety and Reliability Society 29(4), 47–78 (2009)
28. DIN1087: Integriertes Prozess- und kennzahlenbasiertes Referenzmodell für Logistikanbieter. Beuth Verlag, Berlin (2008)
29. Sieg, O.C.: Ein Beitrag zur integrativen Unterstützung des Produktentwicklungscontrollings. Shaker, Aachen (2007)

Dynamic Influences on Workforce Capacity Planning for IPS² Delivery

Horst Meier, Henning Lagemann, and Mario Boßlau

Ruhr-Universität Bochum, Institute for Product and Service Engineering,
Chair of Productions Systems, Universitätsstr. 150, 44801 Bochum, Germany
{lagemann,bosslau}@lps.rub.de

Abstract. Industrial Product-Service Systems (IPS²) are socio-technical systems which provide the customer with a certain function, a promised availability or a contracted result rather than a mere physical product. Thus, IPS² represent solutions which can be dynamically adapted over the lifecycle in order to meet changing customer requirements and supplier capabilities. On the one hand, this poses challenges to the planning and management of resources during IPS² delivery. On the other hand, flexibility potentials can be used to absorb demand peaks and the IPS² supplier has more information about customer processes as well as the condition of the IPS² and thus a more profound basis for capacity planning. Against this background, the objective of this paper is to systematically examine the dynamic influences on capacity requirements of service technician workforce for IPS² delivery by means of the System Dynamics (SD) approach as a foundation for further research.

Keywords: workforce capacity, IPS² delivery, System Dynamics.

1 Introduction

Industrial Product-Service Systems (IPS²) are integrated value offerings in industrial applications, which consist of interdependent product and service shares [1]. Various types of business models can be realized through IPS², e.g. with function-, availability-, or result-oriented value propositions [2]. Due to the lifecycle-oriented perspective on value creation through IPS², the provider's responsibility does not end with the installation of the physical product at the customer's production site. After planning, development and implementation, the delivery of physical and service shares is a key success factor as well as a significant expense factor for the provider of the IPS². Since the IPS² provider is integrated into the customer's value chain throughout the delivery phase of the IPS², he bears responsibility for the performance of the IPS². Depending on the contracted business model, the provider's ability to maintain a certain function, availability or result does not merely determine customer satisfaction, but may also have a direct impact on the cash flow resulting from revenue streams and the cost structure.

Due to the uno-actu principle, service shares of IPS² cannot be inventoried. Since production and consumption of services cannot easily be decoupled, stochastic

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 323–334.
DOI: 10.1007/978-3-642-30820-8_28

volatility in demand directly leads to volatile workload for IPS² delivery [3, 4]. Thus, in order to be able to flexibly meet unplanned and unscheduled demand, necessary resources for IPS² delivery need to be kept available [5]. The underlying optimization problem is based on the well-known trade-off between flexibility and resource utilization, which can be modeled by balancing fix costs of idle capacity on the one hand and variable costs of compensation payments or losses of customer satisfaction on the other hand [6].

Recently, several publications have addressed the challenge of capacity planning for service delivery (e.g. [7], [8]) as well as IPS² delivery (e.g. [9, 10]). However, most publications do not take into account the dynamic interdependencies between the various factors influencing resource capacity and supply for IPS² or service delivery. On the one hand, the triggering events for IPS² delivery occur stochastically and can only be predicted to some extent. On the other hand, unlike processing times in manufacturing, process times for IPS² delivery are not deterministic and can vary significantly depending on various internal and external factors [11]. An important internal factor are experience gains and learning effects of the service workforce, which are expected to positively influence both quality and process times during IPS² delivery [7, 12]. Hence, the objective of this investigation is to model the dynamic influences on strategic resource planning with a focus on service workforce capacity planning.

2 Conceptual Background of Workforce Capacity Planning

2.1 Strategic Resource Capacity Planning for IPS² Delivery

A variety of internal (disposed by provider network) and external resources (disposed by customer) are required for the delivery of service shares of IPS². From the perspective of service engineering research, resources represent the necessary potential (potential dimension) to deliver a service (process dimension) in order to achieve a certain result (result dimension). The planning of resources can be considered as an ongoing process on various planning levels. Often, three planning levels are distinguished: strategic, tactical and operational. These planning levels are interconnected by information and feedback loops. In strategic resource planning, the required capacity for IPS² delivery is estimated based on demand forecasts for a long-term planning horizon, whereas the allocation of resources to specific tasks is planned in the following phases of tactical and operational planning [13–15].

The capacity of a resource is defined as the task-specific performance capability within a given period of time (cp. [16]). This understanding is in accordance with the capacity of production systems [17] and has two distinct dimensions to it:

- Quantitative capacity, representing the number of units of a resource and their temporal and spatial availability
- Qualitative capacity, representing the volume of output of a resource under normal operating conditions [16, 18]

Hence it can be noted that the effective capacity of a resource is context-related, depending on the specific task. Different units of the same type of resource, providing the same function or result, often perform heterogeneously regarding process time and quality for the same task.

The strategic planning of resource capacity for IPS² delivery must therefore be based on the described definition of resource capacity, which claims validity for manufacturing operations, IPS² and service delivery. As indicated above, the planning of resources for IPS² delivery involves some challenges which prevent the utilization of established methods for production planning and scheduling. External resources, which cannot be disposed independently by the IPS² provider, need to be integrated into the delivery process. They strongly influence the quantitative and qualitative internal resource capacity required for IPS² delivery [8]. In comparison with production planning and scheduling, demand forecasting is more difficult and unsecure [14], and the delivery times proof to be rather unstable. Recently developed methodologies offer possibilities for reducing uncertainties by utilizing IPS²-specific optimization potentials and business models [1].

2.2 Workforce Planning for IPS² Delivery

In order to reduce the complexity of strategic resource planning problems, not all resources should be considered equally thoroughly. It is beneficial to focus on those resources which are most critical for IPS² or service delivery. For this purpose, [9] presents a model for defining the required strategic planning intensity of resources for IPS² delivery and [10] introduces a procedure for identifying critical resources on an operational level based on actual capacity utilization and process criticality. Another possibility to reduce the complexity of the resource planning problem is to aggregate different capacity units to work centers or capacity groups, which can be considered an entirety for strategic planning purposes [16]. The capacity demand for a work center can be derived by calculating the required capacity of a representative resource within the work center.

For IPS² delivery, it is reasonable to consider the service personnel as reference resource within each work center since the main focus is usually on the planning of the service workforce [7, 14]. Besides logistic costs for optimal stock keeping of spare parts and tool management, the workforce of highly qualified field service technicians is the greatest cost factor and most important resource to be considered in the strategic capacity planning for IPS² delivery – especially in high-wage countries [13]. Other resources required for IPS² delivery are either directly related to the number of service technicians and thus part of the work center (e.g. standard tools, service vehicle fleet), or need to be planned separately on a case-by-case basis (e.g. special tools, spare parts and other materials). Because of the key role of the service workforce in IPS² delivery planning, this paper will focus on the particular challenges in workforce capacity planning.

2.3 System Dynamics in Strategic Planning

System Dynamics (SD) is a method to enhance learning and understanding of complex socio-technical systems, especially in a complex business environment [19]. It is thus a suitable tool for analyzing IPS² and the associated dynamic influences on workforce management. In addition, it is applicable for the simulation of strategic problems at high levels of abstraction and provides a way of viewing human systems by stressing the importance of certain structural features, such as feedback control [20]. By means of qualitative SD modeling, it is possible to get useful insights into the operation of workforce systems. Nevertheless, it is often necessary to provide a computer-based simulation model to understand why the modeled system behaves in a certain way. Hence, the SD approach is based on simple graphical notations to model systems: causal loop diagrams for qualitative analysis (see section 3.1) and stock and flow diagrams for quantitative models and simulation (see section 3.2). Especially simulations can support the management to find better ways in operating the system by demonstrating their consequences [20]. A comprehensive introduction to SD is given by Sterman who demonstrates how this method is applied especially to business issues [19]. The dynamics of competitive strategy are explored by Warren [21], the dynamics of strategy and business dynamics in general are explored by Morecroft [22] and Warren [23].

3 Influences on Required Workforce Capacity in Strategic Planning

There are two perspectives to strategic resource capacity planning for IPS² delivery. First, is to identify the required demand for IPS² delivery processes. Second, is to calculate the required capacity for meeting this demand [14]. In order to be able to generate a quantitative resource planning approach, various influencing factors and drivers as well as their dynamic interdependencies need to be analyzed. For this purpose, a qualitative model of the influences on required workforce capacity will be presented in the following. The presented model mainly focuses on IPS² delivery in the machine tool industry, but it can also be easily adapted for other industrial settings of service and IPS² delivery.

3.1 Qualitative Model

The required resource capacity for IPS² delivery, in the following referred to as capacity demand, cannot be determined with certainty. The further the planning horizon, the greater the uncertainty of demand forecasts will be. In strategic workforce planning situations, capacity demand will often have to be estimated for at least one year in advance. This is the approximately equivalent time which is needed to strategically adjust workforce capacity by hiring and qualifying service technicians for future IPS² delivery tasks in technology-intensive industries [13]. As a consequence, the modeling and planning approach for strategic resource planning often relies on aggregated data since it is not possible to schedule single processes such as installations or corrective maintenance (repair) [14]. Usually, only predetermined maintenance processes based on established or contracted time intervals can be planned with sufficient certainty, but these processes may also be subject to rescheduling in the medium- or short-term planning. Thus, aggregation of demand and aggregation of substitutive (horizontal aggregation) or complementary (vertical aggregation) capacity units to work centers or capacity groups are common strategies to reduce complexity with acceptable forfeiture of planning accuracy [8, 14].

If aggregated data is used for strategic capacity management, a quantitative model for capacity planning must include the most important influences on capacity demand and supply. Capacity demand for IPS² delivery is dependent on the frequency of occurrence and the process times of all delivery processes. In the machine tool industry, the number of installed machines at customer sites, henceforth referred to as the installed basis (IB), is expected to be an adequate indicator for the anticipated capacity demand, provided that the IB is sufficiently homogenous. Usually, different types of machines should be distinguished. This categorization should be based on a qualitative and quantitative assessment of service shares to be delivered for each type of machine. The qualitative dimension refers to the types of service processes and the internal resources which are needed for the delivery; the quantitative dimension refers to the frequency and duration of the delivery processes.

Especially, the maintenance effort is known to be strongly dependent on the condition of the physical components of the IPS². A typical failure rate function of technical systems is displayed schematically in Figure 1, showing the technical failure rate over the lifecycle of a technical system, e.g. a tool machine. During the *early failure period* (A), material defects or inaccuracies and mistakes during production or installation become effective. The longest period, the *constant failure period* (B), is characterized by a relatively low failure rate with random defects. Finally, the failure rate increases again during the *wear-out failure period* (C) which ends with the closure of the technical system [24, 25].

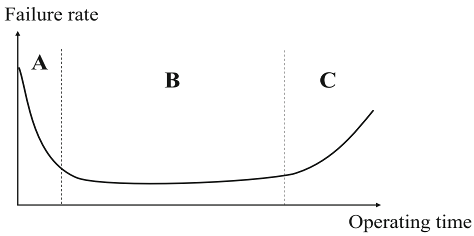


Fig. 1. Schematic failure rate function [24]

Furthermore, the quality of delivery processes has an impact on capacity demand. The mean operating time between failures (MTBF) is influenced by the quality of various delivery processes such as maintenance, repair, operator training and process optimization. Likewise, operation parameters need to be considered since they may have a significant influence on capacity demand. Information for a profound assessment of the condition of the IPS² can be obtained through integrated sensors and condition monitoring software agents [26] and from the IPS²-specific strong integration of provider and customer processes (depending on the business model).

Capacity supply refers to the quantitative and qualitative capacity available for IPS² delivery within a particular time period [16]. The quantitative capacity of service technicians is calculated by subtracting training time, in-house days and other necessary or planned “unproductive” times from the net working time and by cumulating this gross operating time over all service technicians. Travel times also need to be considered and are to be subtracted from the gross operating time. The net operating time represents the quantitative capacity of a service technician within a given period of time (cp. Figure 2).

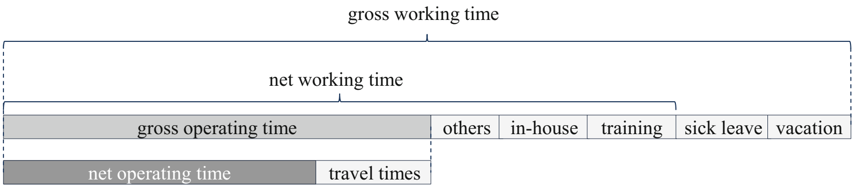


Fig. 2. Working time and operating time of service technicians

The qualitative capacity of the workforce is characterized by the service technicians’ productivity, which can be measured by evaluating the time needed (input) for a certain standard delivery process (output). Training (learning before doing) and experience (learning by doing) of the workforce will enable productivity gains with positive effects on process times [7, 27]. Furthermore, learning effects are also expected to increase process quality, which will have a positive effect on the condition of the IB and thus reduce future demand for maintenance activities [28].

To visualize and understand the feedback structure of the strategic workforce planning problem, a qualitative model of various factors on capacity supply and demand for IPS² delivery is given in Figure 3. This causal loop diagram is intended to be of use in understanding the broad structure of the dynamic workforce system. Each link in the diagram is represented by an arrow that carries a sign at its head to indicate the direction of causality of the link [20]. These links are assigned a polarity, either positive or negative, to indicate how the dependent variable changes when the independent variable changes [19]. Within this causal loop diagram there are feedback loops, which can either have a reinforcing (even number of negative polarities) or balancing (uneven number of negative polarities) character. In total, nine different feedback loops can be identified in the causal loop diagram. The explanation of some examples of these loops will help to understand the interdependencies.

When the *number of technicians* is increased by hiring personnel, the capacity supply increases and thus the *hiring of technicians* ceases (B1). Equally, an increase in the *number of technicians* allows for a higher *specialization of technicians* on certain types of delivery processes. Due to greater specialization, which leads to increased learning effects (*technicians’ knowledge and experience*), technicians are expected to be able to complete deliveries faster (process times), thus increasing *capacity supply* through enhanced qualitative capacity (B2). By analogy, *hiring of technicians* has a negative effect on *technicians’ knowledge and experience* which causes an increase in *delivery process quality*. Considering this, the *condition of IB* increases as well, which results in a decreased *service demand* (R1).

Considering these examples, it becomes obvious that strategic workforce planning for IPS² delivery implies complex feedback structures which are important to consider for a more detailed quantitative analysis.

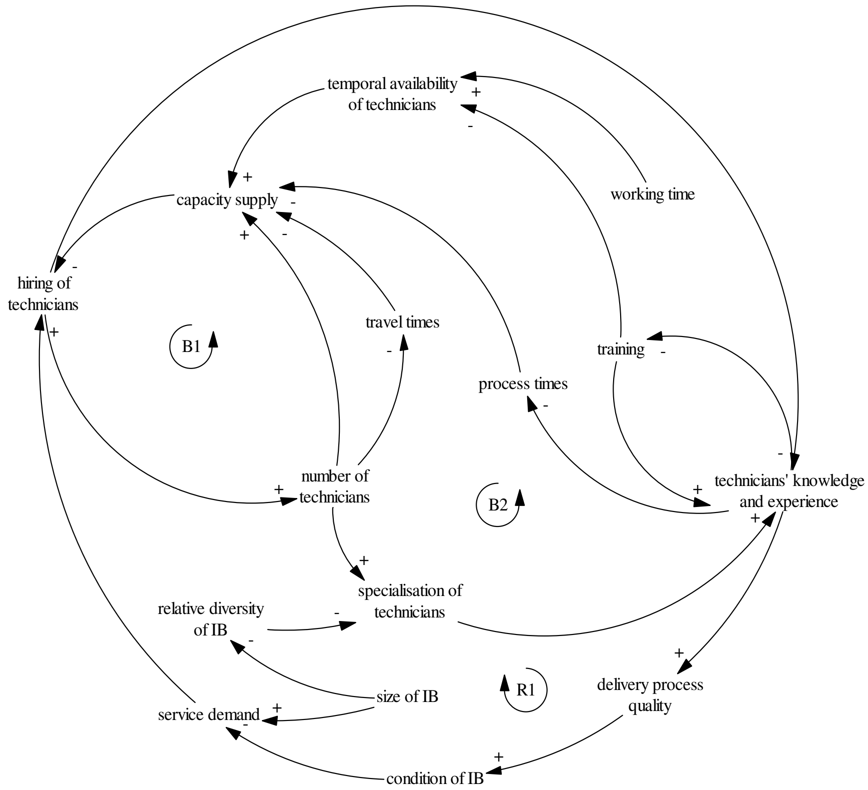


Fig. 3. Causal loop diagramm for strategic workforce planning

3.2 Quantitative Sub-model

SD supports the strategic management in understanding their complex and dynamic business. Just as an airline uses flight simulators to help pilots learn, SD is, to a certain extent, a method for developing computer-based management flight simulators, to help managers learn about the dynamic complexity of their business [19]. To be able to do this, a quantitative model has to be developed based on the qualitative feedback structure discussed in the previous section.

Causal loop diagrams are well suited to describe interdependencies and feedback processes. Nevertheless, they suffer from a number of limitations and can easily be abused. A major limitation of causal loop diagrams is their inability to capture the stock and flow structure of a system [19]. The main symbols of these stock and flow diagrams are shown in Figure 4. Stocks are accumulations and characterize the state of a system and generate the necessary information for decision support. They are represented by a rectangle. Inflows are represented by a pipe pointing into the stock. Outflows are represented by a pipe pointing out of the stock. Flow rates are represented by a valve on a double line and control the flows. Clouds represent the sources and sinks for the flows and thus the model boundary [19, 20].

In Figure 4, the main part of a SD model of the described strategic planning problem is illustrated. For the sake of clarity and rationality, this model includes all variables from Figure 3 except travel times, training, delivery process quality and condition of IB.

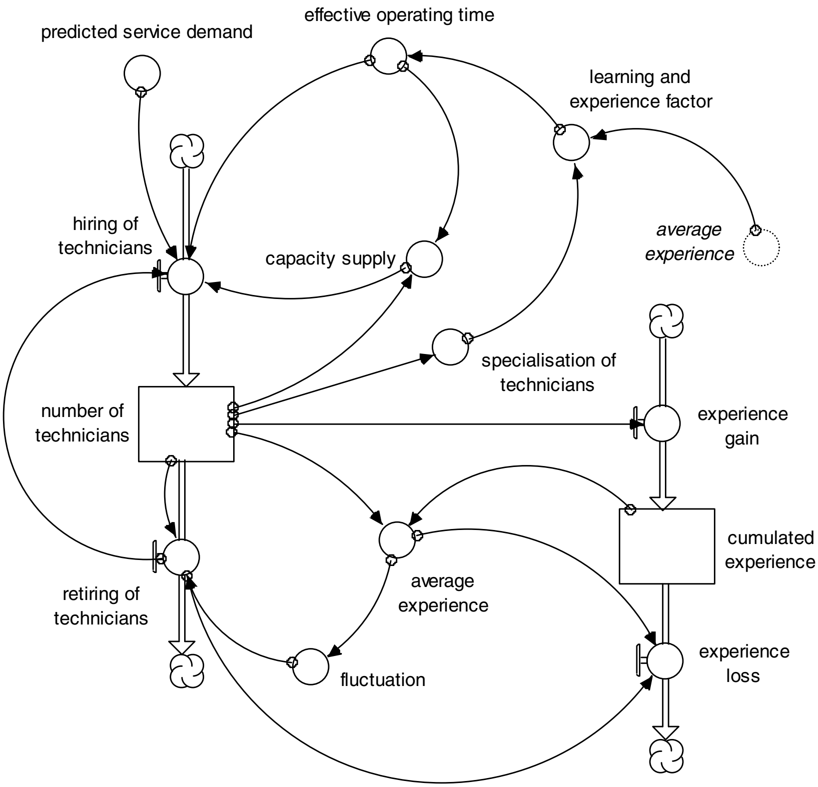


Fig. 4. SD sub-model

Within the scope of this paper, not all correlations and formulae of the quantitative sub-model can be explained in detail. Exemplarily, the calculation of the number of technicians which need to be hired to meet service demand is shown in Formula 1.

$$\text{hiring of techn.} = \frac{\text{predicted service demand} - \text{capacity supply}}{\text{effective operating time}} + \text{retiring of techn.} \tag{1}$$

The predicted service demand and the capacity supply are given as the total sum of working hours. The effective operating time corresponds to the quantitative and qualitative capacity of an average service technician, measured in working hours per technician.

Learning in Strategic Planning. Learning effects in industrial settings were first investigated by Wright for production processes in the airplane industry [29]. Since then, learning effects have been examined in various publications and different industrial settings (cp. [7]). In the quantitative model, learning effects will be included with the following equation:

$$y(n) = a \cdot n^{-b} \tag{2}$$

Here, y is called the learning and experience factor and denotes the worker efficiency after n repetitions of the same processes. a and b represent constants which can be adapted in order to scale the learning function. A learning and experience factor of 90 % means that on average, delivery processes can be executed in 90 % of the target time. The number of repetitions (n), which determines the learning and experience factor, is mainly influenced by two factors:

Experience of Technicians. In simplified terms, the experience of technicians is expressed by the duration of employment in years.

Specialization of Technicians. The potential for specialization of the service workforce is determined by the number of service technicians and by the variability of the processes which need to be delivered (cp. Section 3.1). When the number of process variants is low compared to the number of available service technicians, then a high level of specialization is possible. Thus, service technicians can become experts for certain repetitive processes in which they acquire high levels of skill. This effect is promoted in large service companies and in cases where service processes have a high level of standardization.

3.3 Scenario Analysis

Based on the SD model described in the previous section, a series of simulation runs is performed to visualize two different scenarios:

1. A workforce of 80 service technicians in an established marked with an IB of 2150 IPS². The growth rate for the next 5 years is around 3 %.
2. A service provider in an emerging market has 10 experienced service technicians to deliver services for 215 IPS² in operation. Growth rates decline from 18,2 % in the first year to 13,1 % in the fifth year.

Figure 5 illustrates these two different scenarios. In the established market with a moderate growth rate (scenario 1), significantly more IPS² can be supported per technician compared to the strongly growing market (scenario 2). The main reason for this effect is the high level of acquired skill through experience over time and a greater specialization rate in the larger, established market.

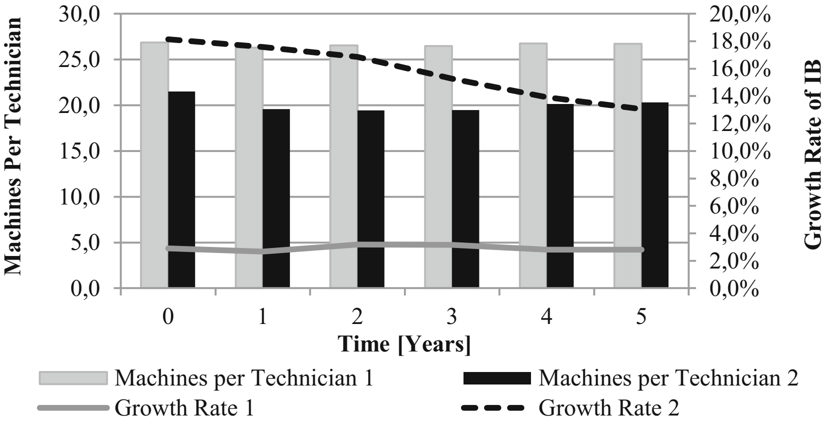


Fig. 5. Diagram machines per technician and growth rate

This statement is supported by Figure 6, in which the *learning and experience factors* for both scenarios are plotted, together with the average experience. It turns out that in both cases the average experience of the service workforce is eight years at the beginning (experienced technicians have been sent to support the service team in the emerging regional market in scenario 2).

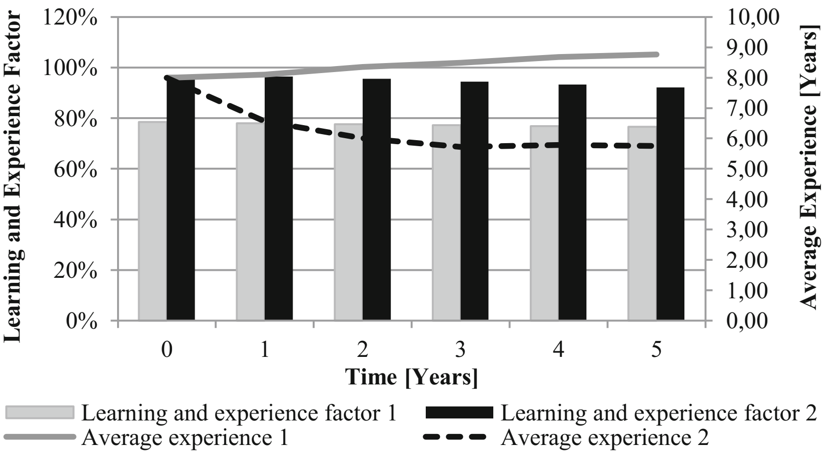


Fig. 6. Learning and experience diagram

However, due to the hiring of many inexperienced technicians, which is necessary to meet the rapidly increasing demand, the average experience drops from 8 years to 6 years in scenario 2. Besides higher levels of specialization, further economies of scale are to be expected in large service organizations and well-organized IPS² provider networks. For example travel times, which have not yet been considered in the quantitative SD model, will decrease when the IB and the service workforce grow (cp. Section 3.1).

4 Summary and Outlook

In this paper, some of the most import influence factors on workforce capacity planning for IPS² delivery have been identified. The dynamic interdependencies of these factors have been described qualitatively using a causal loop diagram. Based on the quantitative analysis, an initial stock flow diagram has been developed in a SD model. The objective of this quantitative SD model was to give a hint about the implications of the interdependencies in the form of a conceptual case study based on two different scenario settings. Further research will aim at refining the quantitative model and incorporating all aspects described in the qualitative causal loop diagram. Furthermore, aspects of organizational learning beyond the individual's experience-based learning curve as well as the customer's influence and learning effects will be analyzed. Finally, the model needs to be evaluated in a real industrial setting.

Acknowledgments. We express our sincere thanks to the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) for financing this study within the Collaborative Research Center Transregio 29 (CRC/TR 29) on Industrial Product-Service Systems – dynamic interdependencies between products and services in the production area.

References

1. Meier, H., Völker, O., Funke, B.: Industrial product-service systems (IPS2). Paradigm shift by mutually determined products and services. The International Journal of Advanced Manufacturing Technology 52(9), 1175–1191 (2011), doi:10.1007/s00170-010-2764-6
2. Meier, H., Boßlau, M.: Dynamic Business Models for Industrial Product-Service Systems. In: Proceedings of the 30th International Conference of the System Dynamics Society. 13th PhD Colloquium, Plenary Session, St. Gallen, Switzerland (2012)
3. Shemwell, D.J., Cronin, J.J.: Services Marketing Strategies for Coping with Demand/Supply Imbalances. Journal of Services Marketing 8(4), 14–24 (1994), doi:10.1108/08876049410070691
4. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems - IPS2. CIRP Annals - Manufacturing Technology 59(2), 607–627 (2010), doi:10.1016/j.cirp.2010.05.004
5. Olhager, J., Johansson, P.: Linking long-term capacity management for manufacturing and service operations. Journal of Engineering and Technology Management 29(1), 22–33 (2012), doi:10.1016/j.jengtecman.2011.09.003
6. Möller, K., Cassack, I.: Prozessorientierte Planung und Kalkulation (kern-) produktbegleitender Dienstleistungen. Zeitschrift für Planung und Unternehmenssteuerung 19(2), 159–184 (2008), doi:10.1007/s00187-008-0051-6
7. Qin, R.: Workforce Planning over the Service Life Cycle. Service Science 3(1), 22–40 (2011), doi:10.1287/serv.3.1.22
8. Hübbers, M.: Modell zur Kapazitätsplanung von Dienstleistungsressourcen in Leistungssystemen, 1st edn. Apprimus-Verl., Aachen (2011)
9. Krug, C.M.: Framework zur strategischen Kapazitätsplanung hybrider Leistungsbündel. Schriftenreihe des Lehrstuhls für Produktionssysteme. Shaker, Aachen (2010)

10. Meier, H., Funke, B.: Resource Planning of Industrial Product-Service Systems (IPS2) by a Heuristic Resource Planning Approach. In: Sakao, T., Larsson, T., Lindahl, M. (eds.) Industrial Product-Service Systems (IPS2). Proceedings of the 2nd CIRP IPS2 Conference. Linköping University, Linköping (2010)
11. Mjema, E.: A simulation based method for determination of personnel capacity requirement in the maintenance department. Shaker, Aachen (1998)
12. Edward, G., Anderson, J.R.: Managing the impact of high market growth and learning on knowledge worker productivity and service quality. European Journal of Operational Research 134(3), 508–524 (2001), doi:10.1016/S0377-2217(00)00273-3
13. Meier, H., Lagemann, H., Dorka, T.: Requirements for Transfer and Application of IPS2 Resource Planning – Case-Study of a Global Machine Tool Manufacturer. In: Shimomura, Y., Kimita, K. (eds.) The Philosopher's Stone for Sustainability, vol. 122, pp. 423–428. Springer, Heidelberg (2013)
14. Voudouris, C., Owusu, G., Dorne, R., Lesaint, D.: Service chain management: Technology innovation for the service business. Springer, Heidelberg (2008)
15. Fliess, S.: Dienstleistungsmanagement: Kundenintegration gestalten und steuern, 1st edn. Gabler, Wiesbaden (2009)
16. Blackstone, J.H.: APICS dictionary, 13th edn. APICS, Chicago (2010)
17. Kern, W.: Die Messung industrieller Fertigungskapazitäten und ihrer Ausnutzung: Grundlagen der Verfahren. Beiträge zur betriebswirtschaftlichen Forschung, vol. 15. Westdt. Verlag, Köln et al (1962)
18. Carrillo, J.E., Gaimon, C.: Improving Manufacturing Performance Through Process Change and Knowledge Creation. Management Science 46(2), 265–288 (2000)
19. Sterman, J.D.: Business dynamics: Systems thinking and modeling for a complex world. Irwin/McGraw-Hill, Boston (2000)
20. Pidd, M.: Tools for thinking: Modelling in management science, 2nd edn. Wiley, Chichester (2003)
21. Warren, K.: Competitive strategy dynamics. Wiley, Chichester (2002)
22. Morecroft, J.D.W.: Strategic modelling and business dynamics: A feedback systems approach. John Wiley & Sons, Chichester (2007)
23. Warren, K.: Strategic management dynamics. J. Wiley & Sons, Chichester (2008)
24. Schenk, M. (ed.): Instandhaltung technischer Systeme: Methoden und Werkzeuge zur Gewährleistung eines sicheren und wirtschaftlichen Anlagenbetriebs. Springer, Heidelberg (2010)
25. DIN Deutsches Institut für Normung e.V.: Instandhaltung - Begriffe der Instandhaltung (Maintenance - Maintenance terminology). Beuth, Berlin 03.080.10(13306) (2010)
26. Meier, H., Uhlmann, E., Geisert, C., Krug, C.M., Völker, O., Stelzer, C.M., Roy, R., Shehab, E.: Dynamic IPS2-networks and -operations based on software agents. In: Roy, R., Shehab, E. (eds.) Industrial Product-Service Systems (IPS2). Proceedings of the 1st CIR IPS2 Conference, pp. 305–310. Cranfield University, Bedford (2009)
27. Ebert, R.J.: Aggregate Planning with Learning Curve Productivity. Management Science 23(2), 171–182 (1976), doi:10.1287/mnsc.23.2.171
28. Fine, C.H.: Quality Improvement and Learning in Productive Systems. Management Science 32(10), 1301–1315 (1986), doi:10.1287/mnsc.32.10.1301
29. Wright, T.P.: Factors Affecting the Cost of Airplanes. Journal of Aeronautical Science 3(4), 122–128 (1936)

Development of the IPS² Factory Management

Eckart Uhlmann[1,2], Christian Gabriel[1], and Christian Stelzer[1]

[1] Department of Machine Tools and Factory Management, Chair for Manufacturing Technology, Technische Universität Berlin, Pascalstraße 8-9, 10587 Berlin, Germany
[2] Fraunhofer Institute for Production Systems and Design Technology, Pascalstraße 8-9, 10587 Berlin, Germany
gabriel@iwf.tu-berlin.de

Abstract. The approach of the IPS² factory management faces the challenges to deliver IPS². A framework of process steps for the planning, development and use of an IPS² leads to a structured acquisition of necessary processes and activities on the IPS² provider's and customer's site to procure and operate a production system.

The development of the generic framework for the IPS² factory management bases on a literature research. Therefore processes and activities of the factory planning as well as for the factory management were concerned. The identified processes and activities were aggregated and assigned to the IPS² life cycle phases by the chronological arranging under consideration of the activities' in- and output. By varying the responsibility of different process steps, concrete customer-provider-relationships were presented. This approach enables the selection and arrangement of product and service shares in the early life cycle phases for the customer and IPS² provider.

Keywords: IPS² development, factory management, factory planning.

1 Introduction

The approach of Industrial Product-Service Systems (IPS²) focuses on the integration of product and service shares. Thus, the IPS² provider assumes responsibility for process steps within the procurement and operation of machine tools to support the customer and increase its benefit.

To face this challenge an overview of deliverable service shares in the production area has to be achieved, so the IPS² provider is able to deal with production factors, i. e. time, costs, quality, and risks. Therefore a process map with processes of factory management, factory planning, and methodical designing shall be developed. The development of this IPS² factory management will be presented in this paper. In the framework of the IPS² factory management, the possible range of processes, which are necessary to procure and to operate a machine tool, is arranged. Subsequently the description of interfaces between the IPS² provider, customer, and network partners allows the control and assessment of customer-provider relationships in the early phase of an IPS², which is the further goal of the IPS² factory management approach. To demonstrate the current application of the IPS² factory management the arranging of processes for the supply of milling tools to increase the organizational availability of a machine tool will be presented.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 335–345.
DOI: 10.1007/978-3-642-30820-8_29

2 Industrial Product Service Systems (IPS²)

2.1 Definition

Industrial Product-Service Systems consists of tangible products and intangible service shares over an entire IPS² lifecycle. The IPS² provider develops and delivers customized solutions to fulfill various customer requirements [1-3]. Offering IPS² leads to new possibilities of business models [4].

2.2 Lifecycle

The main lifecycle phases of an IPS² are [5]:

- IPS² planning
- IPS² development
- IPS² implementation
- IPS² operation
- IPS² closure

The IPS² planning phase starts with the first customer contact. In a second step of the IPS² planning the customer requirements are identified by the IPS² provider. The IPS² planning phase ends with an offer for a customer specific IPS². This is based on a requirements list and is connected to a customized IPS² business model.

A functional and conceptual model of the IPS² is generated in the IPS² development phase. The needed IPS² function can be realized by service shares, product shares or as a module with a combination of both types.

In the IPS² implementation phase, which follows the development, the IPS² with all product and service shares is built up.

The main characteristic of the subsequent IPS² operation phase is the parallelism of the use of the IPS² product share and the delivery of the IPS² service shares. In this phase, the IPS² creates value and the processes of the IPS² service shares are supplied. The IPS² closure phase follows the contractual run time. In this phase the product shares are removed and the delivery of service shares is stopped.

2.3 Business Models

In the context of IPS², the customer-provider relationships lead to new possibilities of business models, due to the wider range of customizing product and service shares. Three exemplary IPS² business models are the function-oriented, the availability-oriented and the result-oriented business model [4], [6].

Function-Oriented IPS² Business Model. Within the function-oriented IPS² business model the IPS² provider distributes a machine tool and ensures its function. The customer is responsible for the operation of the machine tool. Considering the lifecycle phases, the IPS² provider offers additional service shares in the use phase, e. g. maintenance processes, staff training or supply of auxiliaries. The customer is responsible for the ordering of the additional service shares.

Availability-Oriented IPS² Business Model. In this IPS² business model the IPS² provider guarantees a defined availability of the machine tool. Therefore it has to be distinguished which kind of downtime is in the IPS provider's responsibility and which is in the customer's. Additional measures to maintain the specified degree of availability are necessary. Therefore the IPS² provider can equip the machine with sensors for condition monitoring to minimize the probability of sudden failures. A proactive detection of a critical process situation will enable the IPS² provider to trigger a repair measure during planned downtime. In this way the availability of the machine tool will not be affected negatively. An efficient communication is necessary between the IPS² provider and the customer to ensure the efficient planning of maintenance processes.

Result-Oriented IPS² Business Model. In this IPS² business model the IPS² provider assumes the overall responsibility for the production work pieces. The production risk shifts from the customer to the IPS² provider, as the customer only pays for properly produced parts, in contrast to a function oriented business model. To minimize the risks in this IPS² business model the IPS² provider needs an IPS² network to overcome possible unforeseen production failures.

3 Goals for the IPS² Factory Management

Enabling machine tool manufacturers to offer IPS², the influences of the integrated approach of product and service shares have to be considered. IPS² providers have to expand their scope of performance to fulfill the increased service level. Therefore the following challenges exist:

- Taking over of responsibilities and thereby risks for machine tool availability or the result of the machine tools' production processes according to the IPS² business models.
- Creation and organization of IPS² networks to realize the wide range of possible customer requirements.
- Customizing the level of performance according to the individual customer requirements.

The IPS² factory management will be developed as a framework to arrange the necessary processes to fulfill the wide range of customer requirements. Its application takes place in the early phases of an IPS² to deliver an overview about the wide range of possible processes, which the IPS² provider can take responsibility for in the production area. Thus, the definition of interfaces between IPS² provider, customer, and network partners for all IPS² lifecycle phases shall be enabled. Additionally, the modularization of process steps increases the ability to react on changing customer requirements efficiently and simplifies the comparison of different IPS² alternatives.

In the following the proceeding for the development of the IPS² factory management will be presented. Afterwards the application of the IPS² factory management will be demonstrated and exemplary performed.

4 Development of the IPS² Factory Management

To ensure the ability of machine tool manufacturer to deliver IPS², the IPS² factory management is a generic process map for the planning, development, implementation, operation and closing of IPS² for the production of industrial goods.

The development of the IPS² factory management was conducted in four steps:

1. Literature research of existing approaches for factory planning, factory management, and methodical designing in order to identify necessary tasks in the production area for the IPS² factory management.
2. Description of the identified processes and activities under considering of the identified tasks for the IPS² factory management.
3. Determination of the in- and outputs of the developed processes and activities.
4. Arrangement of the processes and activities in a process map for the IPS² factory management by means of the in- and outputs.

4.1 Literature Research

The task of the factory management is widely seen as the planning, controlling, and monitoring of processes and activities to ensure the production of products [7], [8]. To develop and deliver IPS², this consideration has to be extended. The IPS² provider cannot focus exclusively on the production of products but has to overtake responsibility for processes at the customer's site, too. Therefore, factory planning as well as methodical designing approaches were taken into account additionally within the literature research.

Table 1. List of researched tasks

No.	Authors	Described tasks
1	Bracht, U., Wenzel, S., Geckler, D. [9]	Production planning, production control, processing bill of materials, creating routing plan, control means of production
2	Eversheim, W. [10]	Processing bill of materials, creating routing plan, creating nc program, control means of production, selecting process sequence, specifying raw material, planning operations
3	Grundig, C.-G. [11]	Creating production program, Planning location, creating ideal layout, creating real layout, planning execution
4	Helbing, K. W. [12]	Estimating machine tool area, creating factory function, examining locations, designing factory, planning factory execution
5	Pahl, G., Beitz, W., Feldhusen, J., Grote, K.-H. [13]	Setting requirements, creating outline solution, designing solution, creating manufacturing documents
6	Pawellek, G. [14]	Defining corporate goals, planning layout, planning execution
7	Spur, G., Stöferle, T. [15]	Production planning, production control, structuring overall system
8	VDI-Guideline 2221 [16]	Describing customer requirements, developing operation principle, developing functional principle, developing realizable modules, specifying modules, specifying complete solution, creating manufacturing documents
9	VDI-Guideline 5200 [17]	Defining corporate goals, defining boundary conditions, creating ideal layout, creating real layout, planning realization
10	Wiendahl, H.-P. [18]	Defining corporate goals, defining boundary conditions, planning concept, detailing concept, planning realization

The research of the literature, listed in Table 1, delivers a wide range of necessary tasks in the production area. In the following step these tasks were considered to build up processes for the IPS² factory management. The processes have to be mutually exclusive and represent the whole range of necessary tasks to manufacture parts with machine tools.

4.2 Identified Processes

The result of the literature research is an overview of tasks, which are described in the approaches of factory planning, factory management and methodical designing. To fulfill these tasks several activities have to be executed. According to the literature, processes can be characterized as presented in Figure 1. Thus, a process is a sequence of mutual influencing activities with a beginning, an end, and defined in- and outputs [19-22]. Applied to the field of factory management, the process steps relevant to IPS² were distinguished and listed in the appendix.

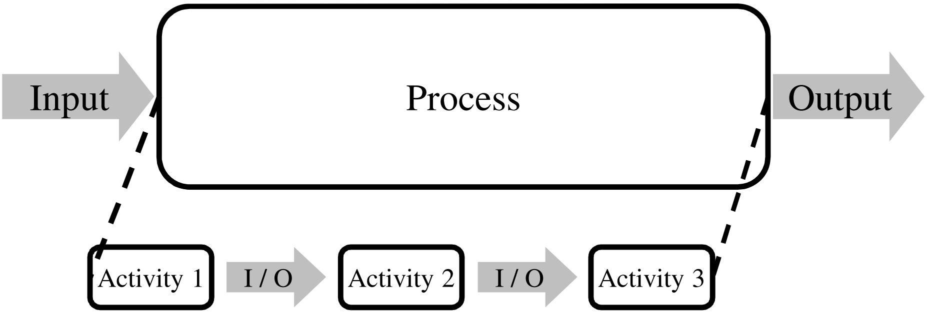


Fig. 1. Structure of a process according to [19]

As an example the task planning of factory location, according to Grundig [11], see Table 1, will be separated in three process steps:

- Setting location requirements
- Identifying and describing locations
- Selecting location

4.3 Build-Up of Processes

In the following step the identified processes for the IPS² factory management were built up and detailed according to the introduced process characterization in Chapter 4.2.

Representatively for all identified processes, the process '*Selecting machine tool*' shall be explained in detail, see Figure 2. The output of this process is the decision of appropriate machine tools for a production order. Therefore the ideal sequence of manufacturing processes for a work piece has to be known, e. g. sawing, turning, and milling. For all manufacturing processes, a machine tool will be selected. Additionally, the process owner needs an overview of available machine tools and their

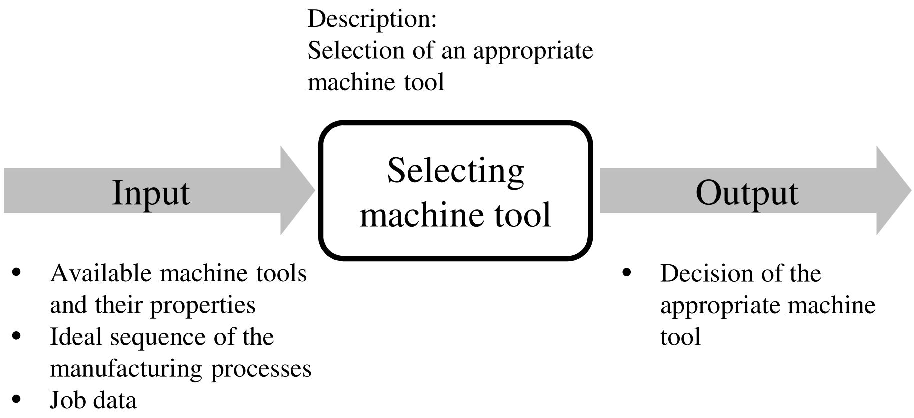


Fig. 2. Exemplary details of the process selecting machine tool

properties in the IPS² network. Under consideration of the job data, which define the lot size, the material and geometry of the work pieces, and the planned working duration, the appropriate machine tools will be selected.

4.4 Arrangement of the Processes and Activities According to the In- and Outputs

By identifying the in- and outputs, the processes will be arranged in the form of a process map. Thereby it has to be differentiated between sequential and parallel processes. This will be shown exemplary for the already mentioned process '*Selecting machine tool*', see Figure 3.

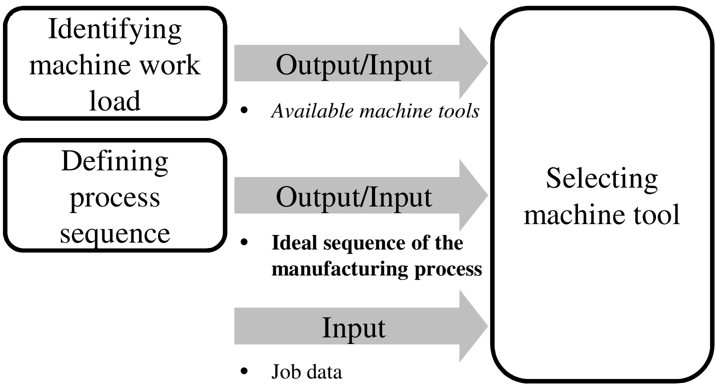


Fig. 3. Systematic for the arrangement of processes

As already mentioned, the process owner needs the information about the available machine tools and the ideal sequence of the manufacturing process. This information is the output of the processes identifying machine work load and defining process sequence. For the process map, this implies that these processes can be parallelized and it is a necessary prerequisite that these processes were finished before the process ‘S*electing machine tool’* starts.

Executing this systematic procedure for every process identified in chapter 4.2, a process map combining all possible processes arises. A section of the existing process map is shown exemplary in Figure 4. The thematic width of the IPS² factory management, while developing the process map, is visible due to the arisen areas in the process map. One benefit of this approach for structuring processes to deliver IPS² is the considering of the interactions between the different areas. Additionally the process map enables the structuring of the entire level of performance, which the IPS² provider delivers his customers. For developing concrete customer-provider-relationships, the IPS² provider tailors the process map, to choose the necessary processes for fulfilling the customer requirements.

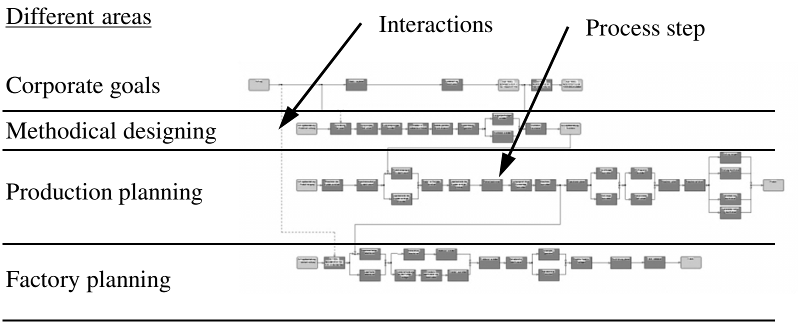


Fig. 4. Section of the process map

The process map covers the whole range of possible steps while integrating a machine tool into a production line. The range of necessary effort for building up and integrating a machine tool can be separated into three cases:

1. Developing and integrating a new machine tool into a consisting production line under consideration of the supply of auxiliaries or the development of appropriate boundary conditions.
2. Adaption of a production line by changing the layout and material flow to integrate a new machine tool.
3. Planning and realization of a new factory building to develop a new production plant with the IPS² provider’s machine tools.

4.5 Approach for the Use of the IPS² Factory Management

After describing the development of the IPS² factory management, the approach for its use shall be introduced, Figure 5. Enabling a machine tools manufacturer to deliver IPS², the process map has to be introduced. For this, the process map shall represent the IPS² provider’s and network partner’s whole scope of performance. After introducing the process map, concrete customer-provider-relationships will be described, due to the customizing of the process map. For this the responsibilities for single process steps have to be defined between the IPS² provider, his network partners, and the customer, according to the identified customer requirements. The structured representation of necessary process steps allows the control and detailing of the workflows on the IPS² provider's site under consideration of the available resources, time, costs and risks. After detailing the necessary process steps the realization of the IPS² starts. During delivering product and service shares as an IPS², the gained experiences lead to an optimization of the process map.

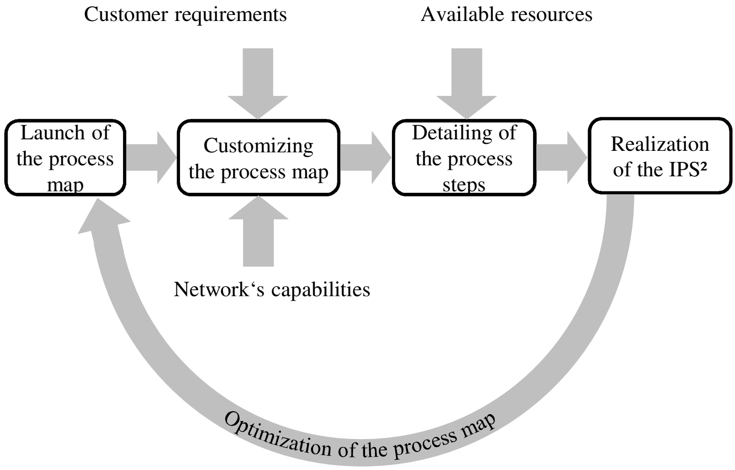


Fig. 5. Approach for the use of the IPS² Factory Management

5 Use of the IPS² Factory Management

As an example the use of the IPS² factory management shall be presented for the organization of milling tools within an IPS² [23]. The determinations of appropriate cutting data as well as the on time delivery of milling tools are two main influences to increase the effectiveness of a milling machine tool. Considering the OEE key figure, which is the product of a machine tool's availability, efficiency and quality [24], the process step determining cutting data influences the efficiency and the process step delivering tools influences the organizational availability.

In this example the IPS² provider is responsible for the selection and delivery of milling tools. Therefore information of process steps on the customer's site are necessary. The process step '*Creating manufacturing documents*' delivers the geometry information, which are important for the selection of the milling tool's type and size. Additionally the information about the work piece material influences the milling tool's material or coating as well as the cutting data. The next process step *'Determining demand of work pieces'* leads to the information about the number of units and the delivery date of work pieces. Therefore, it effects the amount and delivery date of the milling tools. Within the '*Planning of operations*' the machine tool will be defined, which influences the fixing of the milling tool. Additionally the operation planning allows the determination of the cutting volume and thereby the estimation of the necessary tool life.

Under consideration of these information the IPS² provider selects the appropriate milling tools, their amount, and delivery date and chooses the optimized cutting data in accordance with the supplier of the milling tools. This network partner assumes the responsibility for the on time delivery of the milling tool. During the '*Setting of the machine tool'* the customer uses the cutting data and the delivered milling tools.

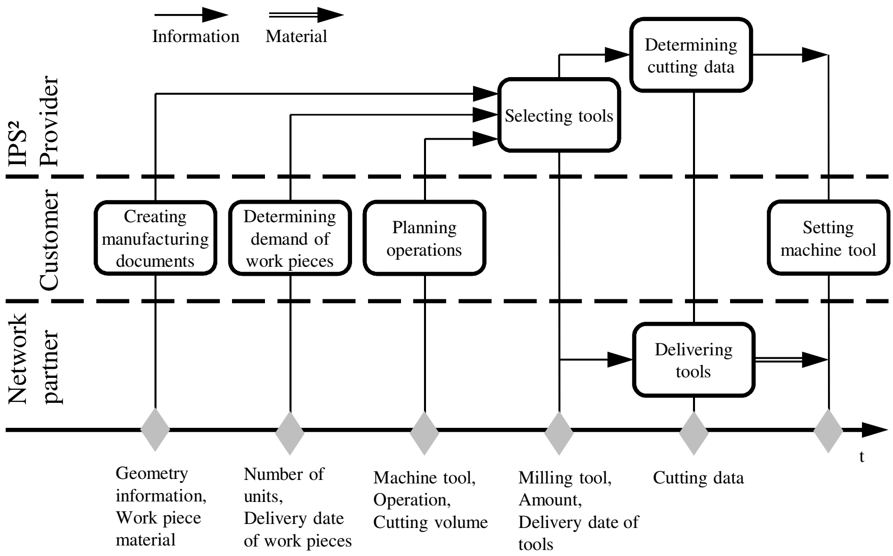


Fig. 6. Exemplary application for the organization of tools

6 Summary

Within this paper the development and the application of the IPS² factory management were described. The development based on a literature research and a methodology, which considers the in- and outputs of processes described in different fields of the production area. Additionally an approach for the introduction of the IPS² factory management was presented, to enable or support machine tool manufacturers while becoming an IPS² provider.

For the further development of the IPS² factory management, the process steps will be added with attributes and resources. Under consideration of concrete customer requirements the sequence of the necessary process steps are describable. On the basis of this description the responsibilities were distributed between the IPS² provider, customer, and network partners. Under consideration of the associated attributes and necessary resources different varieties of concrete IPS² for customers can be simulated and rated in terms of time, costs, quality and risk.

Acknowledgments. We express our sincere thanks to the Deutsche Forschungsgemeinschaft (DFG) for funding this research within the Collaborative Research Project SFB/TR 29 on Industrial Product-Service Systems – dynamic interdependency of products and services in the production area.

References

1. Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M., Wilson, H.: State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 221(10), 1543–1552 (2007)
2. Tan, A.R., McAloone, T.C.: Characteristics of strategies in Product/Service-System Development. In: Proceedings of the 9th International Design Conference Design, Dubrovnik, Croatia (2006)
3. Matzen, D., Tan, A.R., Andreasen, M.: Product/Service-Systems: Proposal for Models and Terminology. In: Proceedings of the 16th Symposium on Design for X, Neukirchen, Germany (2005)
4. Tukker, A., Tischner, U.: New Business for Old Europe – Product-Service Development, Competiveness and Sustainability. Greanleaf Publishing, Sheffield (2005)
5. Uhlmann, E., Stelzer, C.: Core Process of IPS^2 Working state of corporate process modeling in SFB/TR29 – Planning, development and operation. In: Proceedings of the Second International Seminar on IPS^2, pp. 37–41. Shaker Verlag, Berlin (2009)
6. Uhlmann, E., Gabriel, C., Raue, N., Stelzer, C.: Influences of the IPS^2 Business Model on the Development of a Micro Milling Spindle. In: Proceedings of the 3rd CIRP IPS^2 Conference. Springer, Berlin (2011); Davenport, T.H.: Process Innovation: reengineering work through information technology. Harvard Business School Press, Boston (1993)
7. Helbing, K.W.: Handbuch Fabrikprojektierung. Springer, Berlin (2010)
8. Schenk, M., Wirth, S.: Fabrikplanung und Fabrikbetrieb – Methoden für die wandlungsfähige und vernetzte Fabrik. Springer, Berlin (2004)
9. Bracht, U., Geckler, D., Wenzel, S.: Digitale Fabrik – Methoden und Praxisbeispiele. Springer, Berlin (2011)
10. Eversheim, W.: Oragnisation in der Produktionstechnik – Arbeitsvorbereitung. Springer, Berlin (2002)
11. Grundig, C.-G.: Fabrikplanung. Hanser Verlag, München (2009)
12. Helbing, K.W.: Handbuch Fabrikprojektierung. Springer, Berlin (2010)
13. Pahl, G., Beitz, W., Feldhusen, J., Grote, K.H.: Pahl/Beitz Konstruktionslehre. Springer, Berlin (2003)
14. Pawellek, G.: Ganzheitliche Fabrikplanung. Springer, Berlin (2008)
15. Spur, G., Stöferle, T.: Handbuch der Fertigungstechnik – Band 6: Fabrikbetrieb. Hanser Verlag, München (1994)
16. VDI-Guideline 2221: Systematic approach to the development and design of technical systems and products. Beuth Verlag, Berlin (1993)
17. VDI-Guideline 5200: Factory planning - Planning procedures. Beuth Verlag, Berlin (2011)
18. Wiendahl, H.-P., Reichardt, J., Nyhuis, P.: Handbuch Fabrik planung. Hanser Verlag, München (2009)
19. Seghezzi, H., Fahrni, F., Hermann, F.: Integriertes Qualitäts management. Carl Hanser Verlag, München (2007)
20. Davenport, T.H.: Process innovation: reengineering work through information technology. Harvard Business School Press, Boston (1993)
21. DIN EN ISO 9000: Qualitätsmanagementsysteme – Grundlagen und Begriffe. Beuth Verlag, Berlin (2005)

22. Rüegg-Stürm, J.: Das neue St. Galler Management-Modell. Paul Haupt Verlag, Bern (2003)
23. Uhlmann, E., Gabriel, C., Stelzer, C.: Influences of Production Equipment in IPS^2 Use Phase – Organization of Tools as an IPS^2 Service Share. In: Proceedings of the 4th CIRP IPS^2 Conference. Springer, Berlin (2012)
24. Nakajima, S.: Introduction to TPM – Total Productive Maintenance. Productivity Press, New York (1988)

Appendix

Table 2. List of identified processes

No.	Process	No.	Process
1	Planning distribution	23	Creating NC program
2	Describing customer order	24	Developing post processor
3	Describing customer requirements	25	Setting machine tool
4	Developing operation principle	26	Adjusting machine tool
5	Developing functional principle	27	Manufacturing order
6	Developing realizable modules	28	Performing maintenance
7	Specifying modules	29	Performing condition monitoring
8	Specifying complete solution	30	Estimating machine tool area
9	Creating manufacturing documents	31	Estimating storage area
10	Creating bill of materials	32	Estimating material flow
11	Processing bill of materials	33	Creating ideal layout
12	Identifying machine tool's work load	34	Setting location requirements
13	Identifying production program	35	Identifying and describing locations
14	Determining work piece stock	36	Selecting location
15	Determining demand of work pieces	37	Creating rough layout
16	Determining raw material stock	38	Identifying means of production
17	Specifying raw material	39	Designing workplace
18	Selecting process sequence	40	Arranging means of production
19	Selecting machine tools	41	Determining structural aspects
20	Planning operations	42	Planning execution
21	Selecting jigs and fixtures	43	Realizing factory
22	Selecting tools		

Configurable Condition Monitoring Methods for Industrial Product Service Systems

Eckart Uhlmann[1,2], Abdelhakim Laghmouchi[2], and Niels Raue[1]

[1] Department of Machine Tools and Factory Management, Chair for Manufacturing Technology, Technische Universität Berlin, Pascalstraße 8-9, 10587 Berlin, Germany
[2] Fraunhofer Institute for Production Systems and Design Technology, Pascalstraße 8-9, 10587 Berlin, Germany
raue@iwf.tu-berlin.de

Abstract. The continuous monitoring and documentation of the condition of wear-susceptible components is the prerequisite for condition-based maintenance in availability-oriented IPS² business models. This article illustrates the concept of intelligent condition monitoring for mechatronic components. To ensure a real time and precise detection of condition deterioration a toolbox was developed and implemented in MATLAB that combines methods for signal processing, feature extraction and classification. A test rig is introduced that was designed and built for the purpose of roller bearing monitoring. Since roller bearings are the most critical components of a micro milling spindle, they are responsible for a multiplicity of machine tool breakdowns. The toolbox was evaluated in experiments with the roller bearing test rig.

Keywords: Availability-oriented IPS² business models, Condition Monitoring, Roller Bearing Monitoring.

1 Introduction

Condition Monitoring is vital to availability-oriented IPS² business models. The ability to react to spontaneously arising demands for technical service activities necessitates a well-functioning condition monitoring system. In the context of IPS², approaches exist to utilize a network of qualified service providers in order to fulfill such demands for the machine tool industry [1, 2].

In the most favorable case, such sudden occurrences of demands for technical services should be anticipated by detecting the deterioration of critical components. This can be achieved by suitable proactive maintenance strategies. These can range from regular manual inspections over the logging and processing of alarm messages of the machine control to sensor-based condition monitoring.

However, for a condition monitoring system to reliably distinguish between a properly functioning component and one that is about to fail, the acquired sensor signals need to be processed, meaningful signal features need to be extracted and classified so that a conclusion can be drawn about the actual state of the component.

In the framework of this article, a toolbox will be introduced that enables production engineers, who are not experts in the field of signal processing and analysis, to create condition monitoring applications in an intuitive and effective manner.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 347–358.
DOI: 10.1007/978-3-642-30820-8_30

Subsequently, this toolbox will be evaluated with sensor data acquired at a test rig for roller bearings. Different characteristic damages will be generated in roller bearings, subsequently these bearings will be operated under varying conditions. The recorded sensor signal will serve as input for the toolbox and its feature extraction and classification functions. At last, the results will be assessed by applying the classification results to new sensor data.

2 State of the Art

2.1 IPS²

Industrial Product-Service Systems (IPS²) provide means of market differentiation and continuous revenue throughout the whole IPS² lifecycle for companies in industrialized nations. Especially when looking at the pace at which technological standards in the emerging markets such as China, India and Brazil are rising, the proper connection of product and service shares is found to be a useful market differentiation strategy. There are various possibilities of offering service shares generating customer benefit by increasing the performance of the product share. This new and innovative form of business is particularly interesting for manufacturers of complex and capital-intensive goods such as plants and machine tools. There exists a high demand on customer side for accompanying service shares due to:

- The complexity of the sold product share,
- The customer's need to substitute product with service shares or vice versa in order to react flexibly to deviations in the companies' boundary conditions,
- The possibility to outsource tasks that are outside the customer's core competency or not creating value.

A popular characterization of different IPS² business models distinguishes between function-, availability- and result-oriented business models [3, 4]. Although every business model is customer-specific and thus, highly individual, these business model categories are often used as they are particularly characteristic. In an availability-oriented business model, the IPS² provider guarantees the technical availability of the IPS² product share. Downtime of the product share, e. g. a machine tool, directly results in a financial loss. Therefore, any failure of the system should be recognized immediately or better, beforehand, in order to be fixed to prevent any financial loss and fulfill the customer requirement. Condition-based maintenance therefore is a key solution to this challenge.

2.2 Maintenance Strategy

Maintenance is considered as the "combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" [5]. Independent of the technical details of the maintenance and monitoring solutions, maintenance strategies can be distinguished according to general concepts. Most commonly, the forms *reactive* and *proactive* maintenance can be differentiated. Within preventive maintenance, a further distinction can be made between *periodically preventive*, *condition-based* and *anticipatory preventive* maintenance [5]. For a further distinction within reactive as well as proactive maintenance strategies, see [6].

Whereas theoretically, all of these strategic concepts would enable the IPS² provider to keep up availability in IPS² business models, the advantages that apply to the preventive maintenance strategies are of crucial importance when the availability-oriented ISP² business model implies severe fees and absent revenues during machine tool downtime.

The three introduced preventive maintenance strategies differ in the way in which maintenance activities are triggered: Whereas in the *periodically preventive* strategy maintenance activities are executed according to fixed usage intervals such as time periods, usage hours, traveled (covered) distance, etc., the other two strategies trigger their activities on the actual condition of the machine or component. In the *condition-based* strategy, maintenance activities are initiated upon changes in the condition of function critical components. The approach is based on the assumption of progressive degradation [7] of a component. By acquiring the condition-relevant parameters of the component constantly or in fixed intervals, the progress of deterioration is computed and countermeasures can be arranged accordingly.

Despite the clear advantages of *condition-based* maintenance, however, this strategy imposes the challenge of reliably determining the actual wear state of the component. Also, if the assumed, constant progress of degradation is interrupted by a spontaneous event due to misuse or spontaneous material failure, the maintenance strategy must be able to react to these unscheduled demands as quickly as possible.

The *anticipatory maintenance strategy* differs from the condition-based in the purpose of aiming at "hidden" failures that are not detectable by acquiring condition-relevant parameters.

2.3 Monitoring of Roller Bearings

As an important requirement for condition-based maintenance activities in the framework of availability-oriented IPS² business models, sufficient means of online monitoring have to be available.

Online monitoring of critical components such as roller bearings provides information about the current state of deterioration of the component. Generally, different types of parameters can be monitored The most widely used include performance, vibration, motor stator current, shock pulse, acoustic emission, thermography and the detection of wear debris [8]. They differ in the underlying sensor concept and thus, their characteristics regarding sensitivity, robustness, sampling rate and cost. In the context of this paper, means of sensor-based condition monitoring will be presented that enable IPS² provider companies to react to degradation.

Generally, two different approaches of processing sensor data can be distinguished. On the one hand, diagnostic models can be used that resemble the actual physical phenomenon to a maximum possible extent. In the case of roller bearings, such models would take into account exact material, geometrical and operational parameters that apply to the bearing to be monitored [9]. On the other hand, statistical methods can be applied that are based on training data and are specific for the material, geometrical and operational conditions the training data set was acquired under [10]. The first approach is often referred to as *white-box*, whereas the latter as *black-box* approach [11]. The method toolkit considers both approaches to a certain extent: on the one hand, features in the frequency domain such as damage frequencies resemble the physical buildup of the component, other features such as the time domain features serve as input for the classifiers introduced later.

3 Condition Monitoring Toolbox

3.1 Requirements for the Condition Monitoring Toolbox

A software tool was developed for the interactive generation of algorithms in the programming environment MATLAB. The implemented algorithms are to be used for development of concrete condition monitoring applications which follow a general functional sequence (Fig. 1).

For the implementation of condition monitoring applications for complex machines, plants and systems, different data is logged and evaluated. There might be machines and plants that may consist of several parts subject to wear. Generally, the assemblies and components which are to be monitored exist in a wide range of machines and plants, such as gearboxes, roller bearings, and shafts. However, differences exist between these types of parts, in particular in the mode of load stress. Therefore methods and algorithms have to be easily adaptable for analysis and evaluation of the condition of the machine or its components. As a result of the requirements to the software, it is possible to load and plot data with different formats. Besides physical data, such as vibration, pressure, etc., also several types of alarm messages and system-internal information can be stored and used for an improved analysis. Various methods are additionally available to the user through all steps of the development (signal processing, feature extraction and classification).

After finishing the development steps (signal processing, feature extraction and classification) the complete algorithm can be exported as a separate MATLAB m-file. It is envisaged that a vector with percentage probabilities is generated as the output for the classification algorithm. That implies that the vector elements indicate the likelihood with which assigned defect classes match the analyzed measurement data.

The functional requirements which are given above are realized in a graphical user interface (GUI). Users have the possibility to control and to flexibly manipulate the program execution. Additionally, the program can be handled intuitively. The software is implemented in a form that allows additions (self-implemented methods and other algorithms combination) which can be directly linked to the tool via the GUI. Interface specifications ensure the error-free integration of the additional methods into the tool. As opposed to conventional approaches, the developed tool offers more new functions, components and methods to be implemented by the user. Additional information, such as system alarm and system internal messages can even be used for the improvement of classification results.

3.2 Structure of the Toolbox

Analogously to the general sequence of a pattern recognition system, Fig. 2 illustrates the modules of the toolbox in their sequence of function. The development of a specific condition monitoring application requires several steps. The details to the development steps are described below.

Fig. 1. Modules of the Toolbox (Following [12])

Data Input

A variety of data formats can be imported into the tool, such as *.mat*, *.csv*, *xls*, *txt*, etc. Previously acquired sensor data can be imported, processed and analyzed for classification purposes. The circumstances, under which the training data set was recorded, is important for characterizing the resulting classification of the extracted features.

Signal Processing

Generally, measurement signals include measurement noise, process noise and disturbances. Therefore the raw signal must be prepared so that relevant information and signal parts, which can be used for condition monitoring, are extracted. This requires a preprocessing of the raw signal before extracting the features (diagnostic parameters). Signal filtering and signal norming are an essential part of signal processing. The tool allocates the different methods for the signal processing step, such as high-pass filter, low-pass filter, etc.

Feature Extraction

The basis of the reliable detection of parameter changes compared to the normal condition of the component is the generation of crucial characteristics (fault symptoms) which are suited to monitor component state. The fault symptoms can be detected through analysis and evaluation methods of measured data.

For an investigation of the deviation of a physical variable to the normal condition there are several approaches (methods and algorithms) for feature extraction and early fault detection. All methods follow however the same underlying idea. Relevant characteristics of the component condition should be determined from records with knowledge about the plant. The features can be different, consequently the directly measurable values, such as temperature or pressure or the values which can be extracted from the measurement signals, such as frequencies or statistic values.

In the tool, the user can choose statistic values (mean, RMS value, variance, kurtosis and skewness of distribution), spectral values, cepstral values and envelope curve values. The selected characteristics are described in the following:

a. Mean

The mean is the middle value of the given numbers or elements. It is the calculated central value of a given numbers or elements.

b. RMS value

The Root-Mean-Square value (RMS) is the square root of mean of the values x_i^2 of discrete allocation $x_1 + x_2 + ... x_n$.

$$x_{RMS} = \sqrt{\frac{x_1^2 + x_2^2 + ... + x_n^2}{n}} \tag{1}$$

c. Variance

The variance is a statistical measure that describes the variation between measured data and the average value of the set of data.

d. Kurtosis

The kurtosis is a statistical value that describes the variation of given data around the mean.

$$K = \left[\frac{1}{n} \sum_{j=1}^{n} \left(\frac{x_j - \bar{x}}{s} \right)^4 \right] \tag{2}$$

$\bar{x}$: arithmetic average, S: standard variance, x_j observed statistical data.

e. Skewness of distribution

The skewness is used to describe the asymmetry from the normal distribution in a set of observed statistical data.

$$S_k = \frac{1}{n} \sum_{j=1}^{n} \left(\frac{x_j - \bar{x}}{s} \right)^3 \tag{3}$$

$\bar{x}$: arithmetic average, S: standard variance, x_j observed statistical data.

Classification

For the classification of the feature that has been extracted from the preprocessed raw signal, methods of computational intelligence can be used in addition to the statistical classification methods. These methods have the task of allocating the defect classes to the feature. The evaluation of the classification methods requires detailed studies, to maintain the safe and reliable functioning of the selected methods by using them for various applications. Through extensive measurements of different states of the component, the parameterization of the algorithms can be analyzed.

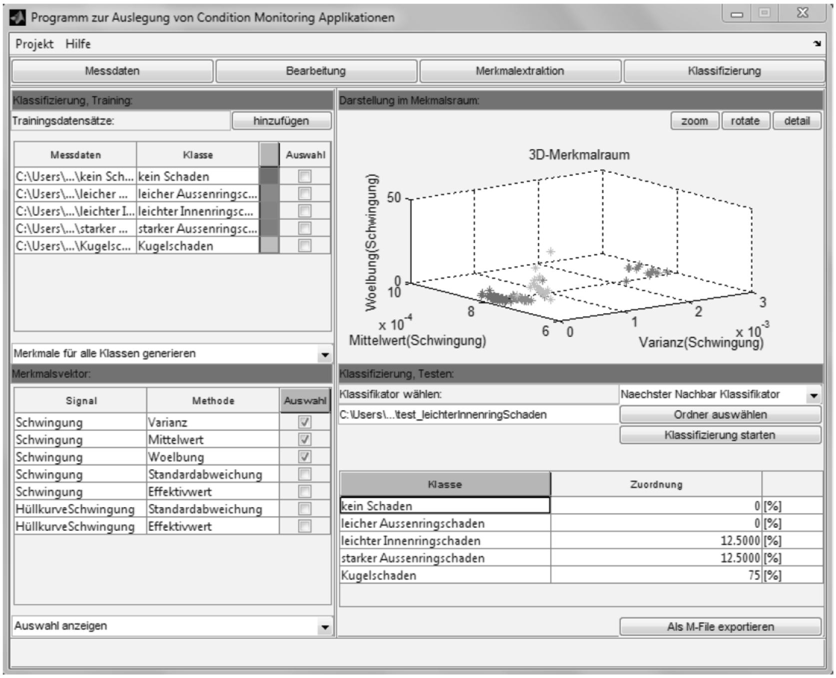


Fig. 2. Graphical User Interface of the Methods Kit displaying classification results

In addition to the above mentioned features which can be extracted from the sensor signals for condition monitoring, the system internal information and alarms can be used through cluster analysis (data mining) to detect patterns. These patterns can be used to further optimize the condition monitoring of the considered component. In the developed toolbox are various algorithms are included. The implemented algorithm is explained in the following:

Naive Bayes Classifier.
The Bayesian classifier appertains to the group of statistical classifiers. The classifier can forecast class belonging probabilities, such as the probability that a observed data appertains to a particular class. This classifier is based on the “Bayesian theorem” and is particularly appropriate when the dimensionality of the input is high.

Fig. 2 illustrates the classification results of the various roller bearing tests with the Nearest Neighbor Classifier algorithm. The classification issue depends on the assortment of the classification algorithm with the parameter used. In practice, there is no general procedure to identify the optimal features, therefore the calculation of the features is still conducted empirically.

4 Evaluation

4.1 Experimental Setup

A test rig was deployed in order to evaluate the toolbox with sensor data of roller bearings in operation. The test rig enables the acquisition of several condition relevant sensor signals, namely temperature, vibration and acoustic emission. For the evaluation of the toolbox, vibration data was used. A Bruel&Kjaer 4518-003 piecoelectric accelerometer, which is inserted into the sensor mount of the bearing block, was applied to acquire vibration data. Through a National Instruments cDAQ module that supports IEPE (Integrated Electronics Piezo Electric) sensors, the vibration signal was acquired and recorded by a program developed in the LabVIEW environment. Data sets of two seconds were recorded using a sampling rate of 25 kHz. For this evaluation, the bearings were operated at a rotational speed of 1800 rpm.

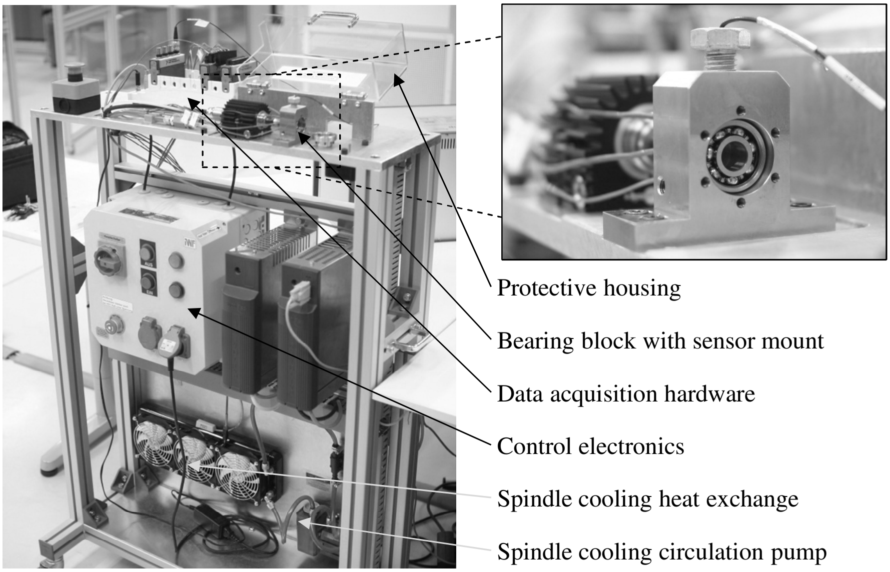


Fig. 3. Test rig setup

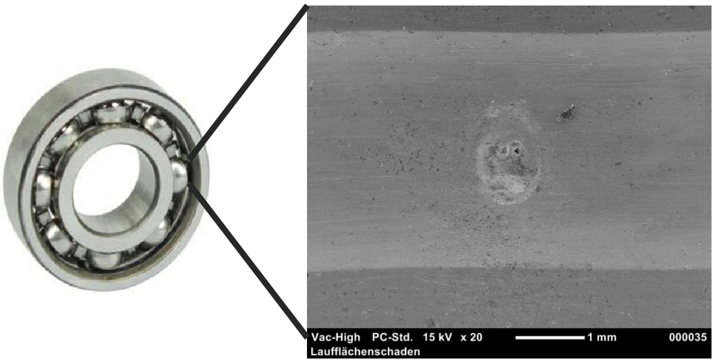


Fig. 4. Roller bearing type 6000 (left) and generated damage on the outer ring (Damage type III)

4.2 Generation of Damage Patterns

Fig. 4 (left) illustrates the roller bearing of type 6000 from the manufacturer SKF, which was used to generate real measurement data on the ball-bearing test rig. Various types of damages in different positions on the roller bearings have been created for evaluation of the developed toolbox.

The damage types on the roller bearings were generated via electrical discharge machining (EDM). The eroding process was repeated sequentially (several eroding holes) so that a large enough crater was generated and a form similarity to the real damage was reached. During operation of the damaged bearing, repeated impacts cause vibration that is transmitted through the surface of the whole machine. In the test rig, these vibrations are detected by the piezoelectric accelerometer.

The most prevalent faults on the ball-bearing were identified on the basis of the literature research [15]. The following error classes were created.

I. Rolling element damage
Failure on the rolling element generated through an electrode with a diameter of 200 µm.

II. Small damage on the outer ring
Damage on the outer ring of the ball-bearing generated through an electrode with a diameter of 200 µm.

III. Heavy damage on the outer ring
Damage on the outer ring of the ball-bearing generated through an electrode with a diameter of 400 µm.

IV. Damage on the inner ring
Damage on the inner ring of the ball-bearing generated through an electrode with a diameter of 200 µm.

Fig. 5 illustrates examples for recorded measurement data on the ball-bearing test rig. (I: Heavy damage on the outer ring; II: Small damage on the outer ring; III: Damage on the inner ring; IV: Rolling element damage).

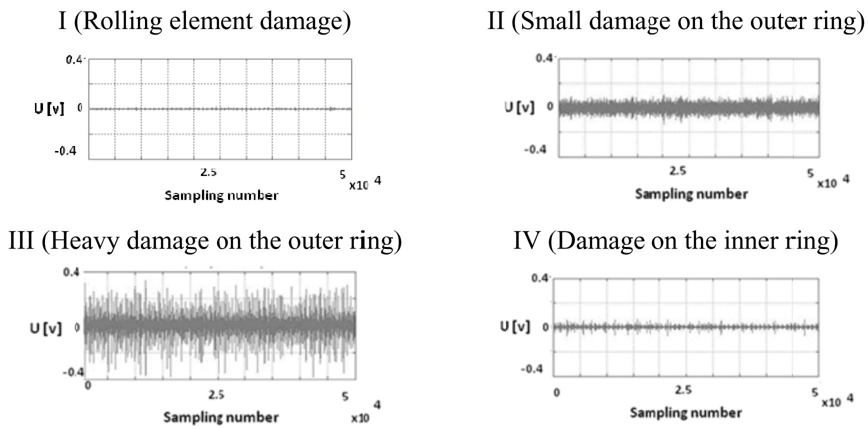


Fig. 5. Recorded measurement data of the ball-bearing test rig

5 Results

For the evaluation of the classification procedure, five features (Mean, RMS, Variance, Kurtosis, Skewness) were applied to three classifiers. The results achieved depend strongly on the selected feature and used algorithms. There are no special procedures for selecting and calculating the features which are suitable for an optimal classification. The varying results of the classification are depending on the algorithm. Table 1 illustrates the percentage of the unknown data that have been correctly assigned to the training data. The algorithm that based on Mahanalobis distance (equation 1) calculates the distance between two points in a multidimensional space. The Mahalanobis distance [16] of the vectors x_1 and x_2 in a multidimensional space is defined as:

$$D_M(x_1,x_2)=\sqrt{(x_1-x_2)^T\,\Sigma^{-1}(x_1-x_2)} \tag{4}$$

Σ : The covariance matrix that is estimated from measured data.

The failure type “IV: Damage on the inner ring” is not successfully classified. This is most likely due to the similarity with the measured data of the failure type “I: Rolling element damage”. The selected signal features of the two classes are of weak distinction and thus overlap in the feature space. The selection of other features, particularly from the frequency domain, could support the classification despite the close resemblance between the data of the two classes.

Table 1. Classification results with **Bayes Classifier** (algorithm type: Mahanalobis)

Bayes Classifier	**Test data**				
Classifier type: Mahanalobis	0	I	II	III	IV
Class Affiliation	[%]	[%]	[%]	[%]	[%]
0: No damage	100	0	0	0	0
I: Rolling element damage	0	100	12.5	0	100
II: Smaller damage on the outer ring	0	0	75	0	0
III: Heavy damage on the outer ring	0	0	0	100	0
IV: Damage on the inner ring	0	0	12.5	0	0

6 Summary and Outlook

In the framework of this article, a Toolbox was introduced to create condition monitoring applications in an intuitive and efficient way. Subsequently, the method toolkit was evaluated using a test rig for roller bearings. Therefore, specific damages were applied to sample roller bearings, which were operated while a vibration signal was recorded under defined operation conditions. The resulting damage classifications were assessed by test runs with bearings from the corresponding damage classes.

In the context of IPS², the developed tool can help provider companies of machine tool-related IPS² to improve the reliability of their condition assessment and thus the execution of their maintenance strategy. Engineers, who are responsible for the operation of the IPS² at the provider company are able to create reliable condition monitoring applications without expert knowledge about the computational background of the classification process.

One advancement of the tool will include the consideration of further classifiers, such as neural networks. The flexibility of the Method Kit regarding the sensor input furthermore allows the classification for the wear assessment of different mechatronic components such as bearings, gear wheels and milling spindles.

Acknowledgement. The authors would like to thank the German Research Foundation (DFG) as well as the states of Berlin and Brandenburg and the Fraunhofer-Gesellschaft for supporting the research in the collaborative research project Transregio 29 and the Innovation Cluster "Maintenance, Repair and Overhaul (MRO) in Energy and Transport".

References

1. Uhlmann, E., Geisert, C.: Availability Oriented IPS^2 Supported by Software Agents – Feedback Control Approaches for Robust IPS^2 Operation. In: Proceedings of SFB/TR29 2nd International Seminar, Berlin, pp. 63–67 (2009)
2. Uhlmann, E., Geisert, C., Raue, N., Stelzer, C.: Automatisierungstechnik für Erbringungsprozesse hybrider Leistungsbündel. In: Meier, H., Uhlmann, E. (eds.) Integrierte Industrielle Sach- und Dienstleistungen. Vermarktung, Entwicklung und Erbringung hybrider Leistungsbündel, pp. 245–263. Springer, Heidelberg (2012)
3. Tukker, A., Tischner, U.: New Business for Old Europe: Product-Service Development, competitiveness and sustainability. Greenleaf Publishing, Sheffield (2005)
4. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems—IPS2. CIRP Annals - Manufacturing Technology 59(2), 607–627 (2010), doi:10.1016/j.cirp.2010.05.004
5. Ryll, F., Freund, C.: Grundlagen der Instandhaltung. In: Schenk, M. (ed.) Instandhaltung Technischer Systeme. Methoden und Werkzeuge zur GewäHrleistung Eines Sicheren und Wirtschaftlichen Anlagenbetriebs, pp. 23–101. Springer, Heidelberg (2010)
6. Deutsches Institut für Normung: DIN EN 13306 - Instandhaltung – Begriffe der Instandhaltung. Beuth Verlag, Berlin (2010)
7. Figueroa, F., Schmalzel, J.: Rocket Testing and Integrated System Health. In: Wang, L., Gao, R.X. (eds.) Condition Monitoring and Control for Intelligent Manufacturing, pp. 373–391. Springer, London (2006)
8. Tandon, N., Parey, A.: Condition Monitoring of Rotary Machines. In: Wang, L., Gao, R.X. (eds.) Condition Monitoring and Control for Intelligent Manufacturing, pp. 109–136. Springer, London (2006)
9. Randall, R.B., Antoni, J.: Rolling element bearing diagnostics—A tutorial. Mechanical Systems and Signal Processing 25(2), 485–520 (2011), doi:10.1016/j.ymssp.2010.07.017
10. Worden, K., Staszewski, W.J., Hensman, J.J.: Natural computing for mechanical systems research: A tutorial overview. Mechanical Systems and Signal Processing 25(1), 4–111 (2011), doi:10.1016/j.ymssp.2010.07.013

11. Ikonen, E., Najim, K.: Advanced process identification and control. Marcel Dekker, New York (2002)
12. Gao, R., Yan, R., Sheng, S., Zhang, L.: Sensor Placement and Signal Processing for Bearing Condition Monitoring. In: Wang, L., Gao, R.X. (eds.) Condition Monitoring and Control for Intelligent Manufacturing, pp. 167–191. Springer, London (2006)
13. Cunningham, P., Delany, S.J.: k-Nearest Neighbour Classifiers. Technical Report UCD-CSI-2007-4, University College Dublin (2007)
14. Alpaydın, E.: Maschinelles Lernen. Oldenbourg, München (2008)
15. Schaeffler Technologies GmbH & Co. KG: Rolling Bearing Damage: Recognition of damage and bearing inspection, Publ. No. WL 82 102/3 EA (2001)
16. Kroschel, K.: Statistische Informationstechnik: Signal- und Mustererkennung, Parameter- und Signalschätzung. Springer, Berlin (2004)

Quality-Oriented Risk-Management-Approach for Service Innovations

Robert Schmitt[1,2], Sven Schumacher[2], and Thomas Zentis[2]

[1] Department of Metrology and Quality Management, Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Steinbachstr. 19, 52074 Aachen, Germany
[2] Department of Production Quality and Metrology, Fraunhofer Institute for Production Technology IPT, Steinbachstr. 17, 52074 Aachen, Germany
r.schmitt@wzl.rwth-aachen.de,
{sven.schumacher,thomas.zentis}@ipt.fraunhofer.de

Abstract. Services offer a great innovation potential due to their adaptability to individual customer problems. Though, many companies meet the challenge to consider customer-driven innovation ideas in a way that market-ready services match the customers' needs. As a result, a significant number of industrial service innovations fail and the required level of service quality and productivity cannot be assured constantly. Instruments are needed, which allow for identifying, analyzing and evaluating the risks and opportunities that come along with the development of innovative services. Therefore an approach has been developed that allows companies in a simple way to identify, analyze and evaluate potential risks that arise in the implementation of innovative ideas. Thus companies are enabled to decide on a profound basis, which innovations are promising to be successful in the market and should be prioritized. Furthermore the identified risks can constantly be considered during the service engineering process, the service implementation and the service delivery.

Keywords: Service, Innovation, Risk Management, Quality Management.

1 Introduction

An even more intense and global competition demands innovative problem solving in even shorter periods of time and for less costs. In this context innovations become a key factor of economic development and growth [1][2]. Especially the increasing dynamic of the global market and the rising complexity of the corporate environment indicate that a professional innovation management is essential [3]. Companies are forced to differentiate themselves from competitors with products and services of comparable quality. A company that is able to assert itself effectively by increasing market share, revenue and profit in a market, which is characterized by competitiveness, is therefore defined as successful and innovative [4]. The implementation of innovations, however, is associated not only with new opportunities, but also with risks. Unidentified risks can cause serious consequences. For instance, if the costs for development and market launch are not recouped, innovations can endanger

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 359–370.
DOI: 10.1007/978-3-642-30820-8_31

companies substantially. In addition, warranty and goodwill costs as well as a huge loss of reputation can occur, which can effect further costs for the company [3][5]. Against that background, companies must be constantly vigilant about the chances and risks at different fields of the business environment.

Due to the fact that customers are not willing to accept compromises with regard to the quality requirements, a decisive factor for the competitiveness of service providing companies is the concatenation of innovation and service quality [5-7]. Depending on the industrial sector 30-50% of all new introduced services turn out to be a failure; respectively they do not match the expectations of the service provider. This often leads to an overreaction like for example removing them directly from the market [8]. The misinterpreted and ignored changes of boundary conditions, which influence the customer acceptance for new innovations, can be a cause for the failure of innovations. Besides the inadequate fulfillment of the customers' demands due to the lack of customer orientation, the capacity overload of companies, which have to handle too many projects in parallel, can be as well a reason for the unsuccessful implementation of new innovations [5]. In many companies, there exists no systematical development of service innovations [9]. They are often evolved accidently and just arise ad hoc based on feelings or intuition. This implementation follows the idea that services are easier to develop than physical goods. Thus, the complexity of the innovative service development is systematically ignored [10][11]. Based on the increasing globalization of markets the conditions for decision-relevant information alters more often. As a result a constant adapted perception of the success potentials for the innovation management is also becoming more important.

Both product-related services and services that are sold independently of a product are playing a more and more decisive economic role for companies [12]. Therefore and due to the adaptability of individual solutions to customer problems, the service sector provides a strong innovation potential. Related to this, however, many companies are confronted with the problem of considering both their own and the customer-driven innovation ideas in their development process of new services. For choosing the best fitting innovation idea out of the abundance in consideration of their complexity, the companies have to prioritize and decide for or against an innovation idea. Companies proceed, as already mentioned above, not systematically enough and partly unprofessional during the development and design of their offered service. New services arise rarely as a result from rational strategic consideration and systematic development processes, but rather from historical grown situations or accidental available opportunities [13]. Thereby sometimes profitable ideas are rejected and ideas which are doomed to fail are pursued. Such wrong decisions cost companies considerable time and money [14].

Taking the aforementioned into consideration, it is the central objective of the presented approach to allow for a preventive quality management by identifying, analyzing and evaluating potential risks that arise in the implementation of service innovation ideas on a simple way.

2 Service Quality and Risks

2.1 Service Quality

The quality of services is a key success factor for companies. Recent studies show, that both the customer's purchasing decision for a product and the company's profit are influenced decisively by the quality of the accompanying service [12]. In this context it gets increasingly important for a service provider to recognize that a competitive profiling is possible only by a consistent customer orientation, which is able to adapt to the target markets [15][16]. Thereby, the quality leadership has to be understood as the central strategy of success for gaining or rather defending a competitive edge [17].

Many services are developed in close interaction of customers and the employees of the service provider. Therefore especially in the service sector an intact, interpersonal information flow determines the competitiveness of the service provider [18]. A service provider, which is able to create a primary immaterial service that fits to the customer's expectations on a certain specified level of requirement, owns the capability to create service quality. The service quality is therefore determined by the rate of compliance between the provided properties or the characteristics of a service on the one hand and the requested customer requirements one the other hand.

Due to the fact that services are in general immaterial and the complex relationship between customer and service provider, it is often not possible to measure the service quality directly. The GAP model represents a comprehensive framework for determining the quality of services from the customer and company perspective [15][19]. Basis of the GAP model is a division of the interaction relationship into the levels service provider and customer. The GAP model gives an important approach for the detection of faults and gaps in the information flow. The Gaps of this model describe the reasons of quality defects – or rather risks – within the service production [20].

2.2 Service Risks

The term 'risk' is used in a wide range of meanings [21-26]. This applies either for the scientific debate as well as for general linguistic usage. In everyday speech the term is normally used, when negative and unpredictability effects accompany particular events, therefore it is often used in the context of ventures and dangers [27][28]. The term 'risk' therefore is defined as "an uncertain event which, should it occur, would have an effect on achieving the objectives" [26].

The following definition of risk, which is also applied within the scope of the presented approach, reflects these characteristics:

"Risk arises from the uncertainty of future events – whereupon this regularly comes along with an incomplete level of information – and is reflected in the action related effect of a negative discrepancy from a fixed aim." [29]

Risks can be classified in several ways. The types of risk and especially the relative importance for a company very much depends on the specifics of the company, especially as branch-specifics, regional characteristics, etc. [30]. The transitions between the different types of risk are of course fluent. While Campenhausen just differs quite widely between strategic, operational and financial risks, Kalweit makes an additional distinction at the strategic and operational risks between external and internal risks.

Within the presented approach the occurring risks can be divided into service specific risks and service unspecific risks. The service unspecific risks come along with every kind of product or service, like latent and also financial risks, for example a change of laws or the general economic situation. These risks have to be identified and controlled, but cannot be influenced by the service provider.

In contrast the companies can use their experience and different management methods to avoid service specific risks. Yet an established risk management system, adapted to the characteristics of service innovations is not existent. Therefore, the focus of the presented approach lies on the examination of the service specific risks.

Services are defined by their constitutive characteristics, as the immateriality, the simultaneity of accruement and consumption, the high individuality, the process character and above all the high level of customer integration [19][32]. Compared to physical products those service characteristics induce additional risks. The high individuality of services in combination with the strong interaction between service producer and customer makes the implementation of a standardized process almost impossible. Furthermore, prior function controls or rectifications are not realizable because of the immateriality and the simultaneity of accruement and consumption of services; these constitutive characteristics demand for a "first time right" service provision. These circumstances create a multitude of service specific risks, which have to be identified, analyzed, assessed and controlled.

3 Risk-Management-Approach for Service-Innovations

In order to support companies with the systematic generation and implementation of service innovations, a holistic model (figure 1) is developed in the scope of the

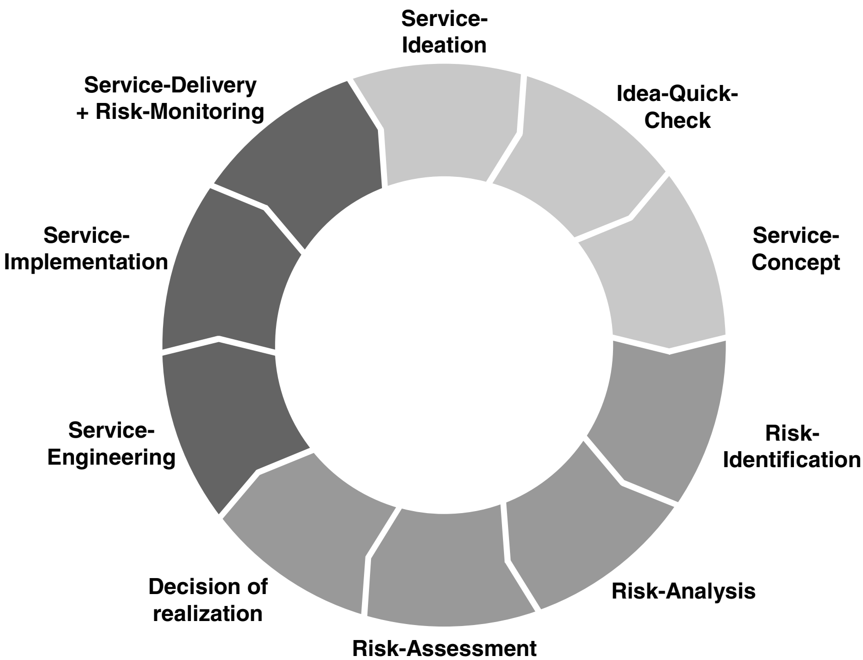


Fig. 1. Quality-oriented Risk-Management-Approach for Service-Innovations

research project ‘ServRisk’, which integrates risk management into the service innovation process to ensure a preventive service quality management. It starts with the generation of innovations, followed by the identification and assessment of risks and ends up with the implementation and evaluation of the performance of the new created service. The approach consists of these three phases, which are divided into ten steps.

3.1 Service-Ideation

The idea for a service innovation arises through the interaction with customers, the study of market and competition conditions, through new technologies or within the company. The implementation of an innovation can occur in connection with new developments of services or through modifying existing processes, organizational structures, forms of contracts and sales channels, changed accompanying products as well as in opening up new markets. Especially the interaction with customers is an important factor for new developments as this provides a maximum information density for innovations and further developments. Furthermore, it supports a substantial reduction of development time [33]. Besides that, it is statistically proven, that an increased autonomy of staff with direct customer contact enhances the innovativeness of service companies [34].

3.2 Idea-Quick-Check

The second step is called "Idea-Quick-Check". By answering seven special questions it serves to check whether an idea for a new service generally has the potential to become a service innovation. A first selection of ideas can be made by using the following questions:

1. Does the innovation contribute to strengthen the customer loyalty?
2. Is the innovation suitable to generate its own income?
3. Allows the innovation for gathering information about the customer?
4. Does the innovation influence the image of the company positively?
5. Does the innovation contribute to offset fluctuations in capacity?
6. Allows the innovation for creating more comfort and security for customer-facing employees and their workplace?
7. Does the innovation lead to a competitive advantage with regard to other companies?

For passing the filtering at least one of these questions has to be answered in the affirmative. If this applies to a considered innovation idea, it should be pursued and the further steps should be continued. In case no question could be answered in the affirmative, there seems no benefit to be given for the company and the service idea can already be discarded at this early stage.

3.3 Service-Concept

In step three a rough concept is designed for the innovative service ideas, which have successfully passed the previous “Idea-Quick-Check”. That basic concept includes first calculations of the required resources, personnel capacity and personnel qualification. Furthermore, it encompasses a basic process design with internal and external interfaces and an appraisal of the expected sales figures.

Consequently, all relevant information that is necessary for a successful identification and evaluation of innovation risks is collected in this step. Thus, it should be handled with great care, because it represents the basis for the following steps.

3.4 Risk-Identification

Within the approach, the service specific risks are divided once more, into strategic risks and risks which come into existence during the service development and delivery process.

The strategic risks include factors such as deficient personnel calculation, inadequate trainings for the personnel, too many hierarchy levels, etc. They are not related to the service delivery process but are, anyhow, affected by the service character of the innovation. The company's location for example could be of greater strategic relevance for a service company, as the physical proximity to the customer is a more significant factor in the field of service delivery than for manufacturing enterprises. Checklists as well as different creative techniques for instance brainstorming and brain-writing can be used for identifying and collecting strategic risks [27].

The service quality and by that also the success of a service innovation depends on the perceived service quality of the customer respectively on the fulfillment of the customer requirements [15]. Therefore, the main risk in fact is that the new implemented service does not comply with the customers' wishes and expectations, which causes a rejection of the service innovation by the customers. Services show a certain process character and in addition to that, the accruement and consumption of services occur simultaneously. Due to that fact, the whole process, including service development and service delivery need to be characterized by high quality, as the customer is involved in every step of the process and by that also perceives the quality of every single phase.

In summary, the process of service development and providing includes the identification of the customers' wishes and expectations, the transmission of those into high quality services and finally the service delivery. In this context a positive customer perception is the main factor of success for a service innovation. Since this perception considers the entire service process, a demand for a concept can be derived, which enables the companies to identify service risks along the entire service process and at the same time considers the special role of the customer. These requirements are achieved by the GAP-Model.

The GAP-Model is a conceptual framework, which supports the determination of service quality from both, the perspective of the customer and that of the company [19][15]. The GAP-Model offers an important approach for the identification of interruptions and gaps during the flow of information and as well for potential risks. The gaps describe the sources of quality defects along the service process. "A set of key discrepancies or gaps exist regarding executive perceptions of service quality and the task associated with service delivery to the consumer. These gaps can be major hurdles in attempting to deliver a service which consumers would perceive as being of high quality." [35]

3.5 Risk-Analysis

Once a risk has been identified, the probability of occurrence as well as the extent of loss have to be assigned to this risk. This requires a detailed knowledge regarding to the causes and consequences of the corresponding risk. Many authors demand a FMEA (failure mode and effects analysis) execution to observe and analyze risks of a new service [18][36]. In the majority of cases such an analysis is, however, quite elaborate [37].

Due to the fact that the presented approach is geared towards small- and medium-sized enterprises (SME) a fishbone- or rather Ishikawa-diagram is envisaged to analyze the risk causes (left-hand side of figure 2). The risk is entered at the 'head' of the fishbone-diagram whereas the main dimensions, which influence the risk origination, will be listed along the 'bones'. This conduces to structure the individual risks as well as the root cause analysis [38]. Thus, it is possible to deduce starting points for reducing or even avoiding a risk.

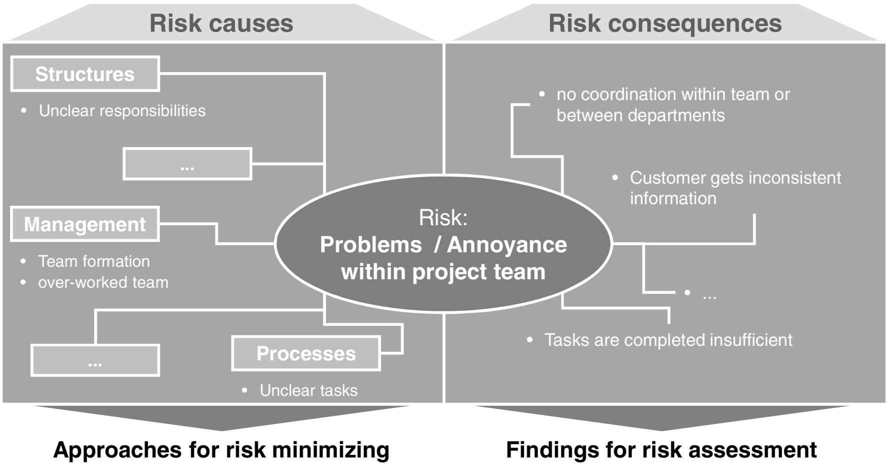


Fig. 2. Scheme of Risk-Analysis

After the causes for risks are identified, the associated consequences have to be estimated in a following step as shown on the right-hand side of figure 2. It is may be appropriate to combine the risk consequences – similar to the causes in the fishbone-diagram – in categories or to form concatenations of risks consequences and display them graphically. Points of reference for the identification of risk consequences can be for instance economic (loss of sales, penalties, fines, surcharges) as well as soft, customer-orientated facts (image, customer relationship etc.). The ensured discussion of the possible risk consequences within the scope of the optional risk analysis allows a precise and realistic risk assessment in the following phase.

3.6 Risk-Assessment

The assessment of the individual service risks is also made in accordance with common risk assessments with regard to a probability of occurrence and a extent of loss. In the presented approach it turned out to be practicable if each the probability and the extent are differentiated into five classes. In addition, another parameter has been implemented, the so called assessability. It is hereby the goal to depict the knowledge of the company regarding to certain risks on a scale from one to five. This parameter is regarded in the risk assessment and shall ensure that the relation between the risk extent and the knowledge or rather the analysis expense is appropriated and in accordance with the risk strategy.

After that the assigned values for the probability of occurrence and the extent of loss of each individual risk are multiplied. Thus, the highest possible level is twenty-five, whereby the lowest possible is one. Specific actions, which are used to handle with individual risks, should depend on the descending order of the prioritized risk values. In this context different opportunities exist to avoid, to reduce, to spread or finally to bear risks.

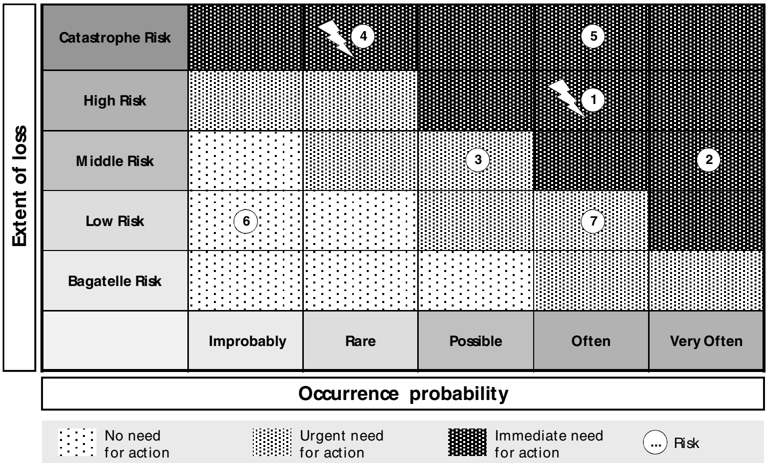


Fig. 3. Risk-Matrix of Risk-Assessment

According to their probability of occurrence and extent of loss the identified risks receive a position within the risk matrix. To clarify the need for action the different areas of the risk matrix are highlighted in different colors. Thereby, red stands for a high, yellow for a medium and green for a minor risk. If the state of knowledge for a risk is very limited or the own knowledge seems to be insufficient compared with the probability of occurrence and the extent of loss this risk is signed with a warning symbol in the matrix. This indicates the need for action with regard to further investigation, which can require a return to the previous, optional step of risk analysis. Figure 3 shows an example for a risk matrix with seven risks. Due to the fact, that the state of knowledge is insufficient for the risks one and four, they are marked with a warning symbol.

3.7 Decision of Realization

The last step of the second phase directs to a reasoned decision whether the innovation should be implemented or discarded. The decision is based on the assessment of risks and possible opportunities.

Innovations, which have a high potential considering their possible opportunities and are fraught with calculable risks should be pursued and implemented.

3.8 Service-Engineering and Implementation

The phase of Service-Engineering includes the development of concepts, elements and processes of service innovations. Followed by the implementation, in which the worked out concepts are realized. This includes for example the creation of documents, the procurement of necessary technical equipment as well as the training of employees.

In the phase of the detailed design and implementation of a service innovation all risks, which have been identified and characterized in advance have to be addressed. This especially contains the design of options for appropriate actions on how to deal with the risks. For the purpose of controlling or manage the risks different goals or rather measures can be followed. The most important include hereby the complete avoidance, the reduction of consequences of an occurrence, the transmission and the separation as well as the retention and setting up of a plan for the recovery of the original state.

The most important elements of a risk management are the risk register as well as the risk management plan. The register comprises primarily documents about the status of the individual risks and should be kept up-to-date. In addition to this it can be used as a basis for regular review dates as well as for the setting up and change of the risk management plan, which designates methods, processes and interfaces of the risk management. Furthermore it regulates responsibilities, authorities as well as roles or rather responsibilities of employees.

3.9 Service-Delivery and Risk-Monitoring

The last step of the presented approach comprises the monitoring of risks and the continuous improvement of services in the delivery. As with all product innovations undesirable conditions and occurred faults have to be expected, which cannot be foreseen in the design and planning phase. This implies that the level of quality and the continuous improvement of the service have to be sustainably ensured by the use of corresponding methods. In this regard the implementation of control loops, an efficient complaint management as well as a regular observation of the risk register and the risk management plan are typical methods. According to a sustainable risk management these particular documents by no means represent fixed recordings of the engineering phase. In fact, they should be seen as working documents for a regular performed review of the service innovation during normal operation.

Based on the detailed evaluation of the delivered services, ideas for new service innovations can be generated by the customer contact personnel. As a result, the cycle of the approach starts again.

4 Conclusion

Innovations serve as an opportunity for companies to differentiate themselves from their competitors, but they are also fraught with risks. The systematically developed approach for identifying, analyzing and assessing these risks was validated with three project partners. It supports the companies considerably within the quality-oriented service development. It enables the identification of risks and the subsequent analysis and evaluation of innovation ideas in the service sector, in order to make a well-funded decision for or against an innovation idea. This will counteract the present trend in practice, in which many decisions are made ad hoc and thus not only financial losses have to be suffered, but also customer loyalty may be damaged.

Acknowledgments. The support with funds of the European Union and the German federal state of North Rhine-Westphalia is greatly acknowledged.

References

1. Dold, E., Gentsch, P.: Innovation möglich machen. Handbuch für effizientes Innovationsmanagement, p. 15. Symposium, Düsseldorf (2007)
2. Albers, S., Gassmann, O.: Handbuch Technologie- und Innovationsmanagement, p. 5. Gabler, Wiesbaden (2011)
3. Klinski, S., Haller, S.: Die unsichtbare Hand im Unternehmen. Mit serviceorientierten Unternehmensstrukturen die Performance steigern und wettbewerbsfähig bleiben. Gabler, Wiesbaden (2005)
4. Barske, H.: Charakteristika erfolgreicher innovativer Unternehmen. In: Barske, H., Gerybadze, A., Hünninghausen, L., Sommerlatte, T. (eds.) Digitale Fachbibliothek Innovationsmanagement. Motivieren, Kooperieren, Führen, p. 1. Symposium, Düsseldorf (2006)
5. Barske, H.: Innovation und Risiko. In: Barske, H., Gerybadze, A., Hünninghausen, L., Sommerlatte, T. (eds.) Digitale Fachbibliothek Innovationsmanagement. Motivieren, Kooperieren, Führen, pp. 1–11. Symposium, Düsseldorf (2006)
6. Wittmann, R.G., Leimbeck, A., Tomp, E.: Innovation erfolgreich steuern. Süddeutscher Verlag, Heidelberg (2006)
7. Bruhn, M.: Wirtschaftlichkeit des Qualitäts management. Grundlagen, Konzepte, Methoden. Springer, Heidelberg (1998)
8. Bullinger, H.-J., Scheer, A.-W.: Service Engineering. Entwicklung und Gestaltung innovativer Dienstleistungen. Springer, Heidelberg (2006)
9. Zangemeister, C.: Innovationsprozessmanagement für Dienstleistungen. TÜV-Media, Köln (2008)
10. Busse, D.: Innovationsmanagement industrieller Dienstleistungen. Theoretische Grundlagen und praktische Gestaltungsmöglichkeiten. Gabler, Wiesbaden (2005)
11. Sommerlatte, T.: Innovationschancen aufspüren – ein Überblick. In: Barske, H., Gerybadze, A., Hünninghausen, L., Sommerlatte, T. (eds.) Digitale Fachbibliothek Innovationsmanagement, Motivieren, Kooperieren, Führen, pp. 1–11. Symposium, Düsseldorf (2006)
12. Eversheim, W., Jaschinski, C., Reddemann, A.: Qualitätsorientierte Dienstleistungsentwicklung. In: Barske, H., Gerybadze, A., Hünninghausen, L., Sommerlatte, T. (eds.) Digitale Fachbibliothek Innovationsmanagement. Motivieren, Kooperieren, Führen, p. 1. Symposium, Düsseldorf (2006)
13. Gatermann, I., Fleck, M.: Technologie und Dienstleistung. Innovationen in Forschung, Wissenschaft und Unternehmen; Beiträge der 7. Dienstleistungstagung des BMBF, p. 59. Campus, Frankfurt am Main (2008)

14. Kriegesmann, B., Kerka, F.: Innovationskulturen für den Aufbruch zu Neuem. Missverständnisse, praktische Erfahrungen, Handlungsfelder des Innovationsmanagement. Schäffer-Poeschel, Stuttgart (2004)
15. Bruhn, M.: Qualitätsmanagement für Dienstleistungen. Qualitätscontrolling für Dienstleistungen. Springer, Heidelberg (2008)
16. Reinhart, G., Schnauber, H.: Qualität durch Kooperation. Interne und externe Kunden-Lieferanten-Beziehungen. Springer, Heidelberg (1997)
17. Hansen, W., Kamiske, G.F.: Qualitätsmanagement im Dienstleistungsbereich. Assessment - Sicherung – Entwicklung, p. 7. Symposion, Düsseldorf (2002)
18. Eversheim, W.: Qualitätsmanagement für Dienstleister. Grundlagen, Selbstanalyse, Umsetzungshilfen, pp. 1–103. Springer, Heidelberg (1997)
19. Meffert, H., Bruhn, M.: Dienstleistungsmarketing. Grundlagen, Konzepte, Methoden. Gabler, Wiesbaden (2006)
20. Jaschinski, C.: Qualitätsorientiertes Redesign von Dienstleistungen, p. 15. Shaker, Aachen (1998)
21. König, R.: Management betrieblicher Risiken bei produzierenden Unternehmen. RWTH Aachen (2008)
22. Dahmen, J.: Prozessorientiertes Risikomanagement zur Handhabung von Produktrisiken. RWTH Aachen (2002)
23. Kalwait, R.: Risikomanagement in der Unternehmensführung. Wertgenerierung durch chancen- und kompetenzorientiertes Management. Wiley-VCH, Weinheim (2008)
24. Rogler, S.: Risikomanagement im Industriebetrieb. Analyse von Beschaffungs-, Produktions- und Absatzrisiken, p. 5. Deutscher Universitäts-Verlag, Wiesbaden (2002)
25. Locher, C.: Risikomanagement in Finanzwirtschaft und Industrie. Eine Analyse des Managements operationeller Risiken in deutschen Industrie- und Dienstleistungsunternehmen, p. 22. Universität Regensburg (2005)
26. Link, P.: Risikomanagement in Innovationskooperationen. Ein Ansatz zur fairen Aufteilung von Chancen und Risiken, pp. 12–19. ETH Zürich (2001)
27. Schnorrenberg, U., Goebels, G., Rassenberg, S.: Risikomanagement in Projekten. Methoden und ihre praktische Anwendung. Vieweg, Braunschweig (1997)
28. Strohmeier, G.: Ganzheitliches Risikomanagement in Industriebetrieben. Grundlagen, Gestaltungsmodell und praktische Anwendung. Deutscher Universitäts-Verlag, Frankfurt am Main (2007)
29. Schulte, M.: Bank-Controlling II. Risikopolitik in Kreditinstituten. Bankakademie e.V., Frankfurt am Main (1997)
30. Wolke, T.: Risikomanagement. Oldenbourg, München (2008)
31. van Campenhausen, C.: Risikomanagement. Was der Manager wissen muss, pp. 14–15. Orell Füssli, Zürich (2006)
32. Freiling, J., Weißenfels, S.: Innovationsorientierte industrielle Dienstleistungsnetzwerke: Aufbau, Steuerung und Wettbewerbsvorteilspotenziale. In: Bruhn, M., Strauss, B. (eds.) Dienstleistungsnetzwerke. Dienstleistungsmanagement Jahrbuch 2003, pp. 467–489. Gabler, Wiesbaden (2003)
33. Alam, I.: Removing the fuzziness from the fuzzy front-end of service innovations through customer interactions. Industrial Marketing Management 25(4), 468–480 (2006)
34. Das, S.: Process innovativeness in technology services organizations: Roles of differentiation strategy, operational autonomy and risk-taking propensity. Journal of Operations Management 25(3), 643–660 (2007)
35. Parasuraman, A., Zeithaml, V.A., Berry, L.L.: A conceptual model of service quality and its implications for future research. The Journal of Marketing 49, 41–50 (1985)

36. Fähnrich, K.P.: Service Engineering. Entwicklungspfad und Bild einer jungen Disziplin. In: Bullinger, Scheer (Hrsg.) Service Engineering, pp. 85–112. Springer, Berlin (2006)
37. DIN 60812:2006 - Analysetechniken für die Funktionsfähigkeit von Systemen – Verfahren für die Fehlzustandsart- und -auswirkungsanalyse (FMEA), p. 31. Beuth, Berlin (2006)
38. Bruhn, M.: Messung der Anforderungen an die Dienstleistungsqualität. In: Hansen, W., Bruhn, M. (Hrsg.) Qualitätsmanagement im Dienstleistungsbereich, p. 9. Symposion, Düsseldorf (2003)

Product Service Systems Design Focusing on System Aspect: Total Value Creation for Various Stakeholders

Fumiya Akasaka, Yutaro Nemoto, and Yoshiki Shimomura

Department of System Design, Tokyo Metropolitan University, Asahigaoka 6-6, Hino-shi, Tokyo 191-0065, Japan
akasaka-fumiya@sd.tmu.ac.jp

Abstract. Product-Service System (PSS) is regarded as a new business concept for manufacturing firms to enhance the value of their products and build up strong relationships with their customers. To realize a sustainable business, it is important for them to make a business situation where each stakeholder involved receives values through the provision of PSS. The designers have to have a holistic view and consider the total value created within the system. This paper proposes a method to design PSS that have high value for each stakeholder. In this method, a PSS is designed through a "design cycle" composed of three phases such as: (1) modeling, (2) simulation, and (3) new scenario description. In this method, a PSS is designed under the simultaneous consideration of values received by various stakeholders.

Keywords: Product-Service Systems, Design, Modeling, Simulation

1 Introduction

Product-Service System (PSS) is nowadays regarded as a new business model for manufacturing firms to gain competitiveness. PSS is a *consisting of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs* [1]. To achieve a sustainable business through PSS offering, it is important to realize a business situation where each stakeholder involved in the PSS can receive sufficient amount of values. Namely, PSS designers have to have a holistic view and consider the "total" value created for all stakeholders in the PSS.

2 PSS Design

2.1 Definition of PSS

The concept of PSS is sometimes regarded as just a combined provision of product and service that fulfills customer needs (e.g., machine and maintenance). However, such vision for PSS can be thought as an insufficient understanding of the concept. The essence of the concept is that realizing a social system where all stakeholders including providers and receivers can receive sufficient values through cross-offerings

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 371–382.
DOI: 10.1007/978-3-642-30820-8_32

of products and services. This "system", which consists of various stakeholders who provide/receive products and services, exactly corresponds to the last "S" in a term "PSS". Meier et al. [2] explains this concept in a context of Industrial PSS as Figure 1. This figure illustrates a PSS is not just a "product plus service" but a system of co- and cross-offering of a product/ service/ product-service combination.

On the basis of the discussion above, in this research, a service is defined as "a social system to enhance social and economic values for stakeholders through the co- and cross- offering of products/ services/ product-services within the system." Here, product-service means the integrated offering of product and service.

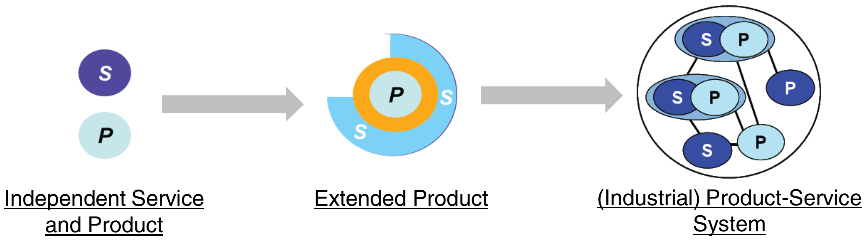


Fig. 1. Evolution of product and service integration (taken from [2])

2.2 PSS Design

Researches to establish a methodology to design PSS have been widely conducted in these years. The authors have proposed methods for designing PSS within the series of Japanese Service Engineering (SE) research [3-4]. In our approach, customer values are represented as parameters; the basic structure of a PSS is modeled with the functional structure that satisfies customer needs, and specific entities are associated with the functional structure. Here, entities include both physical products and human resources.

Meanwhile, Müller et al. proposes the PSS Layer Method [5] for designing PSS. In Layer Method, a PSS is modeled with eight basic elements: Needs, Values, Deliverables, Activities, Actors, Core product, Periphery, and Contract. Needs and Values are firstly defined. Other six elements are then determined on the basis of the defined needs and values.

2.3 Total Value within a PS "System"

As discussed in 2.1, in PSS design, it is important to design PSS structure that creates high values for each stakeholder. A famous PSS example "Power-by-the-hour" by Rolls-Royce plc. [6] is a good design solution from such viewpoint. Here, Rolls-Royce leases out the power of a gas turbine engine rather than transferring ownership of the engine product. Many services such as fixed-fee maintenance, back-up service, condition monitoring, predictive maintenance, and parts-life management are offered to customers. By doing this, risks in the usage of turbine engine can be decreased, and at the same time, the engine provider can collect data on product use that is useful for new product development. The Power-by-the-hour solution can provides values for both provider and receiver and realize the "win-win" relationship between them. In addition, this solution has positive value for the global environment, which can be regarded as a stakeholder, since the reusability of engine parts can be increased through the consistent product management by engine provider.

However, it is difficult to design such PSS structure using the existing PSS design methods reported in 2.2, since they do not explicitly focus on values for all stakeholders involved. The design target of these methods is increasing values of specific customer, who is just one component of its stakeholder network.

This paper proposes a method to design PSS that have high value for each stakeholder. In this method, a PSS is designed through a "design cycle" composed of three phases such as: (1) modeling, (2) simulation, and (3) new scenario description. In this method, a PSS is designed under the simultaneous consideration of values received by various stakeholders.

3 System Modeling and Simulation

3.1 System Dynamics

System Dynamics (SD) [7] is an approach to understanding and analyzing the behavior of complex system over time through the modeling of relationships among components within the system. SD can deal with internal feedback loops and time delays that affect the behavior of the entire system.

In the SD methodology, a system is first represented as the Causal Loop Diagram (CLD). A CLD is a map of the system with all its constituent components and their interactions. By capturing interactions and the feedback loops, a causal loop diagram reveals the structure of a system.

The CLD supports to visualize a system's structure and behavior and to analyze the system qualitatively. To perform a more detailed quantitative analysis, a CLD is transformed to a Stock and Flow Diagram (SFD). In SFD, the structure of a system is modeled with the concepts of "stocks" and "flows". A stock is a component that accumulates or depletes over time. On the other hand, a flow is the rate of change in a stock. Figure 2 illustrates examples of CLD and SFD that represents a social system focusing on the population change. In the CLD (Figure 2 (a)), two kinds of feedback loops are illustrated. A feedback loop colored blue is a positive reinforcement loop that represents the number of "population" will be increased when the more number of "births" is obtained. The other loop colored red is a negative reinforcement loop. This loop represents a negative effect of "deaths" on the number of "population". Figure 2 (b) is the SFD that is translated from the CLD shown in Figure 2 (a). This diagram depicts that a stock variable "population" changes due to two flow variables "births" and "deaths"; and the number of births and deaths are determined by other subsidiary variables such as "the rate of birth" and "the rate of death". The behavior of this system is simulated by producing mathematical descriptions among those variables.

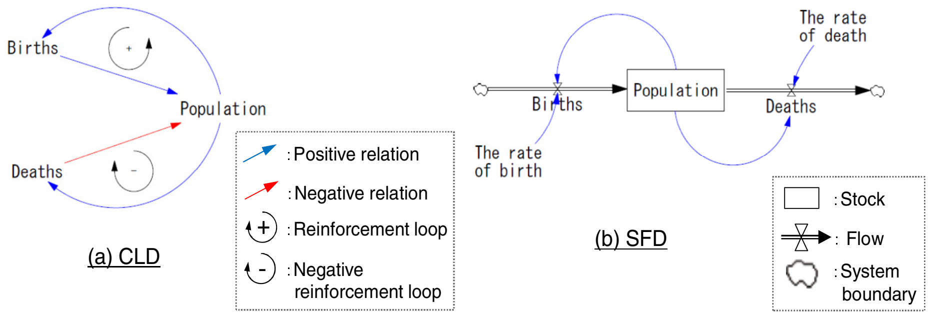


Fig. 2. System Dynamics: CLD and SFD

3.2 PSS Modeling and Simulation with System Dynamics

Generally, the SD is suitable for modeling and simulating a social system that includes multiple and complex feedback loops. A PSS can be regarded as a social system including many feedback loops, since multiple stakeholders exist within the system and they mutually affect each other. In this research, consequently, the SD is utilized to model a PSS structure and to simulate its behavior. The simulation enables designers to evaluate values received by stakeholders in the phase of design.

4 PSS Design Considering Total Value for Various Stakeholders

4.1 Design Cycle

Figure 3 shows the overview of the proposed method. The method enables to design a PSS that has high total values for all stakeholders involved with an approach of a "design cycle" composed of three phases such as: "modeling", "simulation", and "new scenario description".

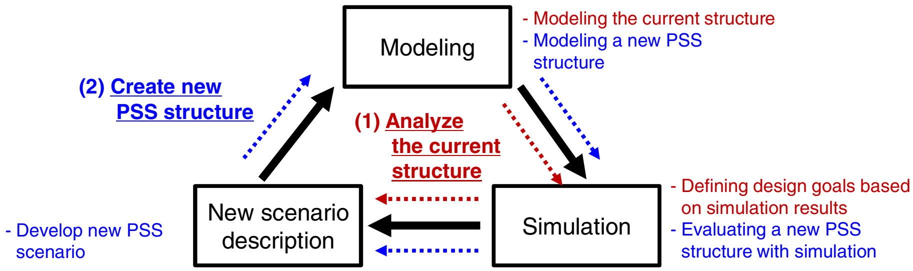


Fig. 3. Overview of the proposed method

The first cycle of this design cycle (colored red in Figure 3) is that for analyzing the current structure of a PSS. In this cycle, the design goals are defined through the modeling and simulation of the current PSS. Subsequently, a design solution can be derived by repeating the design cycle for creating new PSS structure (colored blue in Figure 3). The remainder of the Section 4 (4.2 – 4.4) explains concrete methods and procedures of each phase of this cycle, namely “modeling”, “simulation”, and “new scenario description”.

4.2 PSS Modeling

On the basis of the definition discussed in 2.1, in this research, we model a PSS structure with four elements: “stakeholder”, “value”, “PS provided/received within the system”, and “Material, money, and Information provided/received within the system”. The model is called as PSS network model. Figure 4 shows an example. In this figure, the stakeholder A provides a PS for stakeholder B, and receives information at the same time. Meanwhile, the stakeholder C receives money in exchange for a product, which is represented as material flow in Figure 4. It is noteworthy that a term “value” in this model includes both economic value (e.g., profit, cost, etc.) and social value (e.g, health, usability, etc.).

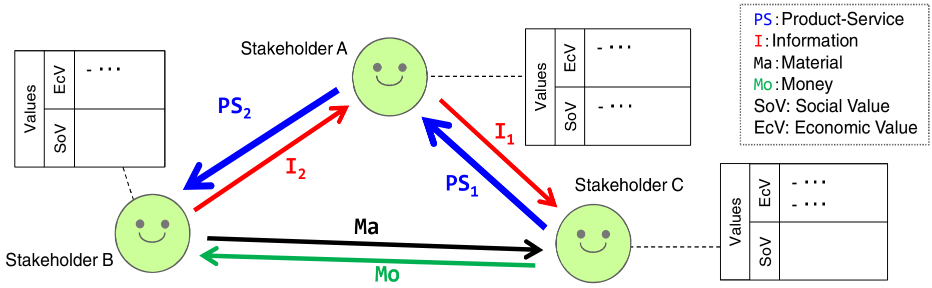


Fig. 4. PSS network model

4.3 PSS Simulation

A CLD is constructed based on the constructed PSS network model. Here, parameters that measure the fulfillment of each stakeholder’s values are determined. Then, variables that have direct/indirect influences for the change of the parameters are collected by, for example, the brainstorming method. These variables and parameters are connected each other with causal relationship, and CLD is constructed. The SFD is then obtained by translating the CLD for the quantitative simulation.

By setting mathematical equations to each relation between variables in SFD, a quantitative simulation to observe temporal changes of the each stakeholder’s values can be carried out.

4.4 New Scenario Description

On the basis of the simulation result, designers co-create hypothetical scenarios regarding new PSS structures in which each stakeholder can obtain higher value.

Designers then model the created scenario with the PSS network model and evaluate it with the SD simulation. If the simulation result satisfies the design goal defined sufficiently, it can be adopted as a design solution. If not, designers have to reconsider new scenario for the PSS.

5 Application to an Example Case

5.1 Example Case: A Car Sharing Example

The proposed method was applied to an example PSS case to verify the effectiveness of the method. The example used in this study was a car sharing operated in a specific area of Tokyo city center. Descriptions below explain the detailed settings of the example.

- The car sharing service is already commonly used in the area.
- Generally, if car sharing services become widely used in a specific area where ca sharing is not so common, the car ownership rate will decline and the total number of cars in the area will come down. However, in this example, we assumed that the car sharing is commonly used and the car ownership rate is already low. Therefore, even in a case that a car sharing service become more popular, the total number of cars in the area will not be decrease but increase due to the increased number of car sharing stations.
- The customers' purpose of using a car is to go to a big shopping mall, which is located approximately 15 kilo meters from Tokyo city center, in weekend. It is noteworthy that each customer goes to the shopping mall once a month, and in the other weekend, they do shopping at the city center without using cars.
- Gasoline cost is included in the fees for car sharing service. Namely the car sharing provider pays for the gasoline to gas stations.
- Too many number of car sharing users results in a decrease of availability of a car sharing service, since the number of cars is limited in the area. In this context, availability means the rate that users can use a car when he wants to use it.
- The increased number of cars on roads leads to the higher probability of traffic jam, which makes users frustrated.
- The car sharing provider can collect data of product use (e.g., user attributes, travel distance, destination, etc.)
- Car manufacturing and use emit CO_2 into the global environment.

5.2 Modeling of the Current Structure of Car Sharing Example

At first, the current structure of the car sharing was modeled with the PSS network model. Figure 5 illustrates the result. As shown in Figure 5, stakeholders of the car sharing were user, car sharing provider, car manufacturer, gas station, shopping mall in Tokyo suburb, shops in Tokyo city center, and the global environment. Here, each stakeholder has his own values. For example, the users require values such as "low cost", "high availability", and "low rate of traffic jam".

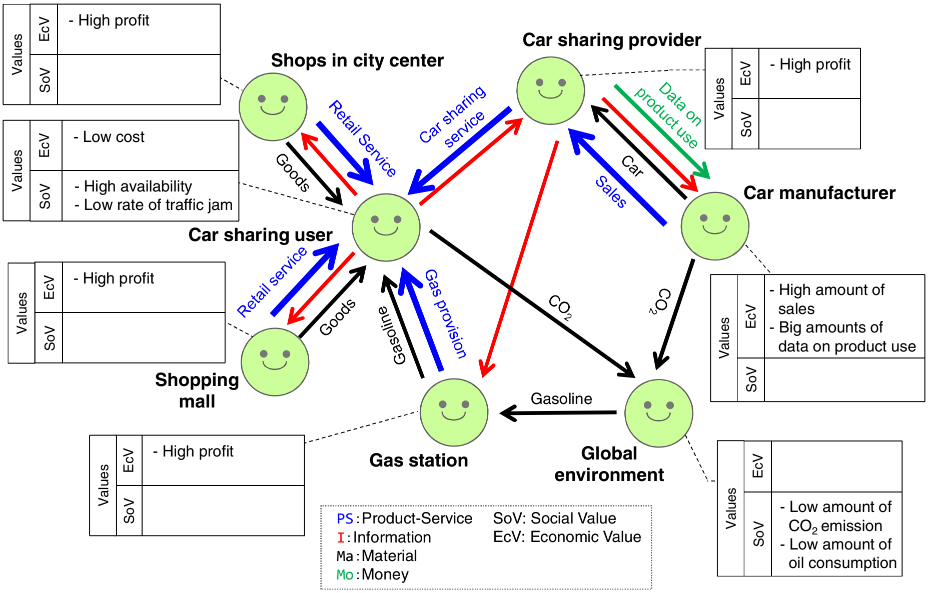


Fig. 5. The result of PSS modeling by the PSS network model

5.3 Simulation of Car sharing Example

From the constructed PSS network model, parameters that measure the fulfillment of each stakeholder's values were determined. For instance, "cost that a user pays for the use of a car" was set as a parameter to measure the fulfillment of a user's value "low cost". Subsequently, variables that have direct/indirect influences for the change of the parameters were collected through the brainstorming process. These variables and parameters were connected each other with causal relationship; and CLD was then constructed. The result is shown in Figure 6. In Figure 6, parameters that measure the fulfillment of each stakeholder's values are colored green; arrows colored blue represents the positive causal relationships and that of colored red are the negative relationships.

In this CLD model, some feedback loops that determine the system behavior can be found. Figure 7 depicts examples of feedback loops as determinants of "Profit of the car sharing provider." Here, three kinds of feedback loops are found. Two of them are positive loops (loops colored blue with "+") that correspond mechanisms to enhance car sharing provider's profit; and the other is a negative loop (a loop colored red with "-") that decrease his profit. The "Profit of the car sharing provider" is calculated by the power balance of these positive and negative loops.

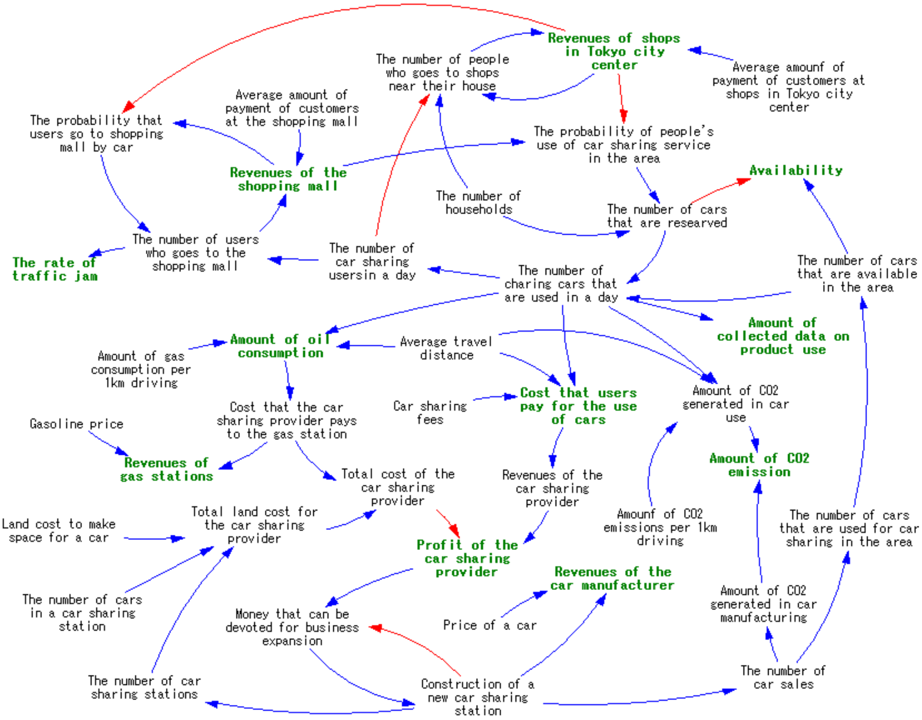


Fig. 6. The result of PSS modeling by the PSS network model

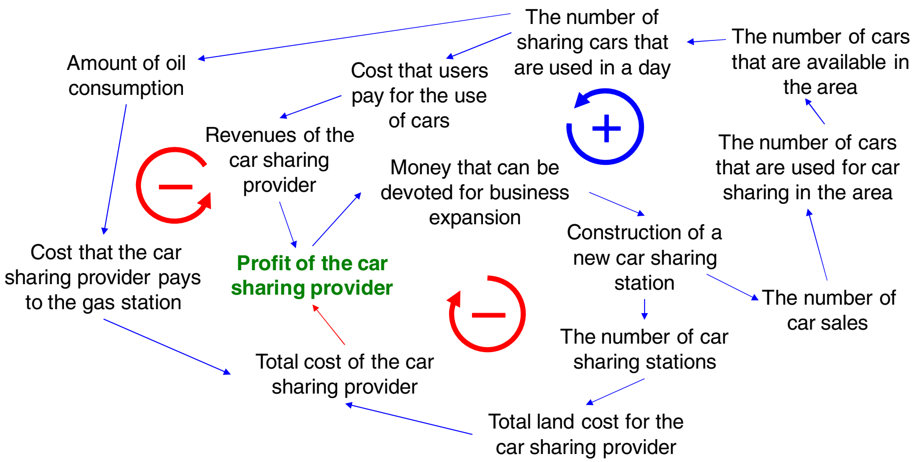


Fig. 7. Feedback loops that determine "Profit of the car sharing provider"

SFD was obtained by translating the CLD and the quantitative simulation was carried out using Vensim [8], which is famous software for SD simulation. The settings in the simulation are described below. In this research, these settings were determined on the basis of the statistical surveys by the Tokyo metropolitan government [9] and other reports concerning the car sharing business in Japan [10-12].

- The number of households in the target area: 44,000 (Car ownership rate: 50%)
- The number of users who use the car sharing service in a weekend: 308 (0.7% of the all households)
- The initial number of car sharing stations: 150
- The number of cars in one station: 2
- Fees for car sharing: 100 JPY/km
- Fuel-efficiency of a car: 12.8 km/L
- Amount of CO_2 emission in driving a car: 35 g/km
- The rate of traffic jams on the road in the target area: 20% up to 120 cars used. If more than 120 cars are used, the probability becomes 50% and it will increase linearly depending on the number of cars.

The results of the simulation were shown in Figure 7. These graphs represent the temporal changes of the each stakeholder's values. On the basis of the results, goals of this PSS design were defined as below.

1. Make the value of availability 1.0 at any time. (All users can use a car at any time when they want to use it.)
2. Reduce the CO2 emissions.
3. Decline the probability of traffic jams.

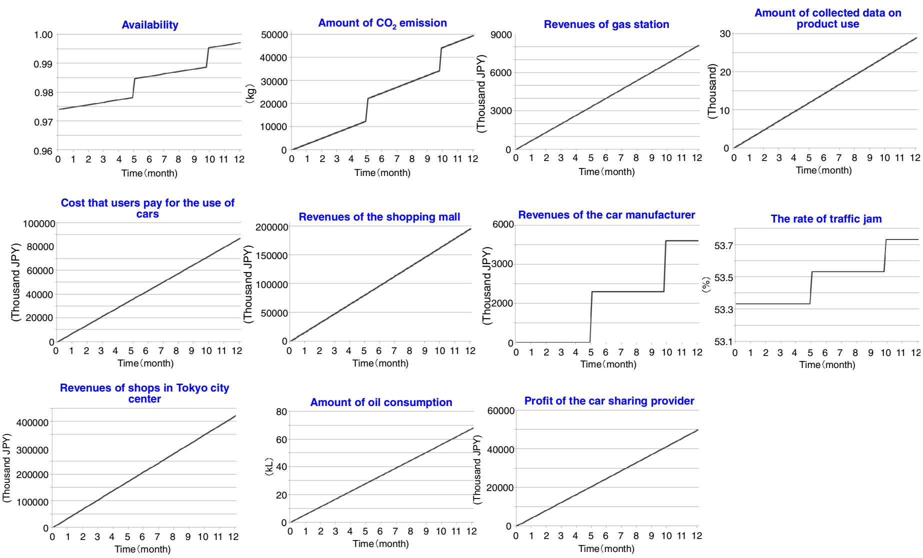


Fig. 8. The result of the simulation of current PSS

5.4 New Scenario Description and Evaluation

In this application, two scenarios, which are described in Table 1, were created to improve the car sharing PSS. The first one was "Electric Vehicle (EV)" scenario and the other was "Cooperation with public transportation" scenario. These scenarios were then translated into the PSS network models, CLD, and finally SFD. Simulations to evaluate the amount of values that each stakeholder receives were carried out. Figure 8 illustrates the simulation results. In Figure 8, graphs regarding "Revenue of the utility company," "Amount of power consumption," and "Revenues of the rail company" are newly appeared, since new stakeholders such as the utility company and rail company were added in the two scenarios created.

Figure 8 shows that the "EV" scenario is very effective to reduce CO_2 emissions and oil consumptions. It also contributes to the increase in profits of the car manufacturer. However, it does not have positive effects to improve availability and to decline the probability of traffic jams. It can be therefore said that this scenario does not satisfy the design goals sufficiently. On the other hand, in the "Cooperation with public transportation" scenario, the value of availability was always 1.0 and the probability of traffic jams were declined by 5% compared to the current PSS. It also contributes to reduce CO_2 emissions and oil consumptions. Moreover, a public rail company was added as a new stakeholder, and his profits can be increased.

From these results, the "Cooperation with public transportation" scenario was accepted as a (tentative) design solution, since it could be thought that the scenario satisfied design goals. However, there is a room to improve the solution, since the profit of the car sharing provider would be decreased in this scenario as shown in Figure 8.

Table 1. Example of a table

Scenario	Explanation
Electric Vehicle (EV)	*Overview*: All of cars used in car sharing are changed to EVs. In this scenario, it is expected to reduce CO_2 emissions and oil consumptions. *Stakeholders and values newly added*: A utility company whose value is "high profit" was added as a new stakeholder. "Less electronic power consumption" was newly added as a value for global environment.
Cooperation with public transportation	*Overview*: The car sharing provider establishes partnership with a rail company offering public transportation. New car sharing stations are newly constructed near a station at Tokyo suburb. Some of users take a train to the station and use a car to the shopping mall. In this scenario, it is expected to decline the probability of traffic jams at city center area as well as reducing CO_2 emissions and oil consumptions. *Stakeholders and values newly added*: A rail company whose value is "high profit" was added as a new stakeholder.

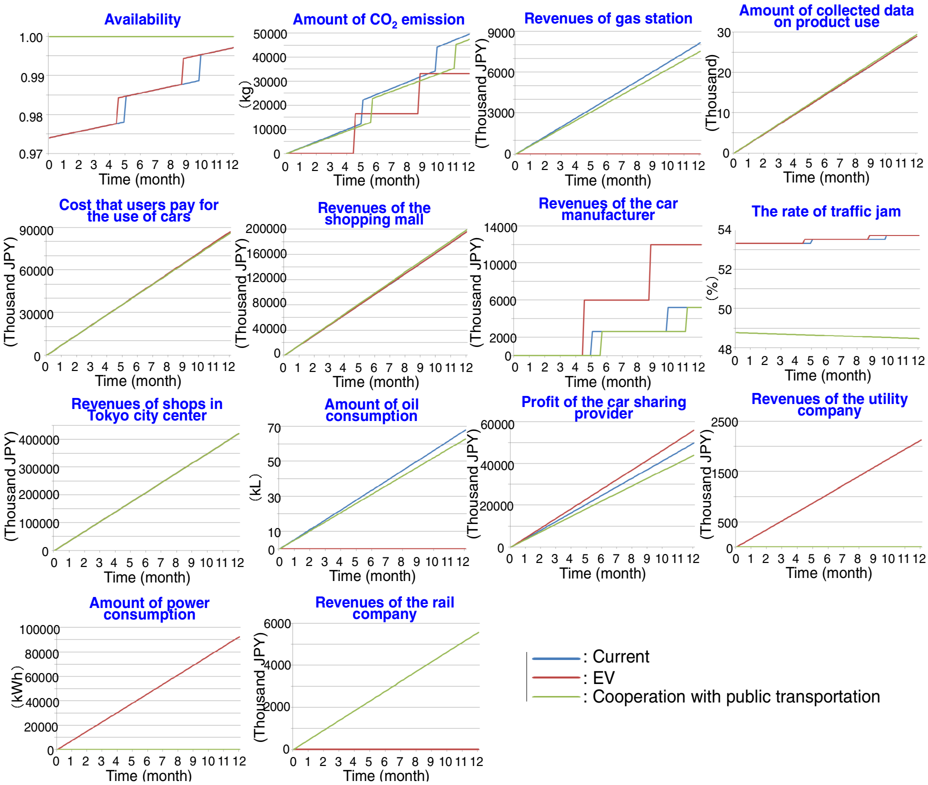


Fig. 9. The result of the simulation to evaluate the derived PSS scenarios

6 Concluding Remarks

In this research, a method to design PSS that have high value for each stakeholder is proposed. The idea of this study is to realize the simultaneous consideration of values received by various stakeholders with the "design cycle" approach. The design cycle proposed in this study is composed of three phases such as: (1) modeling, (2) simulation, and (3) new scenario description.

The proposed method was applied to an example PSS case featuring car sharing. In the application, it was possible to design new car sharing service such as "Cooperation with public transportation" under consideration of values received by each stakeholder involved. Designers could create new PSS scenario on the basis of the results of the modeling and simulation. The models (i.e., PSS network model, CLD, SFD) provided a kind of unified view for co-designing among multiple designers. The simulation enables designers to evaluate the designed PSS structure and the results were effectively used as criteria when they consider new PSS scenarios.

On the other hand, the translation between models, especially translation from the PSS network model to CLD, put a burden on designers. It really depended on designers' experiences and results of the brainstorming. To solve this problem, a method to support designers in this transformation process should be proposed in future works.

Acknowledgments. This research was partially supported by the JSPS (Japanese Society for the Promotion of Science) Research Fellowship for Young Scientist.

References

1. Tischner, U., Verkuijl, M., Tukker, A.: First Draft PSS Review. SusProNet Report (2002)
2. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems-IPS2. CIRP Annals - Manufacturing Technology 59(2), 607–627 (2010)
3. Shimomura, Y., Tomiyama, T.: Service Modeling for Service Engineering. In: Arai, E., Kimura, F., Goossenaerts, J., Shirase, K. (eds.) Knowledge and Skill Chains in Engineering and Manufacturing. IFIP, vol. 168, pp. 31–38. Springer, Boston (2005)
4. Shimomura, Y., Sakao, T., Sundin, E., Lindahl, M.: A Design Process Model and a Computer Tool for Service Design. In: Proceedings of the 12th Design for Manufacturing and the Life Cycle Conference - DFMLC 2007. CD-ROM (2007)
5. Müller, P., Kebir, N., Stark, R., Blessing, L.: PSS Layer Method - Application to microenergy systems. In: Sakao, T., Lindahl, M. (eds.) Introduction to Product/Service-System Design. Elsevier (2009)
6. Rolls-Royce, `http://www.rolls-royce.com/`
7. Sterman, J.D.: Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hill (2000)
8. Ventana Systems, Inc., Vensim, `http://www.vensim.com/`
9. Bureau of Citizens and Cultural Affairs, Tokyo Metropolitan Government: Survey on vehicle use and environment (2010) (in Japanese)
10. Nakao, K.: Carsharing usage patterns: a case study in Kyoto city. Core Ethics 7, 199–210 (2011) (in Japanese)
11. Foundation for Promoting Personal Mobility and Ecological Transportation: Report on the effect of carsharing on the environmental load reduction (2006) (in Japanese)
12. Foundation for Promoting Personal Mobility and Ecological Transportation: Report on the transition of the number of members and cars in carsharing business in Japan (2009) (in Japanese)

Development and Evaluation of a Novel Service Productivity Model

Andreas Petz[1], Sönke Duckwitz[1], Christina Schmalz[2], Susanne Mütze-Niewöhner[1], and Christopher M. Schlick[1]

[1] Institute of Industrial Engineering and Ergonomics RWTH Aachen University, Aachen, Germany
[2] Deutsche Post Chair of Optimization of Distribution Networks RWTH Aachen University, Aachen, Germany
{a.petz,s.duckwitz}@iaw.rwth-aachen.de

Abstract. Although the early stages of engineering service development are essential, methods and tools to proactively and comprehensively evaluate the productivity of service processes are rare. Therefore, this paper presents a comprehensive model for product-service systems productivity assessment along the service provision chain. The novel productivity model distinguishes between potential, process and outcome thus covers all dimensions of a product-service system. The model further differentiates between service provider and customer from both a qualitative and quantitative point of view. A set of value drivers and success criteria is proposed in a structured manner, resulting in various levers to optimize a product-service system. The model is made fully operational by defining influence factors, representing parameters to optimize service productivity and by key figures measuring service effectiveness and efficiency. To evaluate the novel service productivity model, field data and expert opinions from two German engineering companies are considered.

Keywords: Influence Factors on Service Provision, Key Figures, Service Assessment, Service Productivity.

1 Introduction and Motivation

Besides offering pure component development services, providers of complex engineering services are eager to offer complementary design and optimization services across the entire product lifecycle. Thereby, the early phases of product-service systems design play a crucial role and provide the foundation for high product quality as well as for successful and sustainable service provision [1], [21-22].

Continuous productivity improvement in manufacturing belongs to the standard repertoire of business managers. As services gained significant importance in developing and developed countries, existing traditional models, methods and tools for productivity management were not sufficiently adopted to cope with emerging

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 383–394.
DOI: 10.1007/978-3-642-30820-8_33

product-service system-specific characteristics. A holistic approach for performance assessment is needed to comprehensively design and manage product-service systems.

This paper aims to bridge the gap and provides a comprehensive service system productivity model. In the next section, a brief overview of relevant service definitions is given and productivity definitions from manufacturing are discussed. The relevant service productivity models are described and important characteristics of services to be considered in a service productivity model are pointed out. Based on these findings our novel service productivity model is presented and evaluated by field data from semi-structured interviews and workshops with service experts.

2 Services and Productivity

2.1 Services

In literature, the most common starting point for defining services is the macroeconomic division of industry sectors and branches. The World Trade Organization provides a sectoral classification list consisting of 12 sectors and 160 sub-sectors aiming a cross-country comparability and consistency of service policies defined in the "General Agreement on Trade in Services" [10]. Such an approach is not suitable for service evaluation and design due to the classification on a broad level and a fuzzy differentiation of the branches. There are no general accepted criteria for the delimitation and thus the classification remains ambiguous [3].

From the business economics perspective, different approaches for service definition can be distinguished. Simple approaches aim at defining services by examples; more advanced approaches distinguish services from goods by describing main differences. These approaches face the problem that a generally accepted list of differences does not exist [3], [16].

The most common approach on a definition of services is based on the specification of constitutive service characteristics according to Hilke (1989) and Donabedian (1980). Following their dimensional differentiation, services can be defined along the service provision chain in three dimensions: the potential dimension, the process dimension and the outcome dimension. Many scholars have adopted and enhanced this concept by enlarging it with relevant service specific characteristics known as the IHIP characteristics: *Intangibility, Heterogeneity, Inseparability* and *Perishability* [8]. Services are perishable because, unlike goods, they cannot be stored and are highly space and time dependent. The service provision and consumption process are inseparably connected because of the customer integration. As the customer is an integrative part of the service provision and the service itself is intangible, complex services are characterized by a high degree of heterogeneity and the perceived service outcome is from immaterial nature.

2.2 Productivity

A macroeconomic definition of productivity is given by the Organization for Economic Cooperation and Development [17]. Following OECD, productivity is defined as the ratio of value based outputs to inputs for tracing technical change, identifying changes in efficiency as well as benchmarking production processes. Productivity measures are classified either as single factor productivity measures or multifactor productivity measures relating to one or multiple factors of input. OECD further differentiates input factors between single measures like labor and capital or multifactor measures like capital-labor. In terms of output measures, a differentiation between gross output and value added concepts is proposed.

Productivity measurement from the macroeconomic point of view has some advantages for comparing countries and industry branches. The main drawback refers to the black box perspective taken in terms of neglecting the joint influence of a subset of factors. Thus, multifactor productivity measure seems more suitable for a differentiated factor analysis. The drawback of this approach is the diversity of the input as well as output factors. Indexing the price is one possible solution to cope with this problem, but price indices are difficult to measure in the service industry [17]. Furthermore, the measures proposed are only suitable on a broad level; without further research the identification of interrelations of levers for productivity improvements on a business process level is not possible.

Productivity in business economics is defined similarly as the ratio of volumes of output and input, but it is related to isolated production systems, mainly production plants and sites. Corsten (1994, 2007) specifies productivity from a broad, economic point of view and a narrowed, technical point of view. From a broad perspective productivity is considered as the profitability of the company and it is defined as the ratio between income and input factor costs. Technically, productivity is defined as the ratio between volumes of input and output describing the production capability of the system.

The major deficit of business economics oriented productivity concepts is the consideration of isolated production systems, where the customer is not an active part of the process. Thus, service specific characteristics like customer influence and customer perceived quality are not considered in these concepts.

2.3 Characteristics of Specific Service Productivity Concepts

There is a general mismatch between the specific service characteristics like IHIP and the technical, production oriented productivity concept. According to the description of services in section 2.1, some scholars developed specific concepts of service productivity. These service productivity models refer to many aspects of the named constitutive characteristics of services and therefore show some similarities. However, they also differ in certain significant aspects, and so far no generally accepted service productivity model exists.

Provider and Customer Differentiation. An important aspect, which is inherent when considering services, is the integration of the customer in the service provision chain. Here, especially the fundamental findings of Parasuraman et al. (1985) should be mentioned. They identified a significant gap between perceived, delivered service quality by the service provider, and the expected service quality by the customer. These findings had a great impact not only on service quality research but influenced many productivity concepts by considering service quality as well as customer's influence. In his later work Parasuraman (2002) proposes a conceptual framework describing the impact of service quality on provider's and a customer's productivity as well as some causal relationships between inputs and outputs.

A similar approach was developed by Johnston and Jones (2004) who define operational and customer productivity and give some counterintuitive examples on factors influencing both under consideration of their relationships. They also suggest that further research on the relationship between elements of service provider and customer productivity is needed. Finally, Grönroos and Ojasalo (2004) differentiate between three service process stages. In the first stage the service provider produces the service in isolation from the customer. In the second, customer and service provider are interacting for service provision, and in the third stage, the self-service stage the customer produces the service in isolation from the service provider. Furthermore, some examples of input and output factors along with their relationship to the proposed stages are mentioned.

Because of the great influence of the costumer in all dimensions of service provision, it is prerequisite to consider both service provider and service customer in a comprehensive service productivity assessment.

Three Dimensional Approaches. A dimensional differentiation in potential, process and outcome dimension can also be found in the majority of service productivity models. Donabedian (1980) uses this three-dimensional differentiation to assess quality of medical care. Likewise, Jones (1988) describes service operations based on a three stage model where inputs are transformed into outcomes through outputs. He also defines stage specific management approaches for productivity enhancement induced by the proposed differentiation. A two stage based productivity formula is proposed by Corsten (1994), who defines the productivity of the so called "pre-combination" as the ratio of the willingness to perform to the provider's input factors. In the process dimension, where the "end-combination" takes place, the productivity is defined as the ratio of actual output to the sum of willingness to perform and a combination of internal and external factors.

Since Donabedian (1980), Jones (1988), and Corsten (1994) almost every scholar refers to this dimensional differentiation to structure productivity assessment. As a conclusion, the tri-dimensional differentiation is a suitable approach for a service productivity assessment model.

Quantitative and Qualitative Aspects of Service Provision. Another aspect of service provision worth to consider is the importance of not only quantitative but also qualitative aspects of service provision. One of the main differences between traditional production systems and product-service systems is the explicit consideration of quality in every single stage of service provision. The high impact of quality on service productivity is pointed out by Jones (1988), Parasuraman (2002) as well as Gummeson (1998). Parasuraman et al. (1985) not only identify five gaps of service quality but furthermore propose a list of determinants of service quality. Besides objectively quantifiable factors like tangibles (facilities, tools, etc.) also subjective, qualitative factors like courtesy of the employees, credibility, etc. exists. Quality as well as qualitative factors are considered in the service productivity models developed by Vuorinen et al. (1998) and Grönroos and Ojasalo (2004). They define service provision output similar to Parasuraman et al. (1985) as customer perceived quality and stress the importance of qualitative input factors like employees' motivation or behavior.

Concluding, it is prerequisite to consider objectively quantitative factors as well as subjectively qualitative factors in service productivity assessment.

Productivity Assessment in Terms of Effectiveness and Efficiency. Finally, the main objective of a service productivity model is to assess managerial and product-service system performance and to support service manager's and planer's decision making. Among others a manager has to optimize the job being done [7]. A knowledge-worker has to "do the things right" and has to "do the right things" namely to ensure an efficient and effective execution of the job [7]. According to Freeborn and Greenlick (1973) the evaluation of system performance only by considering the three dimensions as pointed out by Donabedian (1966) falls short, it should in addition be further assessed according to the success criteria of efficiency and effectiveness. Hereby, efficiency is defined as the degree of generating a given amount of output with a mi-nimum of inputs or generating a largest possible output from a given quantity of inputs. Effectiveness indicates the degree of the achievement of the service objectives [22]. Effectiveness is often defined as achieving quality for the customer [12]. As a conclusion, a comprehensive performance evaluation has to consider both service effectiveness and service efficiency.

Summing up, none of the mentioned service productivity models covers all relevant aspects of service productivity assessment. Therefore, a novel productivity model is needed for assessing product-service systems performance. Especially due to the complex nature of product-service systems, identifying levers and interrelations of combined quantitative and qualitative factors is crucial for a focused improvement of a service manifestation from service provider as well as customer point of view. The systematical assessment of service efficiency and service effectiveness in a practicable manner is at utmost importance.

3 Development of a Novel Service Productivity Model

3.1 Conceptual Considerations

Existing service productivity models intend to cover all service branches of a company and thereby to cover a heterogeneous spectrum of services within a company. Also the productivity assessments proposed by these models attempt to consider the whole company. One of the problems arising from this global point of view is that potential improvements inherent in the optimization of a single or a similar service process remains unexploited. Our approach is therefore to analyze a single service and to identify levers for improving the service provision and thus the productivity of the service for future services of the same type.

Nevertheless, the goal is to develop a generic model that is able to cover all services of a company. The transition from the generic model to a practical use in the context of productivity assessment of an individual service is done by a company-specific or even service-specific instantiation of our model. By operationalizing the model, it loses its generic nature and becomes applicable in practice.

Therefore, to develop the new service productivity model, a two-stage approach was used. First, a generic model was developed. By providing a systematic procedure to operationalize the productivity model, it becomes usable in the second step.

3.2 Development of a Comprehensive Model of Service Productivity

The comprehensive model of service productivity covers the specific characteristics of services illustrated in section 2 and transfers them into a generic model representing the individual relations and components of a service provision. Here, the basic structuring concept is the generally accepted division of a service in the potential, process, and outcome dimension [8]. On the next level, value drivers are identified in each dimension of service provision, contributing to the success of the service. These value drivers are not represented by specific factors, since this would violate the general approach of the basic model. Rather, these value drivers are formulated as abstract factors that represent the essential characteristics and elements of a service provision, but are not further operationalized within the basic model. The value drivers can be assigned to one or several classes of value drivers in terms of their manifestation:

1. Value drivers addressing the service provider
2. Value drivers addressing the service customer
3. Value drivers addressing both the service provider and the service customer in their cooperative service provision
4. Value drivers describing concrete intermediate or final results of the service provision
5. Value drivers describing agreed or expected intermediate or final results of the service provision
6. Value drivers addressing quantitative aspects of service provision
7. Value drivers addressing qualitative aspects of service provision

Due to their abstract character, value drivers represent factors having a direct impact on the productivity of a service, but cannot be directly influenced by the service management.

The value drivers in the model constitute the course of service provision across all three dimensions. In the potential dimension, value drivers represent the service provider's as well as the service customer's input factors and the resulting joint willingness to perform the service. The transition to the process dimension starts as the organizational willingness's of the provider and customer are brought together in a commitment of a single willingness to provide the service. In the process dimension in contrast to the potential dimension a division into customer and provider is not made due to the cooperative nature of the service provision process. Thus, the process dimension is divided in a quantitative and a qualitative performance share. Here, the quantitative or qualitative provided services as well as the agreed or expected services have to be considered. This division is reflected in the outcome dimension, which represents the result of the service provision. In comparison with the process dimension the identical division of the service result in a qualitative and a quantitative share is combined to a total score in the outcome dimension, which describes the overall success of the service. From this overall success the added value of the service provider and the service customer can be deduced resulting in a separation of the provider and the customer at the end of service provision.

To represent partial service productivities, success criteria are defined, describing the relation of two value drivers. Success criteria can be differentiated in:

1. Success criteria between directly related value drivers represent measures of the *efficiency* of the underlying service
2. Success criteria between unconnected value drivers represent the dimension of *effectiveness* of the underlying service

Success criteria representing efficiency can be found within the potential dimension. Here, they specify how efficient the willingness to perform is hold available in regard to the total potential of the service provider and customer. Furthermore, success criteria representing efficiency exist between the process and the potential dimension as well as between the outcome and the potential dimension. These factors express how efficiently the service was provided on the basis of the joint willingness to perform.

Effectiveness criteria can be found within all dimensions of service provision. In the potential dimension a success criteria is defined to assess the effectiveness of the division of willingness to perform between provider and customer. In the process dimension the compliance of the actual partial, partial service results and the agreed or expected service results is assessed by respective success criteria of effectiveness. This effectiveness assessment is reflected in the outcome dimension to the overall result of the service as depicted in Figure 1.

The basic model of service productivity thus describes the complete service delivery process from the provider's and the customer's perspectives, takes into account the qualitative and quantitative components of service provision and describes the partial productivities of the service provision through success criteria of efficiency and effectiveness. All constructs of the basic model, however, are not directly tangible and measurable in practice; they form an abstract representation of a product-service system. To transfer the model into a fully operational form, both the value drivers as well as the success criteria have to be operationalized.

Our new service productivity model is depicted in Figure 1, showing value drivers and success criteria as well as the starting points to operationalize the model by assigning influence factors and key figures.

3.3 Method for Operationalization of the Comprehensive Service Productivity Model

The operationalization of the value drivers is performed by defining factors directly influencing the specific value driver. These influence factors represent parameters of the service that can be controlled by service managers and thus show a company- or even service-specific characteristic.

To quantify the partial productivities represented by the success criteria they are substantiated in key figures. Key figures hereby have to be quantifiable, collectable with reasonable effort, relevant, and preferably up to date [2], [20]. In addition, only those indicators are to be considered, which allow for a comparability of different services of the same company.

An accurate definition of the key figures results in the possibility to identify potentials for improvement directly during service provision. By linking key figures and influence factors with the help of our generic model of service productivity, a direct determination of the crucial levers for optimizing individual facets of service productivity and correspondingly organize future provisions of similar services in a more productive way becomes possible. Normalizing and weighting the key figures enables an overall productivity assessment of the service provision.

4 Evaluation of the Service Productivity Model by Experts

In order to evaluate the proposed service productivity model, data from explorative interviews with 32 service experts from two engineering companies in Germany are used. The data were accompanied by validation workshops of the proposed novel service productivity model.

The interview notes were analyzed and categorized following an approach proposed by Mayring (2007). The categorization was conducted on the basis of a coding scheme. The results were interpreted by their frequency of occurrence of each category among the interviewee. This step aimed to filter relevant aspects from the gathered data in order of their importance.

The analysis of the main sections of the semi-structured interviews revealed seven key influence factor categories. These seven categories represent the most commonly made statements in the interviews and are applicable to all value drivers of our service productivity model. Two of the categories – motivation and qualification – can further be subdivided in a service provider and a service customer perspective. The categories of influence factors on service productivity can further be classified according to their mostly qualitative and mostly quantitative characteristic (see Figure 2).

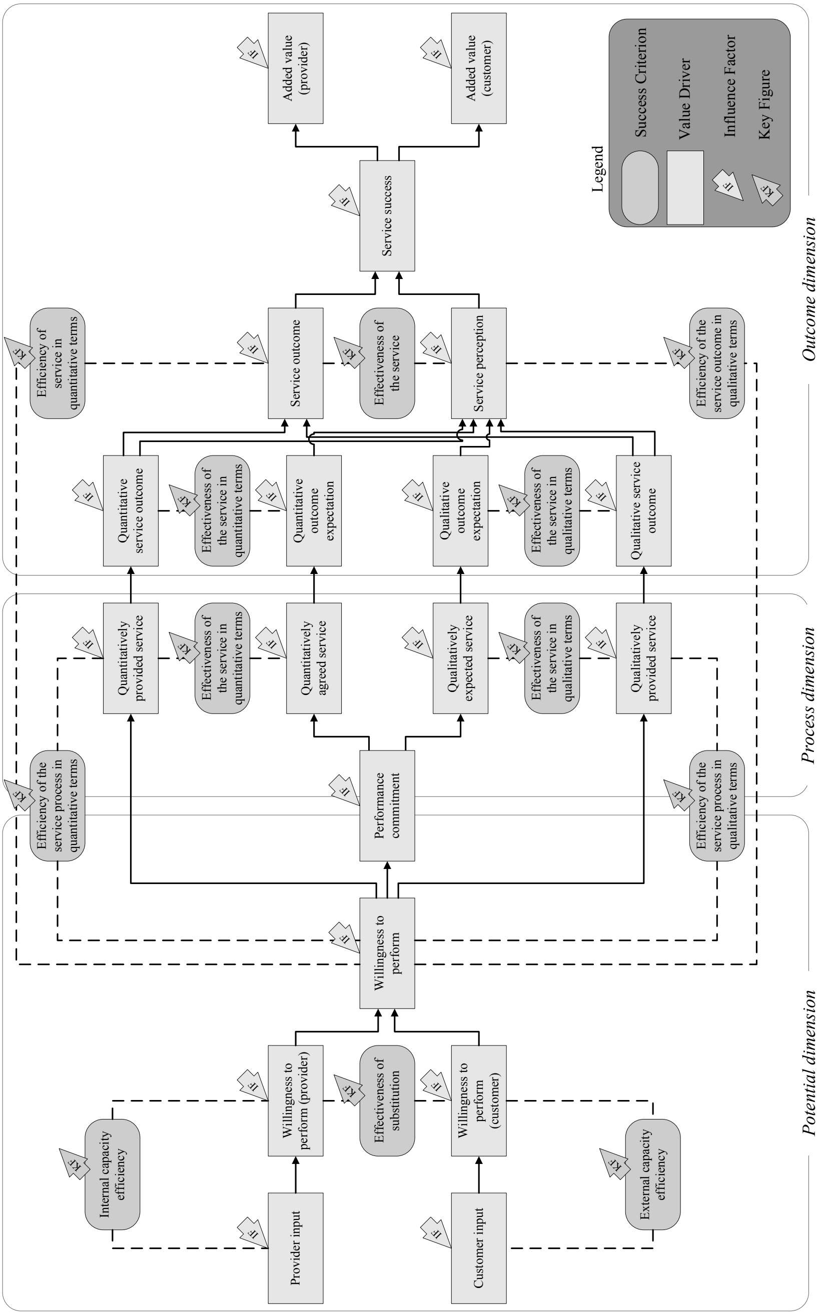


Fig. 1. Generic Service Productivity Model Overview

The weighting of these categories can be derived from the frequency of responses within each category. The results show differences between the two companies in some aspects, but also similarities in other aspects. This indicates that a company-specific instantiation of our service productivity model is essential.

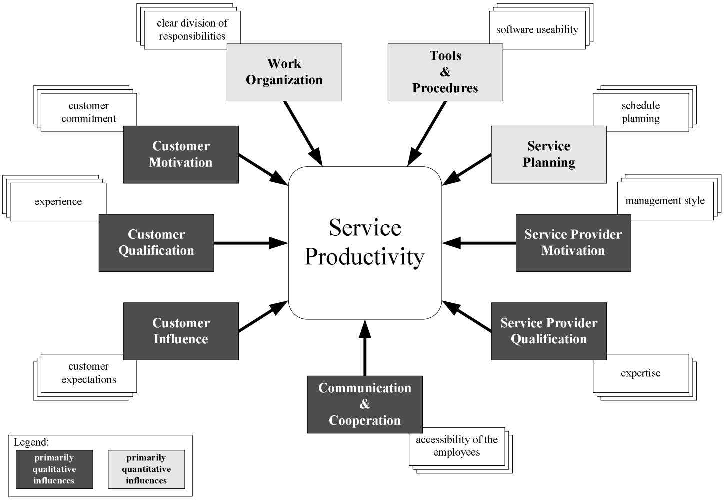


Fig. 2. Interview results: Categories of influence factors on service productivity

In addition to the interviews workshops with service experts were conducted to develop a set of relevant key figures by analyzing typical historical service projects. Table 1 shows the results of the empirical study by presenting an operationalized service productivity model for the core elements of the process dimension.

Table 1. Elements of the new service productivity model and their operationalization

VALUE DRIVER	INFLUENCE FACTOR CATEGORIES	SUCCESS CRITERION	KEY FIGURES
Quantitatively provided service	• Planning • Work organization • Tools & Procedures	Efficiency of the service process in quantitative terms	• Planning accuracy • Rate of changes • Rate of rework
Quantitatively agreed service	• Customer influence • Communication & Cooperation • Tools & Procedures	Effectiveness of the service process in quantitative terms	• Cost consistency • Adherence to schedules • Degree of fulfillment
Qualitatively expected service	• Customer influence • Communication & Cooperation • Qualification (Provider & Customer)	Effectiveness of the service process in qualitative terms	• Customer satisfaction • Employee satisfaction • Quality of communication
Qualitatively provided service	• Communication & Cooperation • Motivation • Customer influence	Efficiency of the service process in qualitative terms	• Levels of interaction • Rate of staff turnover

5 Conclusions and Outlook

Based on findings from literature, a novel productivity assessment model is proposed. The model combines all relevant characteristics of services as well as of productivity assessment in a holistic concept. The model provides guidance for practitioners in order to specify their own success factors and key figures for product-service system management and improvement.

In order to prospectively evaluate the performance of a service, a prototypical work process simulation system is currently developed. The simulation system will be able to cope with service-specific characteristics, such as customer influence and uncertainty of the service provision as well as the characteristics of weakly structured work processes such as iterations and overlapping tasks.

Both, the work process simulation and the comprehensive service productivity model provide a process oriented, dynamic evaluation of service systems for a more reliable and realistic forecast of product-service systems performance. Service operations managers will be able to prospectively evaluate different service scenarios by visualizing the outcome of different service settings under the variation of systematically identified influence factors.

Acknowledgments. The research is funded by the German Federal Ministry of Education and Research (BMBF), Project: ProLoDi, according to Grant No. 01FL10050, Research Program "Productivity of Services" supervised by the Project Management Agency of the German Aerospace Center (PT-DLR).

References

1. Baines, T.S., et al.: State-of-the-art in product service-systems. In: Proc. IMechE Part B: J. Engineering Manufacture, vol. 221 (2007)
2. Burghardt, M.: Projektmanagement: Leitfaden für die Planung, Überwachung und Steuerung von Projekten, vol. 8, pp. 536–562. Publicis, Erlangen (2008)
3. Corsten, H., Gössinger, R.: Dienstleistungsmanagement, 5th edn. Oldenburg Verlag, München (2007)
4. Corsten, H.: Produktivitätsmanagement bilateraler personenbezogener Dienstleistungen. In: Corsten, H. (ed.) Dienstleistungsproduktion, pp. 43–77. Gabler, Wiesbaden (1994)
5. Donabedian, A.: Evaluating the Quality of Medical Care. Milbank Memorial Fund Quarterly 44, 166–203 (1966)
6. Donabedian, A.: The Definition of Quality and Approaches to Its Assessment, vol. 1, pp. 79–128. Health Administration Press MI (1980)
7. Drucker, P.F.: Management: Tasks, Responsibilities, Practices (Book style), p. 36. Truman Talley Books, New York (1986)
8. Fitzsimmons, J., Fitzsimmons, M.: Service Management: Operations, Strategy and Information Technology, 4th edn. McGraw-Hill, London (2011)
9. Freeborn, D.K., Greenlick, M.R.: Evaluation of the Performance of Ambulatory Care Systems: Research Requirements and Opportunities. Medical Care XI(2), 68–75 (1973)

10. GATS, General Agreement on Trade in Services. World Trade Organization (1995), http://www.wto.org/english/docs_e/legal_e/26-gats_01_e.htm (accessed on August 02, 2012)
11. Grönroos, C., Ojasalo, K.: Service productivity towards a conceptualization of the transformation of inputs into economic results in services. Journal of Business Research 57, 414–432 (2004)
12. Gummesson, E.: Productivity, quality and relationship marketing in service operations. International Journal of Contemporary Hospitality Management 10(1), 4–15 (1998)
13. Hilke, W.: Grundprobleme und Entwicklungstendenzen des Dienstleistungs-Marketing. In: Hilke, W. (ed.) Dienstleistungsmarketing, pp. 10–15. Gabler, Wiesbaden (1989)
14. Johnston, R., Jones, P.: Service Productivity – Towards understanding the relationship between operational and customer productivity. International Journal of Productivity and Performance Management 53(3), 201–213 (2004)
15. Jones, P.: Quality, capacity and productivity in service industries. International Journal of Hospitality Management 7(2), 104–112 (1988)
16. Maleri, R., Fritzsche, U.: Grundlagen der Dienstleistungsproduktion, 5th edn. Springer, Heidelberg (2008)
17. OECD: Measuring Productivity, OECD Manual, Measurement of Aggregate and Industry-Level Productivity Growth (2001), http://www.oecd.org/std/productivitystatistics/2352458.pdf (accessed on August 02, 2012)
18. Parasuraman, A., Zeithaml, V.A., Berry, L.L.: A Conceptual Model of Service Quality and Its Implications for Future Research. The Journal of Marketing 49(4), 41–50 (1985)
19. Parasuraman, A.: Service quality and productivity: a synergistic perspective. Managing Service Quality 12(1), 6–9 (2002)
20. Reichmann, T.: Controlling mit Kennzahlen und Managementberichten. Vahlen, München (2001)
21. Shostack, G.L.: How to Design a Service. European Journal of Marketing 16(1), 49–63 (1982)
22. Sundin, E.: Life-Cycle Perspectives of Product/Service-Systems: In Design Theory. In: Sakao, T., Lindahl, M. (eds.) Introduction to Product/Service-System Design, 1st edn., pp. 31–49 (2010)
23. Vuorinen, I., Järvinen, R., Lehtinen, U.: Content and measurement of productivity in the service sector: A conceptual analysis with an illustrative case from the insurance business. International Journal of Service Industry Management 9(4), 377–396 (1998)

Service Shares for Microfactory to Ensure Industrial Product-Service Systems

Nozomu Mishima[1] and Hitoshi Komoto[2]

[1] Graduate School of Engineering and Resource Science, Akita University, Japan
[2] Advanced Manufacturing Research Institute, AIST, Japan
nmishima@gipc.akita-u.ac.jp,
h.komoto@aist.go.jp

Abstract. Industrial Product-Service Systems (IPS²) are promising approaches to realize different customer requirements. The built-up Microfactory is a result of a cooperation of Japanese research institutes and will be focused in this paper. The paper identifies two categories of relevant service shares for the Microfactory. The general service shares for Microfactory cover basic requirements. These distinguish general service shares form complex service shares to fulfill customer specific requirements. Examples for both categories of service shares for Microfactory, are presented. Finally different scenarios can be described under consideration of specific selection of general and complex service shares to fulfill customer requirements.

Keywords: Microfactory, General Service Shares, Complex Service Shares.

1 Introduction

The Microfactory [1] is developed by AIST as a modern compact and distributed manufacturing system. This system allows a flexible combination of different manufacturing, assembly and measuring procedures. It was introduced 12 years ago. Various machine tools and production equipment to fulfill the different tasks covered by the Microfactory have been developed and introduced in the market. One of the remarkable characteristics of the system is the high level of modularity. The modularity allows the minimization as individual products by employing particular downsizing technologies and the fulfillment of customer-specific solutions [2]. There have been some significant approaches [3] to cover industrial practicalities by utilizing high modularity of the Microfactories. However, sometimes the modularity has also prevented the provider of the Microfactory from promoting the system-level innovation of their business, since it is difficult to develop a new business model beyond combining the provided modules. This is the reason why there is no common strategy or framework to make the provider's business successful. Facing the recent serious economic situation, on top of severe global competition and environmental legislation, service engineering and especially industrial product-service systems (IPS²) can be a key to overcome the underlying challenges by creating more innovative businesses and sustainable, customer individual combinations of product and service shares

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 395–406.
DOI: 10.1007/978-3-642-30820-8_34

[2, 4]. Different business models, which are coupled with the customer requirements, are available for such a provider [2, 4, 5]. One important aspect of market acceptance and therefore success of an industrial solution is the integration of product and service shares over a continuous lifecycle [2, 4]. In a former paper [6], basic ideas for service shares have been listed corresponding to the characteristics of the product shares and IPS²-lifecycle stages [4]. In this paper, the identified service shares will be categorized to two defined types; general service shares and complex service shares. The objective of this paper is to propose an appropriate method to categorize those two and show a systematic approach to design IPS² featuring Microfactory. Additionally, some industrial examples will be discussed to verify the reasonability of the categorization.

2 Product Shares and Characteristics of Microfactories

2.1 The Microfactory

The Microfactory combines different product shares, which are realized by machine tools, measuring systems and other production equipment. In the first prototype of the Microfactory [1], the total system was composed of five components. Thus, at the first look, the five micro production machine tools correspond to the basic product shares in the system (see also [6]).

The product shares, indicated from 1 to 5, measuring systems and other production equipments are integrated in the concept of the Microfactory (Figure 1):

1. Micro-lathe
2. Micro-milling
3. Micro-press machine
4. Micro-transfer arm
5. Micro-manipulator (two-fingered micro hand)

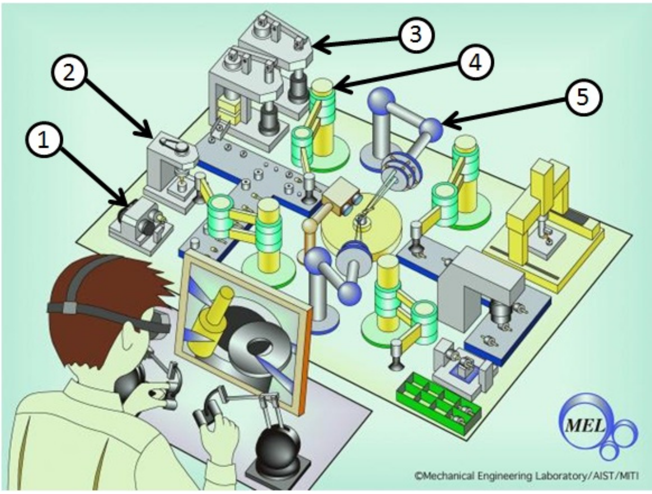


Fig. 1. Illustration of the Microfactory [7]

2.2 Capability of the Microfactory

The Microfactory is a compact production system for precise microproducts [1, 7]. However, a concrete definition has not been discussed thoroughly. Thus, the authors, hereby, define Microfactory by the following sentences: "A production system which is composed of properly downsized machine tools and other production equipment and realize at least one feature of a workpiece, such as tolerances, dimensions etc., with a `micron order´ requirement." Based on the concept, the developed Microfactory had some merits comparing to normal size production system, as shown in Table 1. And these merits can be the key to clarify capability of the Microfactory along with the product and service shares of it.

Table 1. Potential merits of the Microfactory product shares

No.	Product shares	Potential merits
1	Micro-lathe	Compactness, Mobility, Precise (decreasing absolute error), Robustness, Safety
2	Micro-milling	Compactness, Fast-design, Low-cost design, Precision, Low-cost operation, Safety
3	Micro-press machine	Compactness, Fast-design, Energy efficiency, Precision, Low-cost operation, Fast-production, Safe
4	Micro-transfer arm	Compactness, Precision, Low-cost operation, Fast-production
5	Micro-manipulator (two-fingered micro hand)	Compactness, Precision, Flexibility

Based on an existing definition [4], it has been stated that a lifecycle of an IPS² can be divided into five stages. Those are IPS²-planning, IPS²-development, IPS²-realization (or IPS²-implementation), IPS²-use and IPS²-reuse (or IPS²-end-of-life management). Potential merits of a Microfactory are related to the different IPS²-lifecycle stages. Because of the smallness of the machine, it might be possible to use more modularized components and a simple design technique without any necessary critical simulation. By this aspect it is also possible to easily change the factory layout and add new components to the production line. Thus, time for the development process can be reduced (see Table 1). For the design aspect the degree of material use and parts use is usually small. Thus, if the machine tools and other production equipment are composed of commercially available components, the costs are lower. Since the machine tools and other production equipment sizes are small and work-loads are small, a low degree of secondary processes such as providing coolants, lubrication and spare parts is necessary (see Table 1). As an existing study [9] shows, modularized compact production systems can be energy efficient e. g. by designing process time of each modular unit consistently. Corresponding to the flexibility in the factory layout and modularity of the machines, it is possible to increase or decrease the number of machine tools and other production equipment and change production line configurations. Due to the smallness of the machine tools and other production equipment, it is possible to move the whole or the part of the production lines to where demands exist. Because of the size effects of various error factors in machine tools and other production equipment, a downsized machine tool has clear advantages, e. g. in the aspect of theoretical positioning errors [10]. The smallness of the machine tools and other production equipment leads to the characteristic that some error factors may decrease its' effect on the overall positioning error. The smallness can also realize reduced process time such as e. g. warming up, heat treatment and cooling down. Because of the smallness of the machine tools and other production equipment, moving components of the machine tools and other production equipment may not hurt operators accidently (see Table 1)

3 Service Shares of the Microfactory

3.1 List of the Service Shares

Since service shares of IPS^2 relate to characteristics of the product shares, basic service shares of the Microfactory can be listed as a reflection of the potential merits [6]. For example, "Mobility" enables "on-site pay-per-production service" which can never been realized by a normal size production system. Or, "Fast-design" can lead us

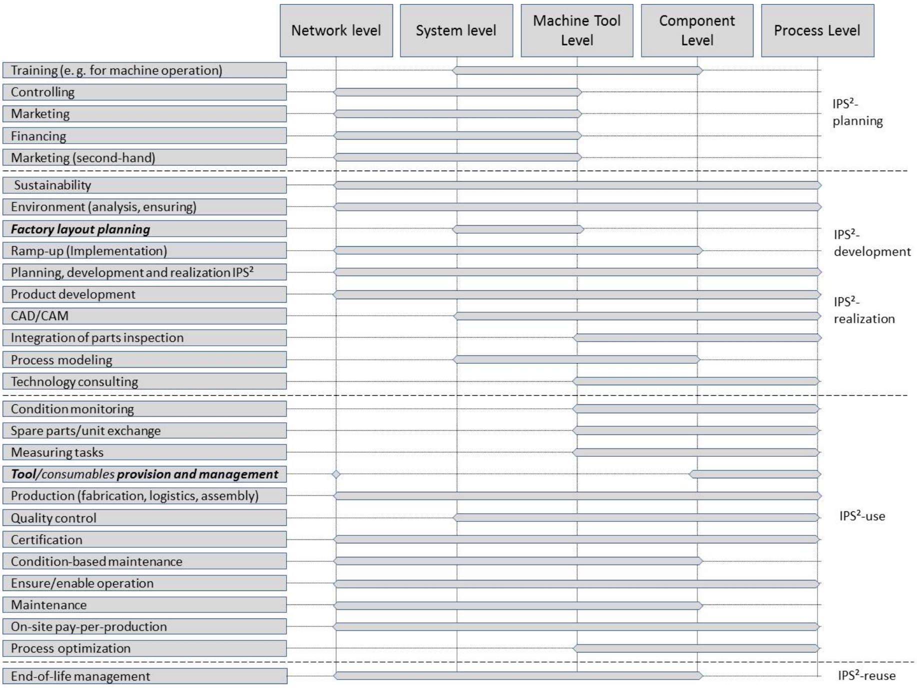


Fig. 2. Basic list of service shares, system integration level and IPS^2-lifecycle stages

to think of “Factory layout design service.” “Safety” feature will be a good character to enable and promote “training of machine operation service,” and so on.

In addition, considerations on the IPS^2-lifecycle stages may lead to much more ideas of service shares and identify connections between different service shares. For example, “Fast-design” feature can be helpful to offer “Marketing service” in the IPS^2-planning stage, since “Fast-design” will surely decrease the lead time to the market which is one of the most important features when we carry out marketing of products. And of course, “Compact” which is the common characteristics of all product shares enables “Implementation of the production set-up service” in the IPS^2-realization stage. Through these consideration and discussion, a basic list of the service shares of the Microfactory was discussed in the former paper [6]. The service shares were also related to system integration level of service activities, since it is also an important criterion to consider service shares [6].

3.2 Criteria of Service Shares

In order to categorize service shares, first a good characterization will be necessary. An existing literature [10] is proposing criteria and characteristics of service shares as Table 2. Since these criteria are generalized to be applied to pure service shares or services offered to general customers, some modifications will be necessary to apply the criteria to IPS^2. It is also necessary to eliminate overlaps and dependent criteria, since the paper will try to evaluate and categorize service shares by using the selected criteria. The first point which can be easily noticed is, “product relationship,” “product connection” and “contact force” are describing similar characteristics. These criteria indicated how deeply the service shares depend on the product shares. So, in this paper, we integrate these three to one; “impact from product shares.” The next point to be discussed is “service utilization.” Although this is an important criterion to characterize service shares, in cases of IPS^2, the services are always utilized by producers to fulfill the customers’ requirements. Thus, this criterion is unnecessary. “Application area” means whether the service is realized only by an internal effort, or not. In this paper, this point is described by “number of providers.” Two criteria “exclusion of the demand” and “customer integration” are expressing similar things. Both indicate whether the receivers of the services are consistent, or not. The paper unifies them to “integration level of customers.” Again, the criterion “operation factor” is not applicable to IPS^2, since this indicates the service is realized by a product or a human, and in a case of IPS^2, any service has relevancy to a product. “Business functional area” identifies the service can be available in which stage of service lifecycle. In the case of IPS2, this characteristic is described as “relevancy to IPS2-lifecycle stages” which was mentioned in the authors’ other work [7]. About “contractual relationship,” it is not a primary criterion for service shares, since there can be many varieties of contract. Finally, “individuality” indicates how services can be standardized. Thus, the paper translates this criterion as “process sequence complexity.”

Table 2. Criteria of the service shares

Criteria	Characteristic
Product relationship	Complementary Substitutive
Product connection	Isolated Combined
Contact force	Embodied Disembodied
Service utilization	Producer Consumer
Application area	Internal External
Exclusion of the demand	Individual Collective
Customer integration	Direct dependence Indirect dependence
Operation factor	With relevance to a product With relevance to a human
Business functional area	Service within the procurement Service within the production Service within the sales Service within the financing Service within the administration
Contractual relationship	One by one Permanent
Individuality	Individual standardized

In addition, as it was shown in Table 2, the authors think that the "system integration level" is also an important criterion to characterize service shares. As the result of unification and translation, the paper has determined six criteria to characterize service shares for microfactory. The six criteria are "impact from product shares," "number of providers," "customer integration level," "relevancy to IPS^2-lifecycle phases," "process sequence complexity" and "system integration level."

3.3 Complexity of the Service Shares

Based on the list shown in Figure 2 of identified service shares, a determination of the complexity of the service shares was carried out. In order to carry out the determination, six criteria were discussed and selected in the former section. Table 3 and 4 are the results of the determination of the complexity of the service shares by considering six criteria.

Table 3. Complexity evaluation of the service shares (first half)

Service shares	Criteria					
	Relevancy to lifecycle stage(s)		Integration level of customer		Number of providers	
	Single	Multi	Low	High	Single	Multi
Training of machine operation	x			x	x	
Marketing		x		x	x	
Marketing (second-hand)	x			x	x	
Financing	x		x			x
Controlling		x		x	x	
Environmental (analysis, ensuring)		x		x		x
Factory layout planning	x			x	x	
Product development	x		x		x	
CAD/CAM	x		x		x	
Integration of parts inspection		x		x	x	
Process modeling		x		x	x	
Technology consulting	x		x		x	
Condition monitoring	x		x		x	
Spare parts/units exchange	x		x			x
Measuring tasks	x		x		x	
Tool/consumables provisioning and management	x			x		x
Production (fabrication, assembly, logistics)		x		x		x
Quality control		x	x		x	
Certification		x	x		x	
Condition based maintenance	x			x		x
Ensure/enable operation	x			x		x
Maintenance		x		x		x
On-site pay per production	x		x		x	
Process optimization	x			x	x	
End-of-life management (dump)	x			x	x	
End-of-life management (remanufacturing)		x		x		x

Table 4. Complexity evaluation of the service shares (first half)

Service shares	Criteria: Impact from product shares		Criteria: Process sequence complexity		Criteria: Number of providers		
	Large	Small	Low	High	Low	High	Number of high scores
Training of machine operation	x			x		x	3
Marketing		x	x			x	4
Marketing(second-hand)		x		x		x	4
Financing		x	x		x		2
Controlling	x			x		x	4
Environmental (analysis, ensuring)	x			x		x	5
Factory layout planning	x			x		x	3
Product development	x			x	x		1
CAD/CAM		x	x		x		1
Integration of parts inspection	x			x	x		3
Process modeling		x		x		x	4
Technology consulting	x			x	x		1
Condition monitoring	x		x		x		0
Spare parts/units exchange	x		x		x		1
Measuring tasks		x	x		x		1
Tool/consumables provisioning and management		x	x			x	4
Production (fabrication, assembly, logistics)	x		x			x	4
Quality control		x		x	x		3
Certification		x	x		x		2
Condition based maintenance	x			x		x	4

Table 4. (*continued*)

Ensure/enable operation	x			x		x	4
Maintenance	x			x		x	5
On-site pay per production	x			x		x	2
Process optimization		x		x		x	4
End-of-life management (dump)	x		x		x		1
End-of-life management(remanufacturing)	x			x		x	5

4 Categorization of the Service Shares

Based on our definition in this paper, general service shares are the service shares that can be standardized and be seen commonly in many IPS². Complex service shares are those which are more specific services shares than general service shares to fulfill more complex and various requirements of customers. Since complexity is a relative aspect, tentatively, we categorized service shares that have high scores in more than four criteria to complex service shares, and the rest to general service shares. In general, the purposes of the categorization of service shares are to build-up a new service, or to optimize an existing service. These two objectives might be realized by modifications of the service shares to more complex shares. But, it can be also possible by simplifications. Thus, categorizing them to two categories can be a good start point to know how complexity plays a role. As the final result led from Table 3 and 4, these are the list of general service shares and complex service shares of the Micorfactory.

- General service shares: training of machine operation, financing, factory layout planning, product development, CAD/CAM, integration of parts inspection, technology consulting, condition monitoring, spare parts/units exchange, measuring tasks, quality control, certification, on-site pay per production, process optimization, end-of-life management (dump)
- Complex service shares: marketing, marketing(second-hand), controlling, environmental (analysis, ensuring), production (fabrication, assembly, logistics), tool/consumables provisioning and management, ensure/enable operation, condition based maintenance, maintenance, end-of-life management(remanufacturing)

5 Industrial Examples

5.1 Training of Machine Tool User

To train machine tool user in the skill of usage of the machine tool is a typical service offered by machine tool manufacturer. However, one of the problems in current training service is that the offered skill is sometimes specific to the machine tool. It is often observed that machine shops have many types of machine tools from many producers. Thus, if it is possible to unite an IPS²-network to offer certain combinations of machine training, it would fulfill the requirements of customers who have many types of machine tool in a floor. This modification of service shares is equivalent to change the complexity level in "number of providers" (see Table 2) from single to multi. In this case, the optimization of the service can be achieved by complexity.

5.2 Factory Layout Planning

There is a Japanese machine tool manufacturer [11] which makes a relatively compact and multi-functional machine tool. Since their machine tools are multi-functional, there are a lot of varieties in manufacturing processes and configuration of machine shops. Thus, the company is not only selling the product but also trying to consult their customers in machine shop floor planning. However, if an IPS²-provider can offer not only the layout existing machine tools, but also a new design of custom made machine tools to meet their customers' various requirements, the service share will be much more attractive. This modification can be led by changing "relevancies to life cycle stages" (see Table 1) from single to multi. In the existing eservice share, corresponding IPS^2-lifecycle stage is limited to IPS^2-realization. But, in the modified case, IPS^2-planning and IPS^2-development stages are relevant. In this case, the build-up of new service can be also achieved by making the service more complex.

5.3 On-Site Production of Medical Devices

Contract manufacturing is a well-observed service in manufacturing industries. In a contract manufacturing, usually the service provider designs the manufacturing process and often designs the product, and of course the production system. The service is relevant to IPS^2-development and IPS^2-use stages. Usually this service can only applied to mass-production. On the other hand, a compact production system like Microfactory is aiming production in smaller batch and there are some demands for more specific outsourcing of production. "On-site pay-per-production" using Microfactory can be a solution. One example is on-site manufacturing of medical devices [12]. In this example, a screw to connect broken bones is made on-site (in the hospital) by patient's own bone. Since there is no pre-set design to be commonly applied to various conditions of patients, every product design and process design is carried out during the IPS^2-use phase only. Thus, this is an example to build-up a new service share by simplification.

6 Summary

In this paper, one of the first ideas to apply service shares to a compact modular manufacturing set-up called the Microfactory is discussed. The paper first identified the general merits of the Microfactory, and listed basic product shares featuring those merits.

Furthermore, the paper tried to categorize the basic examples of service shares for the Microfactory which has been listed through existing papers. The service shares were characterized and categorized to general service shares and complex service shares, based on the complexity level indicated by six different criteria. By this categorization, the service providers can know which criteria of complexities are low. Which of complexity or simplicity is helpful to build-up or to optimize new services depends on cases. Thus, the first step to develop a framework to create a new service is a proper categorization of the service shares.

Through the discussion of industrial examples, it was suggested that build-up or improvement of service shares can be possible by changing complexity. Finally, the paper concluded that IPS² featuring the Microfactory can be a promising area, since the production system can be optimized by various service shares in manufacturing industries. And strategic categorization of service shares will be the key to create new IPS2 business models featuring the Mircofactory.

As a future work, the proposed categorization method should be verified by using more industrial examples and relations between general service shares and complex service shares must be clarified to answer a research question "is there a common method to build-up or optimize a new service share?” In addition, more detailed characterization of service shares to standardize general service shares might be necessary.

Acknowledgments. We express our sincere thanks to Christian Gabriel, Niels Raue and Christian Stelzer at Department of Machine Tools and Factory Management, Chair for Manufacturing Technology, Technische Universität Berlin for their great and deep collaboration to this paper, during the author’s stay in the university.

References

1. Okazaki, Y., Mishima, N., Ashida, K.: Microfactory - Concept, History and Developments. Journal of Manufacturing Science and Engineering, Trans. ASME 126, 837–844 (2004)
2. Uhlmann, E., Gabriel, C., Raue, C., Stelzer, C.: Influences of the IPS2 Business Model on the Development of a Micro Milling Spindle. In: Proceedings of the 3rd CIRP IPS2 Conference (IPS2 2011), pp. 57–62 (2011)
3. Heikilla, R., Jarvenpaa, E., Tuokko, R.: Advances in TUT Microfactory Concept Development. International Journal of Automation Technology 4(2), 117–126 (2010)
4. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems - IPS2. CIRP Annals Manufacturing Technology 59(2), 607–627 (2010)
5. Tukker, U., Tischner, U.: New Business for old Europe. Final report of suspronet (2004)
6. Mishima, N., Uhlmann, E., Stelzer, C., Komoto, H., Raue, N., Gabriel, C.: Proposal of Industrial Services for Microfactories. In: Proceedings of IWMF 2012, Tampere, Finland, ID574 (2012)

7. Mishima, N., Tanikawa, T., Ashida, K., Maekawa, H.: Design of the Microfactory. In: Proc. of DETC 2002: 7th Design for Manufacturing Conference, Montreal, Canada, DETC2002/DFM-34164 (2002)
8. Mishima, N., Kondoh, S., Masui, K.: Proposal of An Efficiency Evaluation Index for Micro Manufacturing Systems. In: Proceedings of IEEE ICMA 2007, Harbin, China, pp. 51–56 (2007)
9. Mishima, N.: Design evaluation method for miniature machine tools utilizing form-shaping theory. In: Proceedings of ASME/DETC 2003, Chicago, IL, DAC-48787 (2003)
10. Corsten, H.: Dienstleistungsmanagement. R. Oldenbourg-Verlag, München (1997)
11. Web page of Takashima Sangyo Co., Ltd., `http://www.takashima.co.jp/en/index_e.html` (accessed September 19, 2012)
12. Hayashi, A., et al.: The development of micro machine tools to process the bone of patients in the surgical theater. In: Proc. of JSPE Fall Meeting (2006) (in Japanese)

Structuring Industrial Service Solutions

Jörgen Sandin

Department of Management and Engineering, Linköping University,
SE-581 83, Linköping, Sweden
jorgen.sandin@liu.se

Abstract. This paper presents a case study containing five mini-cases within a service provider of complex hardware with long operation times. The study describes how a structured approach of development, implementation and operation of total service solutions (TSS) can contribute to customization and flexibility on the one hand and standardization and synergies on the other hand. The basic shape of the organization might change in the beginning of a journey towards TSS. However it might also change back when the solution is implemented. Modules in routines can facilitate managing different external regulations. Further, the service structure can be described via a work breakdown structure and it is possible to simulate different scenarios based on such a structure. Fleet management might be a new capability needed, and it has been realized that in the relevant sector the dynamic capability development of service solutions can be more front-loaded than proposed from other researchers.

Keywords: service solution, service structure, long product life-cycle, dynamic capability.

1 Introduction

Many long life products, from power turbines, to airplanes, have a large installed base (IB) which consequently brings a huge market for maintenance, repair and overhaul (MRO) and other aftermarket activities. It is not unusual that the installed base of capital goods exceeds the annual flow of new products by 10 to 100 times [1]. In the United States the installed-base-to-new-unit ratio for civil aircrafts was 150 to 1 at the end of the 1990s [1]. Hence, the aviation industry is a particularly promising case from an aftermarket perspective. Deregulations during the 1970s made it even more interesting for both provider and customer. Before the 1970s many airlines had their own in-house MRO operations, but after the deregulations new independent suppliers have emerged to offer lower costs services.

In this environment with intensive competition among both airliners and MRO suppliers, new extended service solutions are developed and so called Product-Service Solutions (PSS) with a comprehensive content have emerged [2]. However, new and improved service offerings are continuously emerging also in several other sectors and according to Sakao et al. [3] service solutions may reduce 30-40% of the total product life-cycle cost for a customer. In such an environment with new service

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 407–420.
DOI: 10.1007/978-3-642-30820-8_35

solutions on a market with great competition, providers also compete on an "extended installed base", an installed base not manufactured by the service provider. Consequently, in a fast-moving business environment, sustainable advantage requires more than ownership of difficult-to-replicate asset, it also requires difficult-to-replicate dynamic capabilities [4]. Dynamic capabilities indicate flexibility and customization. At the same time reproducibility is needed and some structure ought to exist [5-8].

However, few empirical studies have analyzed the development and implementation process regarding services in product-based firms [3], [9]. Thus there is a need to identify where and when firms generate, evaluate, and realize various types of service innovations and improvements, relating to e.g. service modularity, organizational changes, and the need to balance cost-efficient operations and standardized processes with customization and flexibility [3].

1.1 Purpose

This paper focuses on how a capital goods industry with long product life-cycles (aircraft services) exploit on total-service solutions. This context implies that the hardware is fixed and that operations are strictly regulated for safety reasons. Many providers expand on their offerings and the key question for them is to understand the potential and limitations for a structured and comprehensive approach to service solutions in this context. Accordingly, the purpose of this paper is to analyze how a structured approach can contribute to practicing providers and to the academia, when a provider of complex hardware with long operation time develops, implements, and operates TSS. This is specified in a research question:

Research Question: How can a structured approach of development, implementation and operation of TSS contribute to customization and flexibility on the one hand and standardization and synergies on the other hand?

2 Theoretical Framework

The great potential for reduced product life costs through total-service solutions brings an interest in many businesses [3]. The incentives are often economical with increased revenue for the provider of the services respectively decreased costs for the customer, i.e. the system operator. The incentives for the provider to move towards extended service solutions can be higher revenue but also an increased possibility to even out the cyclicality of revenues, to gain on untapped markets or becoming a strategic business partner [1], [10-11].

2.1 Structures in Service Solutions Providing Organisations

According to a resource-based view, observable differences regarding performance between different firms can primarily be drawn back to the different resources available [12]. However, resources need to be managed and synchronized [13]. Hence, it is here suggested that being able to efficiently produce services a firm needs human and non-human resources, an organizational shape, including the way of working, information and some input to refine. Winter [14] defines organizational capability as a high-level routine (or collection of routines) that, together with its implementing input flows, confers upon an organization's management a set of decision options for producing sufficient outputs of a particular type. Those high-level routines would preferable be denominated main processes. Typical main-process in a service providing company could be e.g. "develop" or "execute". For a service solution providing organization a typical main-process would be "provide service solution" or "solutions fulfillment". By contrast, capabilities that would change the service, the service process, the scale or market are not just capabilities; they are dynamic capabilities [14]. A dynamic capability view is not without skepticism [14-15], but it attempts to explain how a firm can achieve sustained superior performance in a rapidly changing industry [4].

Organizational Structure. "Firms and markets co-evolve" [16] (p 1198). This is true at least for sustaining successful firms. Service providing organizations require different processes, cultures, leadership, and structures than manufacturing organizations [17]. Consequently many solution providers add independent customer-centric units to the existing product-centric units [18-19]. Structurally, the providing organization needs to centralize and coordinate customer-centric front-end units and flexible capability in resource back-end units [20], [5]. Working together towards better customers' total experience as well as trust and greater customer loyalty becomes more important [21]. Further, when the service solution is up and running the customer-centric units might be moved back to the mother organization [18].

Capabilities. Also new abilities might be relevant when moving towards TSS. Typical skills needed are project management, key accounting, team selling, and conflict management [9], [22]. However, even more important is the ability to capture client needs and to transfer them into profitable actions. Successful solutions providers manage to balance the tensions between client needs and capabilities [5]. It is the ability to take clients insight and small capability edges to build on, that enables creating great solutions. Still, even if a provider masters the act of balancing tensions between client needs and capabilities, a provider has always some limitations regarding capabilities and resources. Experienced suppliers of service systems, e.g. IBM, sometimes integrates rival´s subsystems into their offerings. Further, firms completely based in services have to rely on product sellers to provide a reliable source of products and technology [23].

Dynamic Capabilities. Teece [4] mentions that the traditional elements of business success are often specified in terms of maintaining incentive alignment, owning tangible assets, controlling costs, maintaining quality, optimizing inventories, etc. However, Teece [4] continues with arguing that in a dynamic business environment with a global competition the traditional elements of business success are still necessary, but hardly sufficient for sustained first-rate enterprise performance. Enterprise success rather depends upon the discovery and development of new opportunities. Dynamic capabilities can be defined as the capabilities that operate to extend, modify or create ordinary capabilities [14]. One example is new service development, which reasonably is affected by the IB (or Extended IB).

The capacity to sense and shape opportunities and threats, to seize opportunities and also to maintain competitiveness through combining, enhancing and protecting reconfiguring tangible and intangible assets are crucial in a dynamic environment [4], [24]. The essential coordination task according to the dynamic capabilities framework described by Augier and Teece [16] is internal to the firm, but it might involve strategic alliances as well. "The fundamental question for management is to figure out how best to employ the firm´s existing assets, and how to reconfigure and augment the value proposition being brought to customers" [16] (p 1197).

Galunic and Rodan [25] suggest that recombination can occur when competencies within the firm are combined to synthesize novel competencies, but also when competencies experience a reconfiguration or relinking with other competencies. Further, recombination of competencies can be complemented with recombinative innovations which exploit the possibility opened up by applying new combinations of technical characteristics. The innovation can either be an initiation of a new product by combining the characteristics of two or more existing products, or it can be initiating new products through splitting up an existing product [26].

Processes. The solutions fulfillment process show great differences compared with product delivery. Services are created in connection with the customer, an infrastructure needs to be in place, and the operation is people intensive [24].

The solutions development process consists basically of two sub-processes, one for deciding what to develop and one for developing [9]. The involvement of customers and users are often intensive throughout the complete development process. It is common that lead users are deeply involved with customized offerings as result [27]. The process is often less front-loaded than in product development and the focus is more on rollout than on early phases [27]. This implies that understanding the customer process is crucial. Largely important is also to design a user friendly process easy for the customer to learn [28].

Capabilities are built by building blocks, for example routines [29] and processes. Routines are organizational practices. Hence, improved routines imply both small steps towards improved main processes and improved capabilities.

In a broad sense routine refers to simple decision rules that require low level of information processing but also to complex, automatic behaviors involving high levels of repetitive information processing [29]. Still, routines do not only represent problem solving and coordination procedures, but also control and governance devices [29].

2.2 Service Solution Structures

Service Engineering is a technical-methodical approach with the intention to structure service development and operations [30-32]. The aim is to intensifying, improving, and automating the complete scope of creation, delivery, and consumptions of services [30]. Earlier attempts to explore and describe this area have been done and some models have been proposed for that purpose.

Several methods, models and tools exist [6], [30-34] but will not be accounted for in detail here. One of the methods for structuring services relies on four major steps. In the first, all services are classified according to their objectives. Secondly, the services are subdivided into various modules consisting of result modules, process modules and resource modules. Thirdly, modules are classified in mandatory and optional modules, and finally the dependencies between the modules are determined [6]. Another similar description is made by Bullinger et al. [31] in which a service is characterized by the dimensions structure, process and outcome. The structure is connected to resources (humans, material and immaterial resources).

Dynamic Structures. The most successful solutions are often found were the providers can tailor their offerings to the precise needs of a particular client [5], [35]. But truly customizing the solutions will also be expensive and some kind of reusing is preferable. Hence, modular solution platforms can be useful for many providers and ought to be considered in connection to the development of a service system and its structure [5-7]. To optimizing the customization and using a modular solution platform, the provider must build up some learning experiences [5].

One great challenge is to design a service system for reproducibility but with flexibility enough to recognize and adapt to differences in e.g. regulations, legal systems and culture [8]. Gremyr et al. [9] has identified recombinative innovations as a success factor. It enables new possibilities to combine customization and standardization. Recombinative innovations exploit the possibility opened up by applying new combinations of technical characteristics. The innovations can either be initiating new products through splitting up an existing product, or an initiation of a new product by combining the characteristics of two or more existing products [26]. Innovation can also regard formalization. Formalization innovation concerns standardization and visibility of various characteristics [26].

2.3 Theoretical Framework Summarized

In the *theoretical framework* it has been discussed and made credibly that both organizational capability and service solutions needs a structure. It has also been indicated that there is an even greater potential if the structures are dynamic, but with control.

3 Research Method and Cases

The paper is based on an ongoing longitudinal case study. So far the data collection has been concentrated to two periods, one during winter 2010/2011 and one in spring 2012. The first data collection was a pilot study on one (Case C) of five mini cases within the longitudinal case study. The second data collection was the first in a coming range of data collections. Valuable background information concerning the division and its businesses is available to the researcher, since he was an employee at some related divisions during the years 2001-2009.

The unit of analysis is a division with approximately 110 employees within a large product-based, high-technology business corporation with approximately 10,000 employees. This organization is constantly in an evolvement and approximately four months before the second data collection period, the division was merged with another service providing division.

The case was chosen mainly on four criteria; capital goods, long product life cycle, service innovations and strive for a generic TSS possible to offer to other than the providing company's own installed base. Two of the TSS mini cases were initiated long before the study started, one had just been implemented, and the other two was implemented during the study. See Table 1 for more details.

The data was collected via semi structured interviews with open ended questions. The interviews were focused to the service champions [24] and each interview took between 1.5-2.5 hours. All interviews were recorded and transcribed by the same person who did the interviews. The analysis was primarily accomplished by identifying patterns, in an iterative process derived from the literature and comparing with similar cases reported elsewhere. Particular attention was paid to how the development, structuring, implementation and improvement of the new offering were done.

3.1 The Cases

Even though the product platforms have differed largely between the cases, the provider has been able to reuse the experiences and the major parts of the scope between the different businesses. The scope of the first business (Case A) was new to both the provider and the military customer and involved great challenges. The platforms in Case A were two different types of civilian airplanes. Hence, the customers operation is military but the Extended IB is civilian. In this Special Flights Operation the provider both prepares and flies the airplanes.

When moving to the next TSS business (Case B) the customer is civilian and the provider does not fly, but the rest of the scope was relatively similar to Case A. Case C was originally initiated in another division than the division operating Case A and B. Here, the intention was to buy the IB back from the customer and to offer a total service solution including everything except flying the aircrafts. However, the product platform is a military airplane and buying military equipment in Sweden is not realistic for private company, but the rest of the scope was actuated. In Case C the IB had been manufactured by the provider several decades ago. The customer in Case D uses several different platforms consisting of both airplanes and helicopters. The scope is similar to the former cases. The platform in Case E is a military helicopter and also this scope is similar to the former cases.

Table 1. Empirical Base - 5 Mini Cases within the providing organization

Mini Case (Imple-mented)	Product Platform	Customer (End Customer)	Airplane or Helicopter	Military or Civilian Operation	Turnover MSEK (Years)
A (2003)	2 Bombardier 8 Mitsubishi	FMV[1] (SAF[2])	Airplane	Military	450 (7)
B (2007)	3 Bombardier	The Swedish Coast Guard	Airplane	Civilian	175 (7)
C (2009)	35 Saab	FMV (SAF)	Airplane	Military	900 (8)
D (2011)	6 Eurocopter 1 Bombardier 6 Hawker Beachcraft	Scandinavian Air Ambul-ance	Airplane & Helicopters	Civilian	400 (8)
E (2012)	20 Augusta Westland	FMV (SAF)	Helicopters	Military	350 (6)

4 Results

In the Cases A and B the incentives for the provider to move towards TSS was to secure a continuation of contracts that was running out, to enlarge the scope and thereby the turnover and also to even out cyclic variations over a year.

Case C was initiated in another division than Case A and B. There were three major incentives for the provider (Case C) to move towards total service solutions. The first was to extend the product lifecycle. The system had been in operations since the middle of the 1960s and the customer considered closing it down. The second was an aim of having a leading role in the transition toward changed operations for the customer, which was a pronounced goal. The third was to obtain experiences and references of total service solutions operations. The provider had made a strategic decision to expand the total service solution operations, both to gain scale economy advantages, and to win new market shares and thereby increasing the turnover. Case C was planned to be a pilot-case for a considerably larger service solution on a more modern and complex platform dominating the complete providing organization.

During the development and implementation of Case C the interest for a service solution for the modern and complex platform decreased partly. Hence, that service solution has not been implemented yet. As a consequence the aims changed somewhat and the sight was set on the great possibilities on helicopters. The provider judged that the military helicopter market had great potential, but a reference helicopter business was needed on this Extended IB. Case D is a civilian customer who operates both helicopters and airplanes. Hence, Case D was a useful reference for the military helicopter businesses. Case E is based on a military helicopter fleet implemented in January 2012. This is the first out of totally three helicopter platforms, outsourced by FMV and the total potential turnover is extensive.

[1] The Swedish Defence Materiel Administration.
[2] The Swedish Air Force.

4.1 Organisational Changes

The unit were the total service solutions originate from via Case A, was acquired by the corporate group in 1999. However, the unit was not actually merged with the other service providing divisions in the corporate until 2006 (compare 2007 in Figure 1). Until that the originating unit worked rather autonomous. In 2006 a refined business unit (BU) with four divisions for service solutions was created. The originating unit was merged with another similar division. However, the originating unit was integrated basically on a steering level only. The operations continued more or less as usual. Hence, the development and implementation of Case A and B was basically done by an autonomous unit separate from the rest of the corporate.

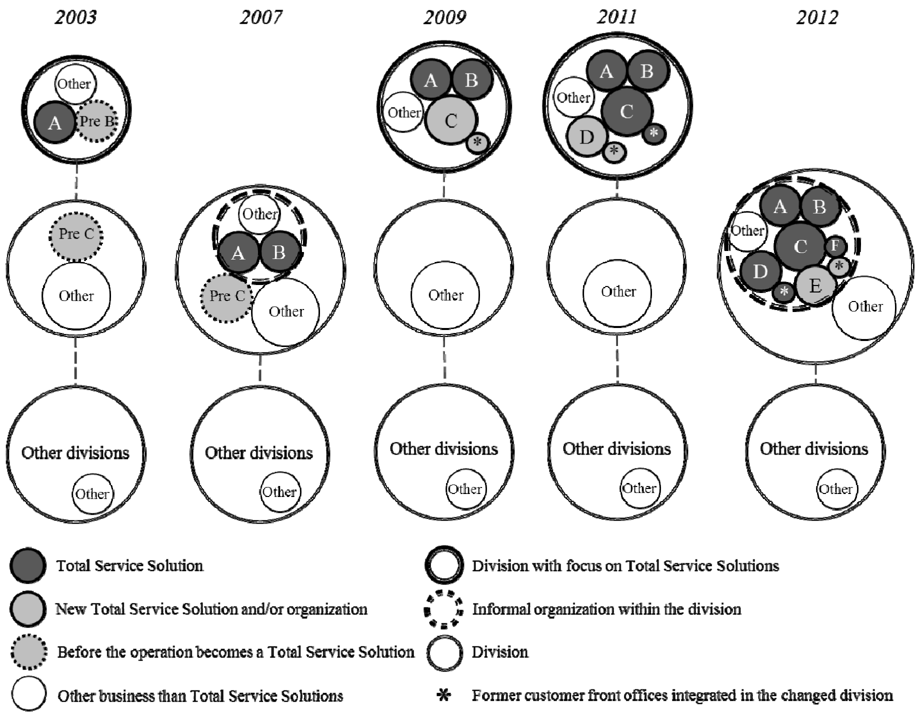


Fig. 1. Changes in the providing organization during 2003-2012

The first outline regarding Case C was done before 2006 when the service divisions were merged together as organizations. Accordingly, the substantial part of the development was done by other individuals than in Case A and B. However the merging 2006 opened up for increased knowledge transfer. Further, when the contract with the customer in Case C was close to being signed, a new division was created. The new division consisted of the origin unit (Case A and B) and the parts of the merged division that was operating the business connected to Case C. Hence, a purified division for total service solutions were developed. Added to this new division were some parts from the customer's organisation. The customer didn´t need all the front-end offices anymore and at the same time the provider needed both the competences and the hardware. Still, not all of the operation was incorporated to the division. Two major sub-suppliers remained. One service champion mentioned that after implementing all the five TSS businesses (2012), the prerequisites have changed compared with having fewer TSS, and choosing to outsource is not equally obvious anymore.

The organisation did not change much as a consequence of Case D and E. Some new front-offices were integrated. However, in parallel with implementation of Case D a road map for a new BU organization was designed. The new organization was implemented almost simultaneously as Case E was secured. Now, the division operating total service solution was merged with some new parts of the BU. The new division contains several more businesses and front-offices, but also several similarities compared with the division created 2006 when Case B was to be launched.

4.2 Capabilities and Structure

During the development of the TSS in Case C it was realized that the customer required information different from the previous product portfolio. The customer wants to select the service elements for himself. Hence, the capabilities from the running businesses A and B were formalized and combined into a capability portfolio to facilitate detailed discussions with the customer. This capability portfolio is described through a generic six armed work breakdown structure (WBS). It is applied to the unique business through activating or inactivating each cell in the WBS, and statement of work, organization, and calculations are connected to the active cells. The interviewed service champions expressed great satisfaction for this way of working. It was mentioned that this WBS has a great importance throughout all the phases for the transition to and operation of TSS.

After the baseline and the business model for the TSS were defined, the baseline could be adapted to the unique businesses. The adaption was done more or less in parallel with sales in an iterative process. Here, the final choices of detailed solutions were made by the customer and parts from the capability portfolio were combined and formalized by the provider. In the extended service solutions the requirements have increased partly on some cells in the WBS, for example program management, key accounting, front-end technicians and technical support. However, fleet management and handling weapons on the military aircrafts ought to be judged as new capabilities.

4.3 New Enabling Capabilities

In Case A, a radically new capability was co-created together with the customer. For the first time a TSS was developed and implemented and a new business model was used as a foundation. When Case B was introduced, the step was not equally large. The difference from Case A was basically running a civilian TSS as an opposite to military. However, the provider also learned how to smoothen out resources between the two existing businesses.

In Case C it was obvious that endurance was important. There have been discussions between the main actors for several years. Much time and money was spent on investigations with fuzzy intentions. A concept was agreed on after roughly 5 years. Although the transition in Case C was partly customer driven, the provider experienced a lack of readiness in parts of the customer organization. Many of the stakeholders were skeptical to the new business concept, the voice of the end-user was not paid enough attention to, and there were difficulties to get access to reliable customer data. The latter includes data regarding operations, maintenance, repair, and overhaul and also data specific for the follow-up on costs, regulations and certificates. When the data was available it was analyzed in a simulation tool developed in connection to Case C. In parallel with Case C, also a MRO module was implemented in the business administration tool to support the operations. Also a lot effort was made on getting extended certificates needed for the operations in Case C. This new capability is however, not completely generic, it is very much connected to the unique Case C.

In Case D service solutions were applied on helicopters for the first time and according to the interviews, the operations should be up and running within six weeks. In Case E another new combination, military operations on helicopters occurred. However, it was only the combination that was new; more or less all the service components had been used before.

Summarized, some new crucial capabilities were necessary to enable this journey towards being a TSS provider on the market aimed at.

4.4 Processes and Routines

The way of working is based on the capability portfolio as a keystone. Connected to this are several routinized activities and below the most obvious are described briefly.

The service champions simulate the businesses in a business simulation tool. This is done both in advance and in parallel with the customer's selection process. The head of the division and even the head of the business unit are involved and have detailed knowledge regarding how different parameters affect the businesses.

Implementation was a great challenge in the cases. Here, description and planning of the operations, and to secure certificates has been pointed out as crucial during the interviews. One example on the first is that the operation part "Technical support" was exposed to new requirements and a formal process description was created to cope with this. However, it was also mentioned during the interviews that creating one "overall process" for the complete service solution is not possible. Case C is somewhat unique. The changed business arrangement resulted in new fields of responsibility (e.g. weapons). This brought challenges that never had been faced before by the customer or the provider. The platform was encumbered with comprehensive regulations and to cope with these, formalization were important to enable the implementation.

Other routines with new opportunities are maintenance planning and resource planning. Having control over five large TSS operations brings an opportunity to smoothening of resources, at least at the back-offices. This was realised already at Case B, and the opportunities have increased with the number of TSS´s. The differences in the military and civilian operations required different education and individual certificates, but this was solved.

Further, when case D was introduced, civilian, military, airplane and helicopter regulations according to authority requirements should be obeyed at the same time. In the interviewees it was mentioned that the different regulations could be used as modules complementing the handbooks.

5 Discussion

According to the theoretical framework new product-service providing organizations often separates service units from product units, but might move them back together when the services are up and running. This was verified in the case. Another structural change in the case was integrating new front-end offices provided from the customers. Further it was indicated that with a sufficient number of TSS businesses, former decisions on outsourcing might be withdrawn.

According to the theoretical framework successful solution providers needs new capabilities and manage to balance the tensions between client needs and the capabilities. In the case this might have been true, however it was more obvious that balancing client needs (uptime) and maintenance costs was crucial. This leads to the insight that new capability “fleet management” was critical. Another new capability was “handling weapons”, even though this capability is rather unique for this single case. Added to the new capabilities, program management, key-accounting, front-end technicians gained an increased importance.

In the framework it is also emphasized that the dynamic capability service development is often less front-loaded than in product development and that it is common that lead users are deeply involved in the development with customized offerings as result. The latter has been verified also in this case. However, in Case C, the first TSS on a military product platform, “back-loaded” process is not completely true. Very much time and money was spent in the early phases. One reason for this was that both the customer and the provider (Case A and B excluded due to organizational reasons) had no previous experience from similar businesses. In addition, parts of the customer organization were skeptical. Further, there were great difficulties regarding access to and agreement on data.

According to Dosi et al. [29] capabilities are built by building blocks, for example routines. In the case some new process was formalized, but it was emphasized that creating one “overall” process would not be possible. Still, the latter is yet to be proved or falsified. However, civilian, military, airplane and helicopter regulations were managed as modules complementing handbooks.

In the framework also several service engineering models, including different components e.g. processes, resources, outcome, material, and dependencies are discussed. In the case the provider kept it simple. The service champions managed the businesses basically via a WBS and connected result/objective, resources/organization and costs to each cell. Miller et al. [5] reports on top managers in other companies that have a committee focusing on learning between the different businesses. In this case the service champions had that role.

According to the framework successful solutions are often possible to tailor and at the same time possible to reuse. The WBS enables customization and at the same time it gives a structure. Further the different scenarios from the customization are possible to simulate in a simulation tool.

6 Conclusions

The study describes how a structured approach of development, implementation and operation of TSS can contribute to customization and flexibility on the one hand and standardization and synergies on the other hand.

The basic shape of the *organization* might change in the beginning of a journey towards total service solutions. At first, independent customer-centric units seems to be useful to enable full attention to the TSS. When the TSS is operating to its full potential (scaling excluded) the directors seems to abandon that strategy.

The *capability* fleet management and also balancing customer needs (uptime) against maintenance costs are crucial to enable profitable TSS in the studied sector and probably also in other similar sectors. Other important capabilities identified in the sector are front-end technicians, key-accounting and program management.

Service development is one important *dynamic capability*. Former literature indicates that new service development is less front-loaded than new product development. This case shows that in TSS development for complex product platforms this is not necessary true. When neither the provider or the customer has previous experiences of TSS, the early phases of the development might need as long as five years and carry several and complicated investigations. During this journey, the provider proved truly dynamic changing strategy from IB to an Extended IB, when the more complex and modern product platform was not realistic to grasp as TSS.

New formalized *processes* and routines might be necessary to enable extended service solutions. In the case it was realized that different modules can be used as options in the operation routines if the provider is governed by different external regulations in the different businesses.

Structured solutions can be accomplished by means of a rather uncomplicated WBS with statement of work, organization and costs connected to each cell. This structure seems to be useful throughout the complete life cycle of the service and enables simulation of different scenarios. Such a structure also enables customization and is by definition a *dynamic structure*. On the same time it is a structure standardizing the solution.

References

1. Wise, R., Baumgartner, P.: Go Downstream: The New Profit Imperative in Manufacturing. Harvard Business Review 77(5), 133–141 (1999)
2. Johnstone, S., Dainty, A., Wilkinson, A.: Integrating products and services through life: an aerospace experience. International Journal of Operations & Production Management 29(5), 520–538 (2009)
3. Sakao, T., Berggren, C., Björkman, M., Kowalkowski, C., Lindahl, M., Olhager, J., Sandin, J., Sundin, E., Tang, O., Thollander, P., Witell, L.: Research on Services in the Manufacturing Industry based on a Holistic Viewpoint and Interdisciplinary Approach. In: Proceedings of 3rd CIRP International Conference on Industrial Product Service Systems, Braunschweig, Germany (2011)
4. Teece, D.: Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. Strategic Management Journal 28, 1319–1350 (2007)
5. Miller, D., Hope, Q., Eisenstat, R., Foote, N., Galbraith, J.: The problem of solutions: balancing clients and capabilities. Business Horizons 45(2), 3–12 (2002)
6. Aurich, J.C., Wolf, N., Siener, M., Schweitzer, E.: Configuration of product-service systems. Journal of Manufacturing Technology Management 20(5), 591–605 (2009)
7. Dong, M., Yang, D., Su, L.: Ontology-based service product configuration system modeling and development. Expert Systems with Applications 38, 11770–11786 (2001)
8. Bitran, G., Pedrosa, L.: A structured product development perspective for service operations. European Management Journal 16(2), 169–189 (1998)
9. Gremyr, I., Löfberg, N., Witell, L.: Service innovations in manufacturing firms. Managing Service Quality 20(2), 161–175 (2010)
10. Nordin, F., Kowalkowski, C.: Solutions offerings: a critical review and reconceptualisation. Journal of Service Management 21(4), 441–459 (2010)
11. Oliva, R., Kallenberg, R.: Managing the transition from products to services. International Journal of Service Industry Management 23(1), 14–26 (2003)
12. Freiling, J., Gersch, M., Goeke, C.: Eine "Competence-Based Theory of the Firm" Als-Marktprozesstheorischer Ansatz: Eine Disziplinäre Basisentscheidungen Eines Evolutorischen Forschungsprogramms. In: Management von Kompetenz - Managementforschung, pp. 37–82. Gabler, Weisbaden (2006)
13. Holcomb, T.R., Holmes Jr., R.M., Connelly, B.L.: Making the most of what You have: management ability as a source of resource value creation. Strategic Management Journal 30(5), 457–485 (2009)
14. Winter, S.: Understanding dynamic capabilities. Strategic Management Journal 24, 991–995 (2003)
15. Arend, R., Bromiley, P.: Assessing the dynamic capabilities view: spare change, everyone? Strategic Organization 7(2), 75–90 (2009)
16. Augier, M., Teece, D.: Staretgy as evolution with design: The foundations of dynamic capabilitis and the role of managers in the economic system. Organizational Studies 29, 1187–1208 (2008)
17. Fang, E., Palmatier, R., Steenkamp, J.-B.: Effect of Service Transition Strategies on Firm Value. Journal of Marketing 72(5), 1–14 (2008)
18. Windahl, C.: Integrated solutions in the capital goods sector: Exploring innovation, service and network perspectives. Doctoral Thesis, Linköping University, Sweden (2007)
19. Tuli, K., Ajay, K., Sundar, B.: Rethinking Customer Solutions: From Product Bundles to Relation Processes. Journal of Marketing 71(3), 1–17 (2007)

20. Galbraith, J.: Organizing to Deliver Solutions. Organizational Dynamics 31(2), 194–207 (2002)
21. Neu, W., Brown, S.: Manufacturers forming successful complex business services. International Journal of Service Industry management 19(2), 232–251 (2008)
22. Gebauer, H.: Identifying service strategies in product manufacturing companies by exploring environment – strategy configurations. Industrial Marketing Management 37(3), 278–291 (2008)
23. Davies, A., Brady, T., Hobday, M.: Organizing for solutions: Systems sellervs. system integrator. Industrial Marketing Management 36, 183–193 (2007)
24. Linneman, K.: Exploring the role of dynamic capabilities in the process of resources recombination in firms. In: Proceedings of CINet 2012 (2012)
25. Galunic, C., Rodan, S.: Resource recombinations in the firm: Knowledge structures and the potential for schumpeterian innovation. Strategic Management Journal 19, 1193–1201 (1998)
26. Gallouj, F., Weinstein, O.: Innovations in services. Research Policy 26(4-5), 537–556 (1997)
27. Kindström, D., Kowalkowski, C.: Development of industrial service offerings – a process framework. Journal of Service Management 20(2), 156–172 (2009)
28. Edvardson, B.: Quality in new service development: Key concepts an a frame of reference. International Journal of Production Economics 52(1/2), 31–46 (1997)
29. Dosi, G., Faillo, M., Marengo, L.: Organizational capabilities, patterns of knowledge accumulation and governance structures in business firms: An introduction. Organizational Studies 29, 1165–1185 (2008)
30. Sakao, T., Shimomura, Y.: Service Engineering: a novel engineering discipline for producers to increase value combining service and product. Journal of Cleaner Production 15(6), 590–604 (2007)
31. Bullinger, H.-J., Fähnrich, K.-P., Meiren, T.: Service engineering – methodoligical development of new service products. International Journal of Production Economics 85(3), 275–287 (2003)
32. Shimomura, Y., Hara, T., Arai, T.: A unified representation scheme for effective PSS development. CIRP Annals – Manufacturing Technology 58(1), 379–382 (2009)
33. Shimomura, Y., Hara, T., Arai, T.: A unified representation scheme for effective PSS development. CIRP Annals – Manufacturing Technology 58(1), 379–382 (2009)
34. Shimomura, Y., Hara, T.: Method for supporting conflict resolution for efficient PSS development. CIRP Annals – Manufacturing Technology 59(1), 191–194 (2010)
35. Gao, D., Chen, R.: A new way of new service development based on service customized approach. In: 2010 International Conference on Management and Service Science, MASS (2010)

Investigating the Sustainability of Product and Product-Service Systems in the B2C Industry

Margherita Peruzzini and Michele Germani

Department of Industrial Engineering and Mathematical Sciences, Polytechnic University of Marche, via Brecce Bianche 12, Ancona, 60131, Italy
{m.peruzzini,m.germani}@univpm.it

Abstract. Numerous companies are recently pushed to move from Products to Product-Service Systems (PSS). The final aim is to increase the value perceived by the market and provide a more flexible and personalized offer by a wide range of services connected with the product use. The research question is: how to understand the performance of new service-based solutions and easily compare to traditional products? Sustainability is nowadays accepted as a guiding principle for both public and corporate strategies. Whereas product sustainability can be validly estimated by several tools, no certified methods have been defined for PSS sustainability estimation yet. This paper proposes the combination of LifeCycle Assessment (LCA) and LifeCycle Costing (LCC) techniques to the whole lifecycle phases for both Product and PSS. Data comparison can be usefully adopted to drive the change towards PSS in industry. An industrial case study focusing on washing machines is presented as a valid example of method application to support decision-making in the B2C industry.

Keywords: sustainability, lifecycle design, LCA, LCC, industrial product, PSS.

1 Introduction

Recently, numerous manufacturing companies are moving from a product-center to a product-service perspective, towards the new concept of Product-Service Systems (PSS) [1]. This trend mainly consists of adding a wide range of services to differentiate the product and increase the value perceived by the customers. Furthermore, diversification of services is rather easy and fast to realize and relatively inexpensive as it is no longer based on product feature innovation but on providing innovative and temporary product-related services. Companies can add a full service portfolio to their products or even sell only the supporting services. In this context, companies are required to change their mind and start thinking in a new way. How can the performance offered by a PSS be validly estimated, quantified and optimized? Conventional tools used to assess traditional products are challenged.

Whereas products can be validly estimated by lifecycle design assessment methods, no structured and certified method has been defined for service estimation yet. At the same time, both the industry and the market need for easy-to-use and reliable tools to compare scenarios and guide their choices.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 421–434.
DOI: 10.1007/978-3-642-30820-8_36

The present paper aims to investigate how the lifecycle design approach can be adopted to estimate the sustainability of PSS and compare performances of product and service. The proposed method considers the whole lifecycle and finally measures the achieved performance in terms of environmental and economic impacts, which are estimated by lifecycle parameters and normalized to find a global performance indicator to objectively compare different solutions. A new indicator SI (Sustainability Indicator) is defined to weight and combine the different contributions. It allows having a homogeneous unit of measurement (monetary value) by overcoming the existing eco-efficiency indicators, whose impacts are expressed by dissimilar and not-comparable units.

The experimental study refers to the B2C industry, in particular the household appliance sector, and focuses on washing machines. The case study aims to assess the sustainability of traditional product and new PSS scenarios to compare them in an objective way. The former analysis focuses on the traditional washing machine use, the latter investigates an innovative business idea consisting of buying the effective washing cycles as a service.

2 Research Background

2.1 From Product to Product-Service Systems

One of the distinctive characteristics of modern B2C industry is the customer attention to solutions and intangible values (such as fun, success, fame, vanity etc.) instead of to tangible products. This fact pushes companies to move from product to Product-Service Systems (PSS). PSS offers some advantages from manufacturers: low-cost and quick diversification, a wider choice of market offer, a shorter time-to-market [2]. PSS starts from the idea of extended product [3], as a mean of adding value by incorporating services into a core product. The core product is the physical item traditionally offered on the market. All around the product, a product shell representing a set of supporting services as intangible additions can be added. It facilitates or supports the product use (e.g. maintenance plans or mobility guarantees). Products and services can be combined in a system to deliver required user functionality in a way that reduces the impact on the environment as defined by Baines et al. [4]. All variants are also linked to the sustainability potential of the system. Differentiating the services offered allows the extended product to be positioned differently on the market (e.g. coding of personalized functionalities). As a consequence, continuous innovation in services assumes a key competitive advantage (e.g. a car and the associated financial, maintenance and configuration services etc.).

Two scenarios can be realized depending on the position of the producer company: Product+Service and Product2Service. Product+Service scenario describes the simultaneous offering of the tangible product (core product + shell) extended with proper tailored services, where both physical product and services contribute to the company revenues and their relation needs to be adaptively determined. Product2Service scenario is sharply decoupling the manufacturing of goods and selling of services, where in most cases the physical goods remain property of the manufacturer and are considered as an investment, while revenues only come from the services (e.g. by selling "mobility" instead of the physical car). The first approach sees services as a means of creating a competitive advantage by adding value in the customer's view and making products more difficult to imitate, creating a "win-win situation" [5]. The second one sees services as potentially replacing products and is concerned with environmental and financial motivation.

In this contest, evaluating what the real differences for industrial practice and which business model is more advantageous assumes a crucial importance for companies. It can be achieved by defining objective indicators able to compare the sustainability of different scenarios and support strategic decision-making.

2.2 Sustainability Assessment Approaches

Sustainability is nowadays accepted by all stakeholders as a guiding principle for both public policy making and corporate strategies and highly competitive solutions. Over these decades, the definition of sustainability concept evolved. Actually, the core of mainstream sustainability thinking has three dimensions: environment, economy, and social wellbeing [6]. However, the biggest challenge for most organizations remains in real and substantial implementation of the sustainability concept. The implementation challenge is based on understanding how sustainability performance can be measured, especially for products and processes [7]. Sustainability assessment considering both the cost and environmental impact of new technologies at the early stage of development process is a crucial aspect to drive strategic decision-making and optimize product and service design as demonstrated also by recent studies [8].

In this context, lifecycle approach can offer a structured methodology to proceed. It basically consists of designing and modelling the product lifecycle through choices about product conception, structure and materials in the early design phase. It includes the application of technological and scientific principles with the goal of protecting the environment and conserving resources, encouraging economic progress, keeping in mind the need for sustainability, and optimizing the product lifecycle [9]. Lifecycle thinking considers the whole product system lifecycle "from cradle to grave". It also suggests that development phases are influenced by the requirements from any lifecycle phases [10]. As a consequence, all relevant phases are designed, specified, analysed and made available for simulation purposes, and a proper set of key parameters including functional performance, manufacturability, serviceability, and environmental impact, can be defined. These lifecycle parameters are used as metrics to assess the lifecycle performance (such as environmental, economic and social) and to compare and analyse alternative solutions.

Numerous assessment methods for environmental and sustainability analysis have been proposed for single product, from basic theoretical approaches to specific methods such as Carbon or Water Foot printing [11]. More recently, simulation methods and tools have been also used for PSS analysis because of their growing importance for companies [12]: from the estimation of cost of both product and integrated solutions [13], to LCS (LifeCycle Simulation) tool for representing the whole Product-Service model [14]. Approaches can vary from modularization-focused, stochastic behaviour-focused, and lifecycle-focused. Garetti [14] provides a deep analysis of the state of art. However, some of them are very theoretical and focus on the definition of an academic simulation model that is hard to implement in practice, while other studies focus on the analysis of specific PSS cases and comparison with the corresponding Product solution is not provided.

It has been demonstrated that creating synergies between LifeCycle Assessment (LCA) and LifeCycle Costing (LCC) analysis can assure the achievement of sustainable and eco-efficiency solutions [15]. LCA is a decision support tool to quantify the environmental impact effects of goods (products or services). LCA takes a holistic approach and therefore presents an accurate picture of the environmental trade-offs of engineered products, services or human activities. It is based on a set of indicators and methods to identify resource consumption and emissions at every stage of the product's lifecycle "from cradle to grave". It starts from the extraction of raw materials to energy production, resource consumption during the use, reuse and final disposal of a product [16]. LCA is usually intended for comparison and not absolute evaluation, thereby helping decision makers to compare all major environmental impacts in the choice of alternative courses of action [17]. LCC can be defined as the total cost associated to one activity performed over one fixed time horizon. It considers not only the market value of product, but also rather a global vision of cost, spread over the whole product lifetime. LCC can be consistent with the LCA approach as described above [18]. In literature some coupled LCA and LCC analysis have been successfully performed, but in all cases they refer to products [7, 8, 19]. Some LCA results refer also to social aspects. Normalizing them into Quality Adjusted Life Years is possible to measure the social impacts in terms of a reduction of well being as proposed by Weidema [20].

3 Method to Estimate Sustainability of Product and PSS

The proposed method is based on the achievement of a sustainable solution by considering both environmental and economical aspects by coupling LCA and LCC analysis. It adopts a lifecycle modelling approach to represent both Product and PSS and finally determines a unique index (Sustainability Indicator, SI) to assess the quality of each analysed solution. LCA is based on modelling the specific case (product or service) and considering the environmental and social impacts according to the standardized methods. LCC is based on the same model and considers all the related economical aspects, including management costs, usage costs, maintenance costs, and recycling costs. Analyses are carried out during the design stage, when their combination allows achieving a wider perspective and validly supporting top managers' decisions. The final aim is comparing alternative scenarios, evaluating the consumed resources and choosing the less-impact solution [8].

The method overview is presented in Figure 1. The method steps are the following:

1. Apply a lifecycle modelling approach to the specific case and carry out a detailed functional analysis to asses the lifecycle stages and the systems / subsystems involved. The lifecycle functional model is organized into three main phases:

- *Manufacturing*: all manufacturing processes to realize the global system components and assemblies. It generally adopts the company viewpoint;
- *Use*: all contributions related to the Product or PSS use. It generally adopts the user viewpoint;
- *End-of-Life*: all data related to the Product or PSS recycling, disposal and eventually re-use. It adopts both the company and user viewpoints;

2. Define the use scenarios, in terms of user behaviours and lifetimes, to be investigated;
3. Develop a LCA that is fully consistent with the analysed model and covers all the lifecycle stages to assess its environmental and social impact;
4. Develop a LCC that is fully consistent with the analysed model as well to assess lifecycle costs;
5. Normalize the LCA results by estimating the corresponding costs to obtain a monetary value for each use scenario. It allows to monetize both environmental and social impacts;
6. Couple normalized LCA and LCC results to obtain a unique evaluation index SI (Sustainability Indicator) for each analysed scenario.

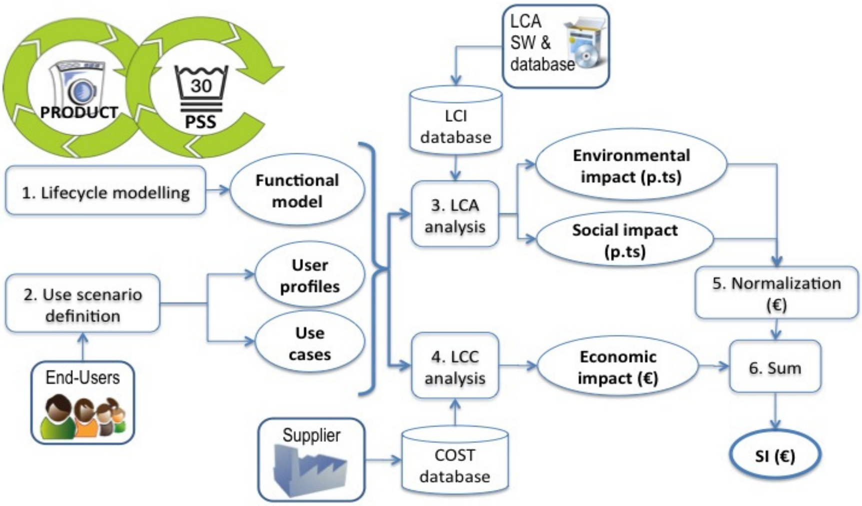


Fig. 1. Overview of integrated LCA - LCC method for sustainability assessment

The proposed approach can be easily applied to different manufacturing contexts of use. Indeed, both products and services are modeled and analyzed through their main phases and all necessary data can be quickly inferred from BOM (Bill Of Material), production documents, use data and disposal practices. As a consequence, for the majority of manufacturing products such an investigation can be straightforwardly carried out.

3.1 LCA Indicators

In order to simulate the whole lifecycle environmental impact, all significant data referring to raw materials extraction, processing, assembling and transportation as well as the use phase data and the end-of-life information need to be collected according to the functional model of the specific case. Analysis follows the four main stages suggested by [16]. Such an approach allows to compare different alternative cases or design solutions by considering the global impact of the three identified phase (Manufacturing, Use, End-of-life) [21]. LCA data need to be multiplied for a set of proper weights in order to have significant results. The Eco-Indicator99 (EI-99) methodology is adopted [22]. It considers the impact of each material or process according to three categories: Human Health, Ecosystem Quality, and Resources. The EI-99 unit of measurement is point (Pt).

3.2 LCC Indicators

LCC analysis aims to assess and compare costs associated to the whole lifecycle by considering the same functional model adopted for LCA. Data can be deduced by preliminary data collection, but usually requires the involvement of managers and stakeholders to describe on detail each analysed solution [23]. It determines a unique analysis framework, which can guarantee the coupling of the LCA and LCC results. A standardized methodology for LCC has not been defined yet and in literature many different viewpoints are adopted (supplier, manufacturer, user, society) [24]. While Net Present Value (NPV) is typically used as a decision making tool for business decisions, LCC takes into account a wide range of technical data which can occur during the whole product lifecycle (e.g. energy or fuel consumption in use, maintenance operations, end-of-life costs), to provide a more technical analysis [25]. The final aim is to highlight the economic impact along the lifecycle by considering a certain lifetime. As a consequence, a proper calculation method needs to be used. In this paper, the Equivalent Annual Cash Flow technique (EA) is adopted. It allows transforming a generic cash flow distribution into an equivalent annual distribution with the same actual value by cost actualization. For cost estimation, the formula (1) is adopted:

$$EA = P\frac{(i+1)^n * i}{(i+1)^n - 1} \tag{1}$$

where n is the lifetime years' number, i is the generic discount rate (for example $i = 3\%$), and P is the value during the all lifetime. The values refer to the three analysed phases as well as for LCA investigation (Manufacturing, Using and End-of-Life).

3.3 Sustainability Indicator

In order to combine LCA and LCC analysis, a Sustainability Indicator (SI) is defined. It provides a monetary index representing both the environmental, social and economical impacts for the whole lifecycle and the considered lifetime. It considers the values obtained by LCA EI-99 according to the impact categories (Carcinogens, Respiratory organics, etc.) [16] that are originally expressed by their own units of measurement (DALYs, PDF*m2yr and MJ surplus). Values can be calculated by a LCA software tools (i.e. SimaPro). Monetization can be done into 3 steps.

Step 1. Data are translated into different units by separately expressing the impact on human health (in QALYs, Quality Adjusted Life Years), ecosystems (in BAHYs, Biodiversity Adjusted Hectare Years) and on resource productivity (in EUROs). Expressing the impacts in QALYs also allows to explicit the social impact of a certain lifecycle [20]. The unit conversion is realized by the following formulas:

$$1\ DALYs = 1\ QALYs \tag{2}$$

$$(PDF * m2yr) * 1000 = 1\ BAHYs \tag{3}$$

$$MJ = \frac{1}{0{,}00411}\ €/year \tag{4}$$

Step 2. QALYs and BAHYs are translated in EUROs by using budget constraints, according to [26]. For QALYs the budget constraint can be determined as the potential annual economic production per capita at full well-being, that is estimated as 74,000 €. For BAHYs, they can be translated in QALYs by comparing the global terrestrial species-area (13×109 ha years) to the global human population (6,2×109 people). The ratio is 21. MJ can be translated into EUROs by considering the lifetime. Adopted formulas are:

$$1\ QALYs * 74.000 = EUROs \tag{5}$$

$$\frac{1.400}{BAHYs} = EUROs \tag{6}$$

$$MJ * \frac{0{,}00411}{lifetime} = EUROs \tag{7}$$

These formulas are based on European average data for having a consistent redefinition.

Step 3. After monetization, LCA contributions can be translated into the corresponding costs and they can be added to LCC data expressing the economic impact to finally obtain the global SI. Such a method can be repeated for each analysed system or scenario (Product or PSS) to compare different solutions.

4 Industrial Test Case: PSS in Washing Machine Market

The proposed case study has been developed in collaboration with Indesit Company and investigates an innovative idea in a very traditional B2C sector, household appliances. In particular it focuses on washing machines and aims to compare the sustainability of traditional Product (Washing Machine, WM) and two PSS solutions (both Product2Service) based on selling washing cycles as a service. The proposed lifecycle assessment method is applied for the case study analysis and modelling, and performance indicators (LCA, LCC and finally SI) are determined for the three cases.

4.1 Product and PSS Case Studies

The Product case study consists of the traditional sell and use of a washing machine (Hotpoint Aqualtis AQ131D-69EU, 11kg). The tangible good (WM) is sold as an assembly of numerous components and it washes clothes by consuming clean water, electric energy and detergents (provided by the user and home infrastructure). The business model is traditional as well: the consumer pays the product at the beginning and than pays for the resources consumed.

The PSS case studies refer to selling Product2Service solutions, when the customer pays only for the service whereas the WM is given for free. In both cases, the user pays only a "payXuse" fee and a special rate for the consumed resources (water, energy and detergents), which is fixed in collaboration with the energy supplier.

The first case (PSS-1) considers a direct payXuse service and the consumption rate is paid for every washing cycle done (0,45 €/cycles). The second case (PSS-2) considers a weekly payXuse subscription and a fixed fee is paid weekly regardless of the number of effective cycles (2 €/week). The product is similar to the Product one, but it is enhanced with some additional components able to connect the WM to the home gateway and Internet network and to allow the remote monitoring of WM behaviour.

4.2 Use Case Scenarios

For both Product and PSS cases, three scenarios are investigated. They consider three different user profiles, which are representative of the European habits. They derive from a marketing analysis conducted by the company marketing referring to washing care: for each profile, a characterization and an average weekly number of cycles are defined:

- *House Manager* (HM), who is an expert user, generally a woman, housewife or retired, taking care to house management and family issues in a special way (4,3 cycles/week with optimized loading);
- *Efficiency Seeker* (ES), who is generally a man with an active social life and an efficient, fast and pragmatic house management (5,8 cycles/week with low loading);
- *Delegator* (D), who is a young user, girl or boy, paying a limited attention to the house care in general and has an intense workload (3,9 cycles/week with medium/high loading).

Three lifetime scenarios are considered (1 year, 6 years and 10 years) for both Product and PSS.

4.3 Analysis of Product Sustainability

The product BOM (Bill of Materials) and the product structure are the starting point to carry out the lifecycle analysis and obtain the product functional model. Then, LCA analysis considers the lifecycle model and organizes all data into three phases: Manufacturing, Use, and End-of-Life.

The *Manufacturing phase* considers all the components used for the production and the final assembly, and all information related to manufacturing processes of BOM components as well as part and material transports. LCA data are organized according to the main functional entities: oscillating group, balancing and suspensions, electrical components, hydraulics, aesthetics, cabinet. Due to the high numbers of components, a 5% cut-off is applied to not consider those parts that have a limited impact. LCC analysis starts from the same functional model and calculates the manufacturing costs as directly considered by the manufacturer (Indesit Company).

The *Use phase* considers the user profile (HM, ES, D) and the lifetime (1, 6 or 10 years). LCA data relate to the consumed resources and materials: electric energy consumption, water consumption, detergent consumption, softener consumption, spare parts (e.g. hydraulic pump, electrical resistance, door seal, elastic belt, pressure valve, drain pipe group). Spare parts are inferred from statistical analysis of assistance service. Furthermore, a realistically decrease of performance corresponding to efficiency losses is estimated, as suggested by real data. Performance decrease is expressed by a cut percentage according to the number of the executed cycles (5% reduction after 500 cycles, 10% reduction after 1000 cycles, 20% reduction over 2000 cycles). LCC considers the product cost and all costs generated by the resource consumptions during the use: electric energy (0,2 €/kWh), water (0,0011 €/lt), detergents (2,5 €/lt), softener (1,4 €/lt) and calcium remover (0,33 €/cycle). Quantities are estimated by statistical analyses on real users over 5 years monitoring in field tests.

In the *End-of-Life phase*, LCA follows European Directive on Electric Equipment Waste (WEEE) for managing the product components: recycling (55%), reuse (10%) and landfill (35 %). Such data are considered on the effective percentage of sold machines that are actually recycled (about 25% of total). LCC takes into account the disposal cost paid by the producer to a third company who is responsible for the product treatment. In LCC analysis, all data are actualized by adopting EA method according to the lifetime and then summed.

4.4 Analysis of PSS Sustainability

About the PSS cases, the lifecycle functional model is organized into the same three phases, with some differences:

- New components in product structure to create the PSS infrastructure, support the additional functionalities providing services and allow the service system management (e.g. the presence of a smart plug, Zigbee module, a more advanced main board, a wiring network, 24/7 call-center assistance, data storage system, etc.);

- Higher performances due to a continuous control of the machine status and real-time monitoring and assistance (i.e. PSS machine is monitored and parts can be substituted in advance to guarantee a high quality performance for the whole lifetime);
- Optimized End-of-Life scenario, because the manufacturer directly manages the disposal (i.e. the machine is a company property also after sale and the company will care about it).

In the *Manufacturing phase*, LCA is carried out similarly to the product one, taking into account the new components, which. Also LCC analysis is carried out in the same way, but PSS production cost differ due to the new system components. A new cost item is represented by the "*service expence*" considering call-center services, the personnel employed there and the wiring network. Cost evaluation for service management and customer assistance has been assessed by company managers.

The *Use phase* considers the user profile (HM, ES, D) and the lifetime (1, 6, and 10 years) as for product analyses. However, the machine efficiency is higher thanks to the network connection and remote monitoring, so that its performances are maximum lifelong and LCA are reduced. LCC contemplates a more complex list of items: product rent, consumption costs (like in the Product analysis), service management cost, service subscription cost.

The *End-of-Life phase* shows the main differences. As far as LCA is concerned, PSS has a 100% of retired products and consequently a higher percentage of recycled materials. Furthermore, the more careful product disposal allows depicting three disposal scenarios according to the lifetime in accordance with WM regulations and data from Consortia on Recycling and Disposal:

- 1-year lifetime: WM is reused after testing and upgrading (99% reuse, 1% landfill);
- 6-years lifetime: WM is partially reused after testing and upgrading and some components can be recycled (75% reuse, 25% recycled, 5% landfill);
- 10-years lifetime: WM goes to disposal (100%).

LCC analysis for PSS is carried out as for the product, but considers also the different disposal scenario and cost for the company.

4.5 Results and Comparison

Table 1 shows LCA results for Product and PSS solutions, according to the lifecycle phase and the user profile. It provides a quick overview of different cases and highlights those with the highest impact. Data are expresses in EI-99 Eco-points. The last row contains the normalized impact calculated by adopting the above-mentioned formulas (2-7).

Table 2 shows the LCC analysis results considering PSS-1 and PSS-2, differing from the adopted business model (cycle fee or weekly rate). Table 3 contains SI values expressing the total impacts for the three analysed scenarios. 10-years lifetime results are reported: they represent the total impact expressed in euros for each solution (Product, PSS-1, PSS-2) and for each user profile. SI evaluation can easily support decision-making in B2C industry since it is able to quickly determine the global impact of a certain solution in respect with the target market. For example, case study results highlight which is the best strategic solution to launch the "payXuse" service on three target markets. Considering a 10-years lifecycle, it is worth to notice that both PSS solutions are advantageous in respect with traditional, independently of the user profile. Indeed, PSS-1 and PSS-2 total impacts are lower for all user profiles. Furthermore, it is possible to highlight the best strategy for each consumer: for Efficiency Seekers (characterizing by an intensive use) PSS-2 solution is preferable (689 € instead of 726 € for PSS-1 and 1.060 for Product), while for Delegators PSS-1 is more advantageous (562 € instead of 577€ for PSS-2 and 801 € for Product). For House Managers PSS-1 and PSS-2 bring comparable advantages (respectively 554 € and 558€).

Table 1. LCA analysis results

10-years lifetime		PRODUCT Eco-points (Pt)						PSS Eco-points (Pt)					
Phase	**LCA category**	**HM**		**ES**		**D**		**HM**		**ES**		**D**	
Manufacturing	Human Health	10,5		10		10		12,5		12		13	
	Ecosystem Q.	5,5	35	8	35	7	35	7,5	40	7	40	7	40
	Resources	19		17		18		20		21		20	
Use	Human Health	30		43		33		25		39		28	
	Ecosystem Q.	8,5	150	15	211	10	173	8	128	12	198	8	141
	Resources	111,5		153		130		95		147		105	
End-of-Life	Human Health	-2		-2		-2		-6		-6		-6	
	Ecosystem Q.	-1	-7	-1	-8	-1	-7	1	-15	1	-14	1	-14,5
	Resources	-4		-5		-4		-10		-9		-9,5	
NORMALIZED IMPACT*		€165,03		€223,67		€181,83		€140,18		€201,76		€150,22	

*calculated by adopting the previous formulas (2-7).

Table 2. LCC analysis results

10-years lifetime	PRODUCT			PSS – 1			PSS – 2		
Phases	**HM**	**ES**	**D**	**HM**	**ES**	**D**	**HM**	**ES**	**D**
Manufacturing	€53,93	€53,93	€53,93	€62,13	€62,13	€62,13	€62,13	€62,13	€62,13
Use	€565,20	€782,95	€565,62	€351,33	€461,77	€349,10	€355,29	€424,59	€364,04
End-of-Life	€0,18	€0,18	€ 0,18	€0,70	€0,70	€ 0,70	€ 0,70	€ 0,70	€ 0,70
TOTAL COST	€619,30	€837,05	€619,72	€414,16	€524,61	€411,94	€418,13	€487,42	€426,87

Table 3. Sustainability assessment (10-years lifetime)

10-years lifetime	PRODUCT			PSS – 1			PSS – 2		
User profiles	**HM**	**ES**	**D**	**HM**	**ES**	**D**	**HM**	**ES**	**D**
COST IMPACT	€619,30	€837,05	€619,72	€414,16	€524,61	€411,94	€418,13	€487,42	€426,87
ENV/SOCIAL IMPACT	€165,03	€223,67	€181,83	€140,18	€201,76	€150,22	€140,18	€201,76	€150,22
SI	**€784,33**	**€1.060,72**	**€801,55**	**€554,34**	**€726,37**	**€562,16**	**€558,31**	**€689,18**	**€577,09**

Varying the considered lifetime, interesting business model analysis can be inferred (Fig. 2): for 6-years lifetime the scenario is similar with some slight differences, but product remain the most expensive case for all the user profiles. For 1-year lifetime the situation is changed as SI value considers both the company and the customer benefits. It could be surprising but it can be explained considering that for such a limited time horizon PSS costs are higher due to depreciation and capital costs.

The proposed method can be adopted by different actors for different purposes: engineers can have useful data to better understand the impact of products and PSS; top managers can easily calculate a performance indicator to support strategic decision-making; marketing experts can compare market solutions; and finally customers have a tangible index to support their purchasing decisions.

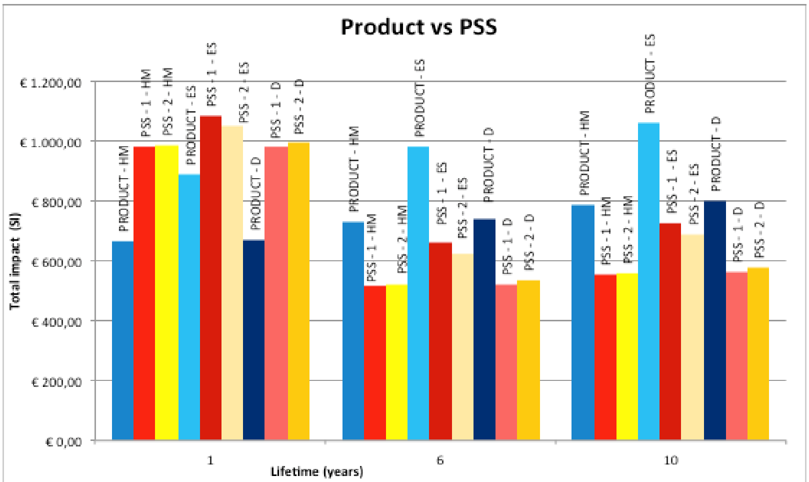


Fig. 2. Comparison of Product and PSS according to SI along the lifetime

5 Conclusions

The paper proposes a method to assess the sustainability of product and PSS based on a coupled LCA and LCC analysis. The experimental study focuses on washing machines and investigates the benefits of innovative PSS solutions for both manufacturers and customers. Experimentation demonstrated that it is useful to easily assess the sustainability of manufacturing products and PSS and compare the achieved performances accordingly to the considered lifetime and user profiles, simulating alternative business models. The study depicted several scenarios and simulated the impact on sustainability on the basis of a unique indicator. Such a method can validly support PSS implementation in practice as well as the identification of the best business model during the design stage. The proposed approach can be adopted by engineers as well as top managers and marketing experts.

References

1. Goedkoop, M.J., Van Halen, C.J.G., Riele, H.R.M., Rommens, P.J.M.: Product-Service Systems – Ecological and Economic Basic. PWC, The Hague (1999)
2. Alix, T., Zacharewicz, G.: Product-service systems scenarios simulation based on G-DEVS/HLA: Generalized discrete event specification/high level architecture. Computers in Industry 63, 370–378 (2012)
3. Thoben, K.D., Jagdev, H., Eschenbaecher, J.: Extended Products: Evolving Traditional Product Concepts. In: Proc. 7th International Conference on Concurrent Enterprising: Engineering the Knowledge Economy through Cooperation, Bremen (2001)
4. Baines, T.S., Lightfoot, H., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M., Wilson, H.: State of the art in Product-Service System. Journal of Engineering Manufacture 221, 1543–1552 (2007)
5. Davis, M.M., Heineke, J.: Operations management: integrating manufacturing and services, 5th edn. McGraw-Hill, New York (2005)
6. Adams, W.M.: The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century. Report of the IUCN Renowned Thinkers Meeting (2006)
7. Finkbeiner, M., Schau, E.M., Lehmann, A., Traverso, M.: Towards Life Cycle Sustainability Assessment. Sustainability 10(2), 3309–3322 (2010)
8. Castella, P.S., Blanc, I., Ferrer, M.G., Ecabert, B., Wakeman, M., Manson, J.A., Emery, D., Han, S.H., Hong, J., Jolliet, O.: Integrating life cycle costs and environmental impacts of composite rail car-bodies for a Korean train. Int. J. Life Cycle Assess. 14, 429–442 (2009)
9. Jeswiet, J.: A definition for life cycle engineering. In: Proc. 36th International Seminar on Manufacturing Systems. Saarbrucken Germany (2003)
10. Melk, K., Anderl, R.: A Generic Framework for Life cycle Applications. In: Proc. LCM conference (2007)
11. Berger, M., Finkbeiner, M.: Water footprinting: How to address water use in life cycle assessment? Sustainability 2, 919–944 (2010)
12. Bullinger, H.J., Fahnrich, K.P., Meiren, T.: Service engineering – methodical development of new service products. Int. Journal of Production Research 85, 275–287 (2003)

13. Wang, W.G., Wang, W.P., Zander, J., Zhu, Y.F.: Three-dimensional conceptual model for service-oriented simulation. LNCS Journal of Zhejiang University Science 10(8), 1075–1081 (2009)
14. Garetti, M., Rosa, P., Terzi, S.: Life Cycle Simulation for the design of Product–Service Systems. Computers in Industry 63, 361–369 (2012)
15. Settani, E.: The need for a computational structure of LCC. Int. J. Life Cycle Assess. 13, 526–531 (2008)
16. ISO 14040, Environmental Management - Life Cycle Assessment - Principles and Framework (2006), ISO 14044, Environmental Management - Life Cycle Assessment - Requirements and Guidelines (2006)
17. Curran, M.A.: Environmental Life Cycle Assessment. McGraw-Hill (1996)
18. Nakamura, S., Kondo, Y.: Hybrid LCC of Appliances with Different Energy Efficiency. Int. J. LCA 11(5), 305–314 (2006)
19. Dobon, A., Cordero, P., Kreft, F., Østergaard, S.R., Antvorskov, H., Robertsson, M., Smolander, M., Hortal, M.: The sustainability of communicative packaging concepts in the food supply chain. A case study: part 2. Life cycle costing and sustainability assessment. Int. J. Life Cycle Assess. 16, 537–547 (2011)
20. Weidema, B.: The integration of economic and social aspects in life cycle impact assessment. Int. J. Life Cycle Assess. 11(1), 89–96 (2006)
21. Norris, G.A.: Integrating Life Cycle Cost Analysis and LCA. Int. J. LCA Assess. 6(2), 118–120 (2001)
22. Goedkoop, M., Effting, S., Collignon, M.: The Eco-indicator 99 – A damage oriented method for Life Cycle Impact Assessment. Manual for Designers, 2nd edn. (2000)
23. Rebitzer: Integrating Life Cycle Costing and Life Cycle Assessment for managing costs and environmental impacts in supply chains. In: Seuring, S., Goldbach, M. (eds.) Cost Management in Supply Chains. Springer (2002)
24. Swarr, T.E., Hunkeler, D., Klöpffer, W.: Environmental life cycle costing: a code of practice. SETAC, Pensacola (2011)
25. Molinari Tosatti, L.: Life Cycle Cost Calculation for Investment Decision in Manufacturing. In: Proc. International Conference on Life Cycle Engineering (2006)
26. Weidema, P.B.: Using the budget constraint to monetarise impact assessment results. Ecological Economics 68(6), 1591–1598 (2009)

Environmental and Economic Contribution of Design Changes in Integrated Product Service Offerings

Mattias Lindahl and Tomohiko Sakao

Department of Management and Engineering, Linköping University,
SE-581 83 Linköping, Sweden
{mattias.lindahl,tomohiko.sakao}@liu.se

Abstract. Design changes performance significantly, as has been proven in the case of physical products. Quantitative research on a real offering in a market consisting of physical products and services is rarely reported. This paper aims to illustrate and discuss how design changes on a physical product or a service can improve the environmental and economic performance of an offering. The series of offerings compared in this paper are provided by a manufacturing company and are currently found in the marketplace. The in-depth study of this case shows the substantial contribution of design changes on performance, and reveals the high relevance of the interrelation between product and service on performance.

Keywords: LCA (Life Cycle Assessment), LCC (Life Cycle Cost), PSS (Product/Service System), IPSE (Integrated Product Service Engineering).

1 Introduction

More and more companies have abandoned traditional sales of products or service offerings in favour of Integrated Product Service Offering (IPSO), which is a term used in this paper to refer to PSS (Product/Service System) [1] with an emphasis on the importance of integration. However, they still often base their new offerings on their traditional products and services, without making any design changes (see e.g. Sakao & Lindahl [2]). Even though several researchers (e.g. [3-5]) have advocated that companies need to redesign their physical products in order to make their new offerings profitable and environmentally friendly, this is rarely realized. The reasons include that their current products and services were developed based on the old business logic, where spare parts and maintenance during the active use phase was considered to be very profitable. In the IPSO business logic, spare parts and maintenance are considered as costs and thus detrimental in terms of improving the economic performance of the offering. The subject of this paper how a provider's processes (mainly design) influence IPSO performance.

In general, different processes affect the performance of an IPSO, with the major processes being design, production, and use. Note that other processes by a provider such as logistics, maintenance, and take-back are modelled here as service within an

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 435–446.
DOI: 10.1007/978-3-642-30820-8_37

IPSO. In addition, production and use of service happen simultaneously, i.e. simultaneity or ubiquity of service [6], while that of a product occurs sequentially. The contribution of design on life cycle performance is perceived to be high. Specifically, the earlier stage of design is most influential. From the economic aspect, for instance, in the case of products, "the task clarification stage of product design accounts for only 10-15% but determines 50-70% of the total cost" is well-known [7, 8].

The influences of design, production, and use on economic and environmental aspects using real-life cases in industry have been reported, especially in the last decade. The influences of design are reported mainly from the automotive sector. For instance, Alonso *et al.* [9] and Schmidt [10] show the life cycle cost and the life cycle environmental impact of different materials and/or designs for a specific part of a car. Concerning production, the relationship between manufacturing process precision and environmental impact is quantified by extending the LCA methodology, and was reported to be positive in the case of an automotive drive train [11]. The use process' influence is also addressed. For instance, Avram *et al.* [12] proposed a method for adopting AHP (analytic hierarchy process) and applying it for sustainability assessment of different alternatives within the use phase, such as cutting parameters, to a case on machine tool systems. Fig. 1 depicts the processes and aspects of an IPSO system, as well provides some example references for the processes.

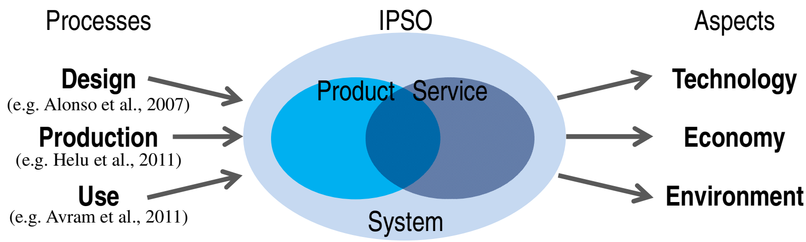


Fig. 1. Processes influencing an IPSO and major aspects for evaluation

As briefly reviewed above, existing literature based on real-life cases in industry focuses on physical products. One of the few papers reporting the different economic and environmental performances, depending on if it is an IPSO or product sales, is Sundin *et al*. [13]. There is clearly a lack of knowledge on how design of an IPSO, especially its service component, influences the economic and environmental aspects.

2 Objective

The objective of this paper is to, based on an in-depth case study in a manufacturing company providing an IPSO, illustrate and discuss how design changes on a physical product or a service can improve the environmental and economic performance of an offering. In contrast to Sundin *et al.* [13], this paper addresses a series of design changes longitudinally in order to better illustrate the design activities of IPSOs in industry.

The paper discusses the contribution of changes on a contract of IPSO business based on our earlier investigation, in an integrated manner, with the changes on a physical product. The value of this paper lies in its argumentation on the importance of design changes on the IPSO context, i.e. those on a physical product and a contract, based on real cases in the manufacturing industry.

3 Method

Literature studies, interviews and questionnaires were the methods used for gathering data about the case. Strong trust between the authors and participating companies, built over many years, has enabled unique access to data that are considered to be business secrets in many companies. These data have been carefully managed and agglomerated so that the final results do not reveal sensitive secrets, yet maintain the sufficient sources for scientific argumentation.

Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) methodologies have been used to illustrate the quantitative changes in environmental and economic performance, the two of which are briefly described below.

3.1 Life Cycle Assessment

LCA is a method used to assess a product's life cycle's total environmental impact, from an overall perspective, associated with all the stages of its life, from cradle-to-grave. These stages span from raw material extraction to manufacturing processes and use in waste management, including all transport and energy consumption. Life cycle analysis can be done in all human activities and products such as food, packaging, electronics, fuels, transportation, etc.

3.2 Life Cycle Cost

LCC is a cost model that reflects the total cost of an investment, product or system. All costs associated with all the stages of its life, from cradle-to-grave, are summarized, i.e. from raw material extraction, through manufacturing processes and use in waste management, including all transport and all energy consumption. It is a method used for instance in the analysis of overall costs and comparative studies in procurement, product development and maintenance planning.

4 The Case – Core Plugs for Paper Mills

Polyplank AB has developed a process to transform plastic waste and wood fibres into a cheap, recyclable and moisture-resistant composite material used in different system solutions, one of which is the core plugs used by paper mills [13, 14]. Paper mills use core plugs, on which the paper is rolled up; thus, the core plugs follow the roll out to the customer. Below is a description of how Polyplank's core plug IPSO concept has been developed over time, and how the development has influenced - and has been influenced by - the core plug design.

4.1 Background

Polyplank's core plugs have, in several cases, come to replace previously used core plugs that were made of a formaldehyde material. Fig. 2 shows an example of how they can look. Formaldehyde-based glues are used extensively in the woodworking industries, e.g. in the glues that bond particle board together. Formaldehyde core plugs are normally made of moulded wood chips that are glued together with formaldehyde-based glues. Core plugs made of formaldehyde material have several drawbacks that caused both paper mills and their customers various problems.

Fig. 2. A traditional core plug made of formaldehyde material

One problem was that they often gave rise to splinters that destroyed the paper so that it could not be used. This caused a financial loss for the paper mill and especially their customers. Furthermore, since these plugs were designed for single use, it caused the paper mill's customers extra work and costs for waste disposal. All this implied that the paper mill was interested in finding a new, more suitable plug that could solve the problems above.

4.2 The Orginal Polyplank Core Plug Design

By coincidence, Polyplank obtained information about the paper mill's need. The paper mill company had already started to consider a core plug made of virgin plastic, and had also come up with a design for the plugs. Together with a competitor that made core plugs based on virgin plastics, Polyplank started to deliver and sell core plugs in a traditional way, i.e. for single use, as shown in Fig. 3.

From a traditional sales perspective, the core plugs were nearly perfect. As a single-use designed product predefined by the customer, it required a lot of material and was dependent on the geometry, which was complicated to produce. Sharp edges and corners implied extra requirements on the tool for the injection moulding, and also for the time in the tool. At the same time, the production complexity implied that the company could charge a premium for the production. Furthermore, the selected geometry also implied a relatively high weight, which also meant high use of Polyplank's material. This was also good from a traditional sales perspective, especially since the company could refer to the initial customer's specification. The paper mill's customer, however, still had difficulty disposing of the used core plugs.

Fig. 3. The orginal Polyplank core plug design

4.3 The Take-Back System of Destroyed Core Plugs – The Starting of an IPSO

One of the major benefits of Polyplank's self-developed material is that it is easy to reuse in new core plugs or other Polyplank offerings. This also implied that Polyplank had an idea from their beginning to be able to take back and reuse the material in their old products. This goal has also had an impact on how they have designed their products or systems; in other words, it should be easy to take back the Polyplank material. It was, therefore, not unusual when Polyplank proposed to their customers that they could start to take back their core plugs and as well as those made of virgin plastic. Those made of virgin plastic became a raw material when producing the Polyplank material.

The paper mill agreed and used reverse logistics to handle the take-back, something that became immediately successful. The paper mill and their customers had less costs for waste. From Polyplank's perspective, this was of course a win as stated above, since after a chopping process it could reuse incoming scrapped core plugs as direct raw material for new ones.

4.4 The Reuse System for Core Plugs

Those within Polyplank continued to think of how they could improve their offerings. They realized that a lot of the core plugs that came back were like new and could be reused by the paper mill company. However, in order to secure the quality, they had to be inspected and washed. Only the worn-out or destroyed core plugs should be sent back for material recycling. Therefore, they proposed to the paper mill that they should launch a take-back and refurbishment system within their own operations, i.e. reuse of core plugs from their customers. From a traditional business perspective, this made no sense for Polyplank, but the company had a longer and broader perspective. The paper mill set up a take-back system, including cleaning, as seen in Fig. 4, and from the beginning this was a success for both their customers and themselves.

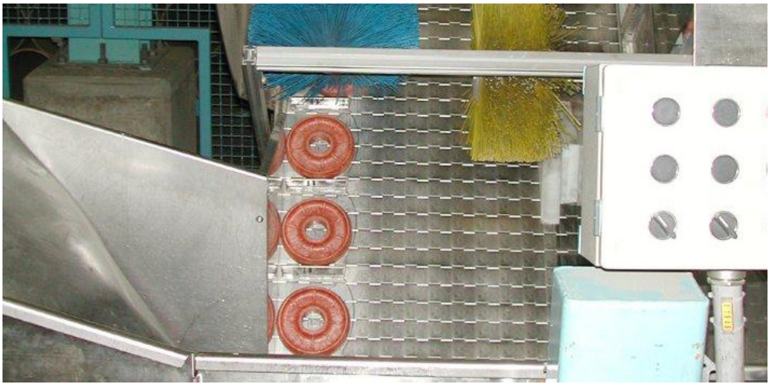


Fig. 4. Cleaning of used core plugs at the paper mill company

At the same time, it started to become obvious that the core plugs' original geometry with sharp edges and corners, often the starting points for cracks (see Fig. 5), had several cons. Even though broken new core plugs didn't cause major damage to the paper, e.g. that caused by splinters, they still resulted in an economic loss since the core plugs could not be reused, but instead had to be sent back for material reuse. After introducing the tack-back system, it also became obvious that the complex geometry also made it tricky for the paper mill to clean the plugs before reuse. This, however, this was not a cost that affected Polyplank.

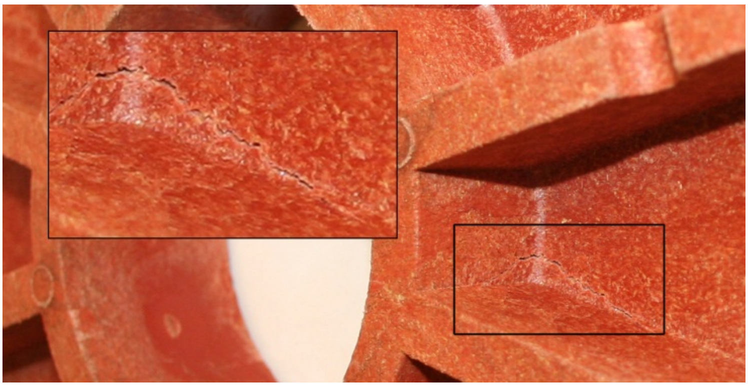


Fig. 5. Magnification of cracks on a core plug

4.5 The New Polyplank Core Plug Design

Even though Polyplank creates their products and IPSOs based on recycled material, they prefer to use as little material as possible in their offerings. Cutting down the material use has been a core value for Polyplank since the beginning; they want to develop, from a life cycle perspective, resource-efficient and effective products.

In line with this, internally Polyplank also had thoughts of how they could modify the original core plug design into a design that not only solved the above described cons with the existing core design, but also reduced their cost for providing the offering.

Even though they could reuse their material, their idea was to develop a core plug that required less material, was easier to produce, was easier to transport and clean and, not least, more durable. The latter was important in order to make the plug more competitive, and also allow more reuse between the paper mill and their customers. The key was to use less material in the product. By using less material in each core plug, less material had to be chopped and processed in Polypank's factory, i.e. heated up etc. in the moulding machine and transported to the customer. In addition, the paper mill's transportation costs could be reduced.

Together with the paper mill they started up a redesign project in order to design a more system-optimal core plug. In collaboration with a consultancy company and a university, they began to re-design the current core plug. The company performed advanced Finite Element Method analysis to find a design that could improve the core plugs' durability while also making the core plugs easier to wash, produce and transport. The result was a core plug that was 35% more durable, and at the same time 30% lighter, as shown in Fig. 6. The higher durability implied more loops between the paper mill and their customers, and the reduced weight meant less transportation and production costs, since less material needs to be managed in the production process, for example in the injection moulding used for producing the core plug.

Fig. 6. The new Polyplank core plug design

The core plug IPSO is now more than 10 years old, and has resulted in Polyplank taking market shares from competitors as well as a close collaboration between Polyplank and the paper mill company. Normally, the core plugs go back and forth several times between the paper mill and their customers before the plugs return to Polyplank.

5 Changes in Environmental and Economic Performance

As described above, the core plug and the system in which it is used has been changed several times over the years; the question is the effect this has had on the offering's environmental and economic performance. In order to investigate and illustrate this, LCA and LCC analysis have been used. All calculations are based on data provided by Polyplank.

Based on how the core plug and its system have changed over time, nine different alternatives have been calculated to illustrate the performance effect of the changes. Table 1 presents the different alternatives.

Table 1. The different alternatives used for the calculations

ID	Product	Product reuse?	Material recycle?
1	Virgin plastic core plug	No	No
2	Polyplank core plug with original design	No	No
3	Polyplank core plug with new design	No	No
4	Polyplank core plug with original design	5 times	No
5	Polyplank core plug with new design	5 times	No
6	Polyplank core plug with original design	No	5 times
7	Polyplank core plug with new design	No	5 times
8	Polyplank core plug with original design	5 times	5 times
9	Polyplank core plug with new design	5 times	5 times

Discussed below are some of the most important effects of changes performed. Note that all of the results below are related to the entire life cycle. Also important to note is that the compared LCA result only relates to global warming (CO_2 eqv); other environmental categories, such as savings regarding natural resource etc., are not included.

5.1 Effects of the Introduction of Polyplank's Core Plugs

Since it is not possible to make a comparison with core plugs made of formaldehyde, the starting point and reference used is core plugs made of virgin plastics that are used one time before being scrapped.

Not surprisingly, the introduction of the Polyplank core plug resulted in a substantial environmental performance improvement, 31% for the old design and 57% for the new design. This was the case despite that they would be sold in a traditional way and only used one time before being scrapped. The economic performance improvement was even higher at 36% and 62%, respectively.

5.2 Effects of the Take-Back System of Destroyed Core Plugs

When comparing the effect of the take-back system of destroyed core plugs with the single-use system of core plugs made of Polyplank material, the relative environmental / economic improvement effect is high, 57% vs. 51%. When comparing the improvement between the old core plug design used once and the new core plug (reused for material 5 times), the effect is 70% vs. 66%.

5.3 Effects of the Reuse System for Core Plugs

Compared with the newly-designed core plugs, used only once, core plugs used five times have a significantly improved environmental and economic effect, approximately 71% and 73%, respectively. If the core plug could be reused even more times, this would further increase the improvement effect. However, the percentage improvement effect decreases for each time the product can be reused, since the relative cost for reuse in comparison with the production cost increases.

5.4 The Total Effect of the Polyplank Core Plug Offering

Fig. 7 shows the environmental and economic improvement effect of Polyplank's Core Plug Offering in comparison with different alternatives. In the figure below, the most interesting is Alternative 9, since it is most like the offering that Polyplank provides. The exact number of reuse and material recycling instances, however, differs slightly from the real case.

Nevertheless, in comparison to the original core plugs sold for single use, their offering's environmental and economic performances have improved, 9% vs. 13%. If compared with the core plug made of virgin plastic, the figures are 6% and 8%, respectively. At the same time, the offering's performance also improved, something which was not anticipated.

6 Discussion

As shown in the previous section, all of the design changes on either the product or the service (such as product reuse and material recycling) in the case were found to improve the environmental and economic performance compared with Alternatives 1 or 2. Note that Alternative 2 represents the traditional product sales business with the original design at the IPSO provider. This means that this provider could design a product or a service that contributes to both the economy and the environment: i.e., Alternative 3 (new design of product) or Alternative 8 (new design of service) as a reference to Alternative 2. However, it is important to note that Alternative 3 and Alternative 8 are both unrealistic. Considering each service, Alternative 3 has excessive quality regarding the product, while Alternative 8 may have insufficient quality regarding the product. On the other hand, Alternative 9 (new design of both product and service) makes sense because the implemented product quality is required by the provided service. In fact, the new product design was carried out based on the service (as shown in Section 4.5). This case shows how design of service and design of product influence each other on a real offering in industry, and serves as evidence of the need for the integrated design of product and service.

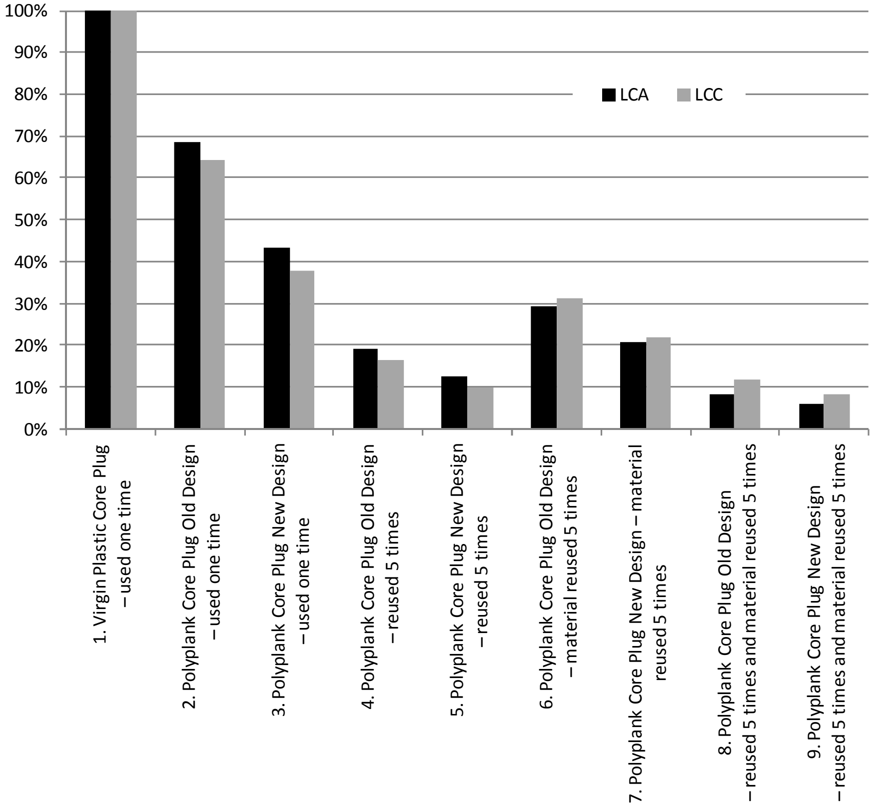


Fig. 7. Relative comparison of the environmental and economic effect of different alternatives

The degrees of contribution by design changes on performance given different alternatives were found to be up to approximately a factor of 10 (with Alternative 1 as a reference) in this case. This case did not show the contribution of production and use of this IPSO on performance. Such quantitative comparison between the contribution by design, production, and use would be an interesting topic for future work.

Correlation between environmental and economic improvement was found to be positive in most of the comparisons of different alternatives in this case. Although this cannot be generalized, earlier research [13] also shows that some other cases have a similar trend. It would be interesting to identify the key factors influencing this trend, and this will be part of our future research.

Another interesting research avenue is determining the factors that enabled Polyplank to design this series of IPSOs. Apparently, successes in designing IPSOs with better performance on the environment and the economy like Polyplank are not so common. One can ask what kinds of factors are keys to this success – product characteristics, company characteristics, or something else.

Unfortunately, since it has not been possible to obtain any data for the formaldehyde core plug, this is not included in the comparison. It would have been interesting to calculate the environmental and economic performance change related to the losses of paper and extra work at the customer caused by the formaldehyde core plugs.

7 Conclusion

This paper presented one of the first in-depth and quantitative studies of an IPSO's effects on the environment and the economy. It focused on design changes rather than changes of production or use. The case showed substantial improvement (reduction of approximately 80 to 90% in terms of both LCA and LCC) by the provider's design changes of a product or a service on environmental and the economic performance. Most importantly, the high relevance of the interrelation between the product and the service on the performance was shown.

This case can be used as a reference to illustrate the effects of design changes of IPSOs on the environment and the economy, as well as to argue for the importance of the integration of product and service design. It should be mentioned that this is thanks to the in-depth study. In addition, the relatively simple structure of the physical product can be argued to support the ease of understanding the comparison among different alternatives. Our future work includes conducting similar case studies with different types of offerings to obtain more insight within this area, and investigating key factors for success such as in the presented case.

Acknowledgments. The authors of this paper would like to thank Polyplank AB in Sweden and Stig Nilsson (former CEO) for their support.

References

1. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems - IPS^2. CIRP Annals Manufacturing Technology 59(2), 607–627 (2010)
2. Sakao, T., Lindahl, T.: A value based evaluation method for Product/Service System using design information. CIRP Annals - Manufacturing Technology 61(1), 51–54 (2012)
3. Arai, T., Shimomura, Y.: Proposal of Service CAD System -A Tool for Service Engineering. Annals of the CIRP 53(1), 397–400 (2004)
4. Aurich, C., Fuchs, C., DeVries, F.: An Approach to Life Cycle Oriented Technical Service Design. Annals of the CIRP 53(1), 151–154 (2004)

5. Maussang, N., Zwolinski, P., Brissaud, D.: Product-service system design methodology: from the PSS architecture design to the products specifications. Journal of Engineering Design 20(4), 349–366 (2009)
6. Regan, W.J.: The Service Revolution. Journal of Marketing 47, 57–62 (1963)
7. Fabrycky, W.J.: Designing for the Life Cycle. Mechanical Engineering 109(1), 72–74 (1987)
8. Hollins, B.: Successful Product Design, What to Do and When. Butterworth (1989)
9. Alonso, J.C., et al.: Electrical and Electronic Components in the Automotive Sector: Economic and Environmental Assessment. International Journal of Life Cycle Assessment 12(5), 328–335 (2007)
10. Schmidt, W.-P.: Life Cycle Costing as Part of Design-for-Environment. Environmental Business Cases. The International Journal of Life Cycle Assessment 8(3), 167–174 (2003)
11. Helu, M., Vijayaraghavan, A., Dornfeld, D.: Evaluating the relationship between use phase environmental impacts and manufacturing process precision. CIRP Annals - Manufacturing Technology 60(1), 49–52 (2011)
12. Avram, O., Stroud, I., Xirouchakis, P.: A multi-criteria decision method for sustainability assessment of the use phase of machine tool systems. International Journal of Advanced Manufacturing Technology 53, 811–828 (2011)
13. Sundin, E., Lindahl, M., Larsson, H.: Environmental and Economic Benefits of Industrial Product/Service Systems. In: Sakao, T., Larsson, T.C., Lindahl, M. (eds.) CIRP IPS 2010 Conference, Linköping, pp. 91–98 (2010)
14. Larsson, H., Kartläggning av miljö- och kostnadsfördelar som ett Integrerat Produkt- och TjänsteErbjudande av en hylsplugg ger jämfört med traditionell försäljning, LIU-IEI-R–09/0076–SE, Industriell miljöteknik, Institutionen för ekonomisk och industriell utveckling. Linköpings universitet, Linköping (2009)

Knowledge Sharing in Product Development – Delimitations of a White Paper Approach

Johan Holmqvist and Åsa Ericson

Product Innovation, Luleå University of Technology, Luleå, SE-97187, Sweden
{johan.holmqvist,asa.ericson}@ltu.se

Abstract. There is an on-going movement in manufacturing industry towards Product-Service Systems (PSS), which manifests the importance of making experience based knowledge organizationally available. In this paper a study of how white books is used and discussing any delimitations in transferring experiences is in focus. The paper builds on an empirical study in a manufacturing company, which has long ago implemented the white book approach and also has the vision of PSS development. It has been found that the format of a white book and the guidelines for authoring them could be a barrier for expressing individually gained experiences. Subsequently, does not support a knowledge transfer between projects having different aims, perspectives and knowledge domains.

Keywords: Product-Service Systems, knowledge transfer, knowledge sharing, expertise sharing, innovation projects, white books.

1 Introduction

Product-Service Systems (PSS) calls for additional competences of the engineers, for example a capability to simultaneously design service solutions, which insists on skills to understand fuzzy user situations and needs [e.g., 1]. Fundamentally, the service infusion in PSS challenges traditional knowledge transfer due to the different logics of product development and service development [2-3]. A similar difference in reasoning can be discerned in how engineers manage facts (i.e., measured and verified knowing) and experiences (i.e., assessed and sensed knowing) in contemporary engineering projects.

Development of PSS offerings increases the so-called tacit knowledge, as for example experiences, in the process activities. Tacit knowledge is recognized as an important element of product development and design work [4], this knowledge is described in literature as experiential and action-oriented knowledge hard to codify and communicate in writings [5]. The PSS vision stresses the importance of communicating tacit knowledge and experiences throughout the development process, in particular externally gained insights needs to be brought into early stages of conceptual design. And, this is from industry representatives described as a grand challenge for PSS. This might be the case since the problem is already known, sharing

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions,* LNPE, pp. 447–457.
DOI: 10.1007/978-3-642-30820-8_38

experiences is as is today a challenge in existing development projects [6]. A common approach in industry is the efforts to capture lessons learned and experience based knowledge in white papers. A white paper, or a white book in this case, is a written report often authored by a project leader. The intentions are to aid understanding of, for example an issue, a problem, or guide decisions or a subsequent project. By this, a large part of the contents in white papers strive to capture and formalize experiences and tacit knowledge. The paradox of experiences as “not being readily expressed” and “hard to codify” is recognized by organizations, while in lack of more promising approaches the white papers are a good effort.

Within a framework of PSS as triggering a more effective approach to sharing experiences, the purpose in this paper is to exemplify the delimitations of white papers. This is done in order to conclude on implications in general, but also in particular for PSS development.

2 Methodology

The study presented in this paper is not only theoretical, but also based on interviews with industry representatives from a product development company. The company has a background of implementation of PSS solutions, and PSS is also part of the future vision. The company has assisted in finding representatives involved in a knowledge transfer process between two different phases of product development. So far, particularly the knowledge transfer between the advanced engineering project and the receiver, a new product development project, has been in focus.

7 representatives from four similar projects have been involved in semi-structured interviews. Both employees from the transferring sides and the receiving side of such knowledge transfer process have been interviewed based on their previous and current experience. Further, a number of 25 white papers have been examined, not only from these projects where interviews have been conducted, but also from other related projects.

Longitudinal empirical data is used as a base for this study. Data has been gathered when following actions taken in the advanced engineering project for over 2 years.

During company visits, project meetings and workshops have been attended. Shadowing of employees, i.e., following someone when doing ordinary tasks, has been used to gain insights into daily knowledge sharing activities. Interviews with engineers, project leaders and experts have been conducted, transcribed and analyzed. Informal discussions with project members and check-ins on project portals has contributed to a general view of the work. So, all in all, besides interviews and scanning documents, the projects’ work has been observed at the company, but also by participation/observation of the activities at digital portal for project work.

3 Knowledge Management

Product development is often described as a knowledge intensive work and knowledge management approaches are well established in manufacturing industry, e.g., in

Knowledge Based Engineering (KBE), Computer Aided Design (CAD), Product Data Management (PDM) and Product Lifecycle Management (PLM) systems.

Knowledge management refers to the actions undertaken in order to enhance and ensure the organization's knowledge base [7]. As different views on knowledge exist, different perceptions exist regarding how to manage knowledge as well.

In knowledge management literature, the division into two streams is common, namely first and second wave of knowledge management. The first wave describes gathering, managing and control of existing knowledge [8]. This type of knowledge is typically facts, calculations and measures etcetera. This is also the type of knowledge a KBE-tool is based on. This kind of knowledge management tools can be described as *'heavyweight'* support [9], since it needs to be maintained and kept up to date by a specific organizational role, for instance a software engineer.

The second wave of knowledge management relates to creation and sharing of knowledge, but is also described to have a meaning of providing possibilities to learn [8], e.g., from experiences. The second wave type is based on subjective and socially constructed experiences; from this perspective knowledge evolves when people, for example jointly solve problems. This approach has also been categorized as *'lightweight'* [9], due to the low effort to maintain the contents and to find compatible software. This approach is not intended to replace the traditional knowledge management platforms, rather the aim is to complement with more social and tacit dimensions to deal with problems related to product development [9-10].

The differences between the first and the second wave of knowledge management have been highlighted by Huysman and de Wit [11] see Table 1.

Table 1. Differences in approaches (adapted from Huysman and de Wit [11])

	1st wave approach	2nd wave approach
Why is knowledge shared?	Managerial purposes	Daily work
When is knowledge shared?	When there is an opportunity to do so	When there is a need to do so
Where is knowledge shared?	Operational level	Organization-wide
Whose knowledge is managed?	Individual: Human Capital	Collective: Social Capital
What knowledge is shared?	Codified	Tacit and codified
How is knowledge shared?	Repository systems and electronic networks	Via personal and electronic networks

Referring to the description in Table 1 above, the first wave of knowledge management is more related to explicit (codified) knowledge, and therefore suitable for known situations. While the second wave of knowledge management prescribes a more social approach, with which PSS aligns. PSS requires a wider approach and involvement of more actors in the development stages, e.g., an interdisciplinary approach to address complex sustainability issues [12].

How to conduct a knowledge transfer and a experience sharing process differs, thus it is important to be aware of such differences. By definition knowledge transfer has been explained as a process which; *"…occurs when experience in one unit of an organization affects another unit"* [10] and thereby completes a task.

Knowledge transfer is applicable when communicating especially codified knowledge and facts. Knowledge transfer does not need to involve interaction between employees to execute a transfer; rather management systems are well suited to support this. However, when an engineer gets a new position the experiences possessed by that employee will disappear with the person, and become useful to that new division instead. Another situation could be when engineers use a computer-based tool for simulations, these results will have an effect on several parts of the design work not only the task at hand. In such a situation, a receiver of the simulation results might not be able to explain what has happened in the previous step, but can still understand how to use that information based on own experiences. If so, it is possible to argue that information or explicit knowledge is transferred, but not experiences or tacit knowledge.

Knowledge sharing or expertise sharing has been described as the act of making experiences available to others within the organization [13]; by this, knowledge sharing is more or less based on an interchange of lessons learned between humans. If so, any support requires to aid and ease interaction, dialogue, participation and collaborative work.

Experiences can be described as a certain category of knowledge that often relates to the complexity in relationships and networks of large global product development enterprises. Experience is defined as; *"…valuable, stored, specific knowledge that was acquired by an agent in a previous problem solving situation"* [14]. Therefore, one can argue that experience implies some useful lessons learned from solving problems, which is embedded in the person's know how and know why [15].

As argued, incorporating experiences into the organizational knowledge base needs approaches and methods different from managing information and explicit knowledge. Such instruments do not readily exist. In this paper, the white book approach is in focus.

4 White Book

Documents to capture knowledge used in e.g., the field of business to business, are known as white paper or white book, but originates from the area of government. The European Union state that; *"White papers are documents containing proposals for Community action in a specific area… When a white paper is favourably received by the Council, it can lead to an action programme for the Union in the area concerned"* [16]. Yet, a practical and industrial definition is used in the case company for this paper. The term white book is defined on the company's internal wiki-page for abbreviations and terminology as; *"A 'white book' is a summary of positive and* *negative experiences, as well as recommended actions from team members in the entire project".* The target group for a white book is members of future projects, ordering department, steering committees, process owners or other concerned. The idea with white books is to give the receiver a chance to learn from mistakes as well as successes of others, to improve development work and run 'better' managed projects.

The white book approach is well established and used in all projects as a deliverable at the end of the project time. The respondents stressed that the white book should not be mixed up with a project report, which has the purpose to account for facts about final concepts, specifications, economical aspects etc. The objective of a white book is to prescribe changes, not only on the product but also on processes, management, customer relations and internal teamwork. Basically, to share positive and negative experiences from daily work. The layout of a white book is a digital document consisting of a template, thus the respondents have highlighted pros and cons with it. For example, in some cases the format might be too rigid, and consequently constrains the author's possibilities to fill it in. The template guide authors to document different project activities and management aspects by proposing titles and subtitles, and this is found as a benefit since it provides consistency across projects. Also, the white book template propose that the project should be assessed by an outside party.

4.1 How a White Book Is Used

A typical project in the company could be described as often global and long lasting. In Figure 1, an overview of a project is exemplified. The left column named resources shows that 37 persons are directly involved in the project and assigned to activities. From an analysis of contacts to these 37 persons, it has been found that many more people are involved on the basis of specific tasks. These contacts are relying on a person-to-person connection and are not exemplified in Figure 1.

In a typical project, specific technologies, knowledge and skills are needed to conduct the necessary activities. Over the four years, 2007-2011, only one person has been involved throughout the whole project time, in this case it was not the project leader.

Commonly, a project leader participates the whole project time, but due to allocating available resources on an as needed basis, people come in and go out of projects. Thus, people work part time in this project and part time in other projects. Typically, each engineer is involved in more than 3 projects simultaneously. Consequently, transferring and sharing knowledge is of utmost concern. Overlapping activities and meetings are used to support experiences and knowledge to be shared. However, a grand challenge in global projects is to assess whether or not the transfer has been successful. Respondents have expressed that there are dimensions of 'lost in translation', particularly in written text. The respondents—which can be interpreted as being experienced project members—have expressed that in particular the state-of-practice is not straightforwardly transferred or shared. For example, understanding the background for a certain aspect of a problem can originate from previous projects long time ago. Getting access to such experiences is hard if the employee is occupied in a new project or even worse if an employee is retired or has a new employment.

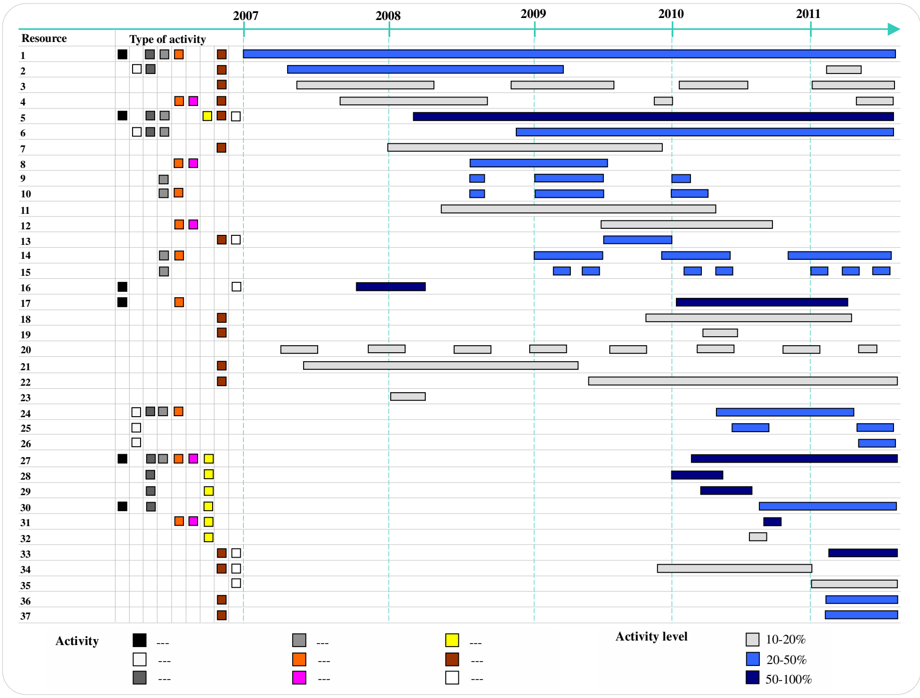


Fig. 1. The involvement of project members over time

Based on the longitudinal data acquired in this study, it can be seen that the individuals' perception of the objective with white books differs; this can in particular be seen in comparison between different departments and sites in the organization. For example, what is a positive and a negative experience and what kind of recommendations a project member prescribes depend on the persons pre-knowledge and domain of expertise. Thus, the text in the white book is inconsistently interpreted, and subsequently what the author intended and what the reader interpret does not correspond to the experiences searching for. Also, the situation where the author of the white book is also the receiver of the white book can occur, due to people coming in and out of different projects.

A key point in white books is that the experiences should describe the learning process for gaining them, yet this is hard to express. Some respondents stress that experiences relate to hunches, intuition, muscle memory and so forth. The situation where experiences are communicated by referring to a previous project in the words, but not stating, for example that projects impact on the development processes, is by the respondents identified as decreasing the possibilities for sharing.

When interviewing, i.e., listening to the respondents' descriptions, a more in-depth view of experiences can be found. Such "stories" reveal a more detailed and reflective view on experiences than what can be found in the white books. For example, one respondent described a positive experience from a supplier business partnership, in particular the approach of how the work had been broken down into separate units and how the units had been assigned to the company and to the supplier respectively was clearly expressed as a successful approach. The respondent could explain the reasons for doing so, and what kind of effects it had to the project as a whole. Following up the interview by reading the relevant white book, it could be seen that this was not mentioned. A possible interpretation of the discrepancy can be that the story told might be too long to capture under a subtitle, and especially in written text. Further, the respondent mentioned a top-one experience in the interview, but this experience was mentioned either in the white book. A possible interpretation of this is that some experiences needs to be digested before being perceived as a lesson learned.

It is suggested that white books should be used continuously during projects, but this is not done in general. Besides time pressure and project deadlines, a possible interpretation could be that reflecting over lessons learned in written text is a process that does not fit into the daily routines. A recommendation for the contents in white books is to clarify how decisions have been made; however micro-decision points are abundant in product development activities and embedded in routines. Further, how a team makes decisions differs from the common approach in another team, and this could relate to how domain specific knowledge has to be managed. To aid understanding there is a need to describe the context for the decisions, and this is yet another hard to do task on the basis of a white book template and format.

Respondents have also described that fairly old solutions can be of interest for a new project, if so the technology as such is not in focus, since it is outdated, but how problems were solved and what kind of concepts that was turned down, maybe due to immature technology at that time, is of utmost interest. However, getting access to, first, old documents is found tricky, and second information about the process and decisions are often lacking.

Respondents have explained that it is hard to address a certain reader when authoring a white book, in parallel it also become hard to fulfill the task of describing experiences. By this, the reflection on the experiences and lessons learned does not have a clear context or clear boundaries. Thus, the respondents describe that they, from time to time, have the feeling of just conducting a task when authoring white books. Finally, the respondents have expressed that they as readers of previous white books find the disconnection from the final project report as troublesome. The experiences and lessons learned needs to be put into the context of the specific conditions of a project and into the nature of the development task.

The respondents were in the interviews asked to rank their personal view in relation to the guidance of each title and subtitle in the white book template, the constrain was to rank them in relation their usefulness of different phases of project, start up, duration, ending and transition to another project. It was indicated that the white books were more useful when being an experienced project member, due to being more informed about previous projects and who the project leader had been. And, that the white books were used to check up issues occasionally, rather than continuously. This finding is supported after investigating 25 white books, 24 of them state that no white book was available to review before project start, and 1 of them provided slightly more text. However, the texts did not provide any further information that was found useful. In relation to this, the respondents stressed the difficulties to find the appropriate white book and also that the often insufficient text was usually not providing enough depth for practical actions.

4.2 Delimitations of a White Book Approach

Experience based knowledge falls into the category of tacit knowledge and in line with the characteristics for that category the knowing is not simply recognized, expressed and thus not easily formalized. The debate about how to define knowledge could be seen as an academic issue, for practical reasons companies commonly does not argue about what it is and what it is not. However, there is a difference in how companies apply information systems and knowledge systems, and subsequently they distinguish information management from knowledge management. When focusing the knowledge management domain, the two waves, the first one aiming for control and monitoring, and the second aiming for the sharing and creation of new knowledge, can be used to exemplify how experiences can be made more visible to the organization. Also, the difference between a "transfer" approach and a "sharing" approach could be to a certain extent clarified.

Experiences should; *"enabling individuals to gain actionable understanding"* [17]. Turban and Aronson [18] also give a practical explanation of knowledge particular in relation to computer-supported decision systems, they state *"knowledge is information in action"*. Systems like KBE, CAD, PDM and PLM fulfill one part of knowledge management in industry, but as seen in the efforts to author white books experiences and lessons learned are of utmost interest. The KBE, CAD and PLM systems focus on providing support for product related knowledge, and PDM is a tool to support the project organization and coordination. The main focus of the white book approach is to identify, capture and disseminate experiences that cannot be formalized and thereby does not fit into existing computer systems. The number one purpose of white books is to, as stated in description provided of the case company, to summarize positive and negative experiences, and recommended actions from the whole project time. For this, continuous work with the white book in parallel with daily activities is needed. It has been found that such an approach is not feasible, and it can be discussed whether or not the format and the layout of the template might instill barriers for experience sharing and knowledge transfer between projects.

Also, the study have found that white books does not sufficiently support the start up stage of a new project, hence it can be argued that the white book approach in its current state is not appropriate for knowledge transfer between projects. Also, for this issue, the format and layout could hinder the necessary communication in the transition stage between projects. This is also recognized by the company, which has implemented a transition approach, where "mentor/apprentice" by one project team to another and face-to-face meetings are included. Such an approach is more efficient and affordable in co-located projects, but quickly becomes a high-cost approach in global teams.

The white book template encouraged the projects to get a second opinion from an objective actor, i.e., a person not directly involved in the project. This has been found as more or less an open innovation approach [19], because external partners provide input. Such an approach could be supposed not being particularly common in manufacturing industry due to more focus on intellectual properties. This part is found as not having a direct effect on the project work, but provide a channel for sharing experiences.

Table 2 provides a list of possible requirements for how experience sharing could be supported. The objectives and requirements are based on theory and the discussion of the empirical data in this study.

Table 2. Proposal of a requirement list for experience sharing support

Objective	Requirement
Sharing personal reflections of daily work at an individual level in projects.	Supporting a personal view by using “I” format.
Comparing expected outcome of an action and actual outcome.	Assisting simple use before project starts and support reflection at project end.
Concentrating reflections on project level.	Preventing a focus on organizational level.
Sharing reflections on an as-needed basis.	Assisting swift and seamless use and documentation.
Supporting reflections on project at hand.	Directing focus on actual project.
Documenting personal experiences from teamwork in line with project process.	Supporting interpersonal and direct communication.
Expressing more dimensions of communication than solely written text.	Enabling use of natural language and visualizations.
Making individual experiences organizational accessible.	Providing possibilities to formalize collaborative learning in real time.
Making individual learning an organizational asset.	Disseminating individual lessons learned in an organizationally aligned format.
Clarifying lessons learned levels.	Differentiating reflections in relation to organizational areas of interest, e.g., product, process, business strategy, partnerships.
Providing point of view and framework of pre-knowledge.	Clarifying interpretation codes and expertise areas.
Enabling proposals to future projects.	Visualizing the connection between expertise areas, project know-how and qualified proposals.
Assessing what is an experience and what kind of lessons that has been learnt.	Relating reflection to context, behavior and consequences.
Facilitating reflection in practice.	Supporting individuals’ explorative skills.

5 Concluding Remarks and Implications for PSS

This paper discusses the white book approach and its delimitations for transferring experiences between different projects in early product development. To address the purpose of the paper a white book approach has been an interest. Interviews with white book authors and an analysis of 25 white books has been the empirical base. It has been discussed that the written format could delimit, or rather become a barrier, in the transfer and sharing of experiences between project teams. Also, templates providing guidelines for how to author white books have been discussed. It has been found that guidelines provide consistency, but also hinders individual differences when interpreting the contents.

In the case of extending business relationships to incorporate PSS development, collaboration across company boundaries is stated to be a key factor for successful products. Also, the necessity to incorporate the service expertise domain into early development stages is an established perspective of PSS development. One managerial implication for PSS development is that the knowledge transfer and experience sharing seem to become even more important, yet, as far as we know, a delimited effort is done to support these softer and more social aspects to support start up of PSS projects. Another managerial implication is the high degree of experience based knowledge in service development and provision, and that knowledge based systems in engineering design are not readily implemented on such type of knowledge. There are efforts done to take into account the more explicit parts of service related knowledge to support control and monitoring, i.e., based on a first wave approach to knowledge management. Still, similar efforts, for instance drawing from the benefits of rules of thumbs, could become a breakthrough for the realization of truly result-oriented PSS solutions.

Acknowledgments. We would like to acknowledge FFI - Strategic Vehicle Research and Innovation (a partnership between the Swedish government and automotive industry) supported by VINNOVA. We would also like to thank the case company and the respondents from the company for allowing open access to empirical data.

References

1. Ceschin, F., Vezzoli, C., Vergragt, P.J.: Small scale socio-technical experiments as stepping stones for eco-efficient product-service systems diffusion: a new role for strategic design for sustainability. In: Proceedings of 3rd CIRP International Conference on IPS2, Braunschweig, Germany (2011)
2. Vargo, S.L., Lush, R.F.: Evolving to new dominant logic for marketing. Journal of Marketing 68, 1–17 (2004)
3. Lush, R.F., Vargo, S.L.: Service-dominant logic: reactions, reflections and refinements. Marketing Theory 6, 281–288 (2006)
4. Hubka, V., Eder, W.E.: Design science: introduction to needs, scope and organization of engineering design knowledge. Springer, London (1996)

5. Choo, C.: Working with knowledge: how information professionals help organisations manage what they know. Library Management 21(8), 395–403 (2000)
6. Engwall, M.: Mysteriet med den orimligamodellen: om utvecklingsmodeller, kunskap ochkontroll. Nordiske Organisasjonsstudier 5(4), 28–53 (2003)
7. Braf, E.: Organisationerskunskapsverksamheter: en kritiskstudieav "knowledge management". Licentiate thesis No. 37, Department of Computer and Information Science, VITS - Development of Informations Systems and Work Context, Linköping University (2000) ISSN: 1401-4637
8. Ackerman, M., Pipek, V., Wuld, V.: Sharing Expertise: Beyond Knowledge Management. MIT Press, Cambridge (2003)
9. Bertoni, M., Larsson, A., Ericson, Å., Chirumalla, K., Larsson, T., Isaksson, O., Randall, D.: The rise of social product development. International Journal of Networking and Virtual Organisations 11(2), 188–207 (2012)
10. Argote, L., Ingram, P.: Knowledge Transfer: A Basis for Competitive Advantage in Firms. Organizational Behavior and Human Decision Processes 82(1), 150–169 (2000)
11. Huysman, M., De Wit, D.: Practices of managing knowledge sharing: towards a second wave of knowledge management. Knowledge and Process Management 11(2), 81–92 (2004)
12. Mont, O., Tukker, A.: Product-Service Systems: reviewing achievements and refining the research agenda. Editorial in: Special Issue of Journal of Cleaner Production 14, 1451–1454 (2006)
13. Ipe, M.: Knowledge Sharing in Organizations: A Conceptual Framework. Human Resource Development Review 2(4), 337–359 (2003)
14. Bergmann, R.: Experience Management: Foundations, Development Methodology, and Internet-Based Applications. Springer (2002)
15. Choo, C.: Working with knowledge: how information professionals help organisations manage what they know. Library Management 21(8), 395–403 (2000)
16. European Union (EU), Summaries of EU legislation, White Paper, `http://europa.eu/legislation_summaries/glossary/white_paper_en.htm`
17. Harrison, A.: Keynote speech. In: 3rd CIRP International Conference on IPS2, Braunschweig, Germany (2011)
18. Turban, E., Aronson, J.E.: Decision Support Systems and Intelligent Systems, 6th edn. International. Pearson Education, Upper Saddle River (2000)
19. Chesbrough, H., Crowther, A.K.: Beyond high tech: Early adopters of open innovation in other industries. R&D Management 36(3), 229–236 (2006)

Experience Feedback Using Social Media: From the Product Lifecycle Phases to the Design Practices

Koteshwar Chirumalla, Marco Bertoni, and Christian Johansson

Product Innovation, Division of Innovation and Design, Luleå University of Technology, SE-97187, Luleå, Sweden
{koteshwar.chirumalla,marco.bertoni,christian.johansson}@ltu.se

Abstract. Many companies have been using lessons learned practices as one of their key knowledge management initiatives to capitalize on past experiences. For product development companies, learning from product lifecycle phases gives a true competitive advantage to improve the next generation of products. However, companies are still struggling in capturing and sharing lessons learned and applying them in new situations. Based on this consideration, the paper proposes a video-based approach−using social media technologies−as a way to leverage continuous capturing and sharing lessons learned from product lifecycle phases to design practices. The paper presents the findings of a case study within the aerospace industry, which investigates the current industrial practices with regard to experience feedback, and illustrates the implementation of a video-based approach. Further, the conceptual mock-up of video-based lessons learned sharing portal and its social platform that are aimed to support the design practices are illustrated.

Keywords: Experience Feedback, Design Practice, Product-Service Systems, Experience Sharing, Lessons Learned, Web 2.0, Social Media, Video Sharing.

1 Introduction

Learning from experience for competitive advantage has received a great deal of attention in recent years [1] [2]. Since product development is an iterative problem-solving process [3], many companies have been using past experiences in form of lessons learned to guide the design of future products in order to avoid reinventing the wheel each time by accessing its past mistakes or successes [4] [5]. Managing experiences is becoming even more important as manufacturing companies are undergoing a fundamental shift in their business operations and are increasingly moving away from the selling of products to the provision of services or Product-Service Systems (PSS) [6] [7]. At an extreme side of this product-service journey, companies are offering 'function of the product' instead of hardware, retaining ownership and responsibility for the product throughout its entire lifecycle [7]. This affects the way new products are conceptualized and designed in the early phases, wherein the focus is shifted from satisfying artifact's physical characteristics to reducing the overall

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 459–471.
DOI: 10.1007/978-3-642-30820-8_39

product lifecycle costs while maintaining performance efficiency [8]. In this setting, reuse of experiences from different phases of product lifecycle, such as business, design, manufacturing, usage, maintenance, and recycling, play a key role to support design teams to address the relevant lessons from the past issues in new designs [9] [10].

Researchers have proposed different approaches to address this gap in a PSS setting. Baxter et al. [11] proposed a knowledge base structure grounded on three core elements of knowledge such as design, manufacturing capability and service to support the design activity. Vianello [6] proposed a documentation model to reuse of knowledge from the service phase of complex products and has identified that the designers require in-service information at a component level to improve next generation of products through design. Further, studies, for example [12] [13], develop KBE [12], PLM [13] based solutions to capture, analyze and reuse both manufacturing experiences [12] and product use experiences [13] in the new designs. However, the current research on experience feedback primarily based on explicit (objective, codified) field data e.g. condition monitoring, operation and service data and statistical databases, there is very limited focus on utilizing experiential learning that occurs through tacit (subjective, implicit) knowledge and social interactions. As highlighted by Clarkson and Eckert [14], "*traditionally, large amounts of knowledge and experience are never written down and are only stored in the heads of individuals* (p. 328)". Lessons learned (here after referred as "LL" in the text) practices are therefore failed to deliver the intended results as lessons are identified and are often not followed through and applied within the organization [15]. Furthermore, LL practices are limited to a 'single department' or to 'specific projects', lacking contextualized information for reuse it in the new situations [16]. Major issues also refer to staff turnover, reassignment of people to the new projects, time-consumption for capturing LL as well as the time lapses in LL capturing [4]. Hence, there is a need for practical, easy, social-based approach that can help organizations to regularly capture and share LL from product lifecycle phases to early design practices.

On the authors' advice, Web 2.0 or Social Media technologies look particularly interesting to enable capturing and sharing of individual/team experiences and tacit knowledge, as well as to improve communication across functional and organizational boundaries [17]. Accordingly, the objective of the paper is to propose a video-based approach−using social media technologies−for capturing LL from different product lifecycle phases and feed that back to early design practices. The paper presents the findings of a case study within the aerospace industry, including the current industrial practice with regard to experience feedback and the implementation of a video-based LL approach. Further, the conceptual mock-up of video-based LL sharing portal and its social platform that are aimed to support the design practices are illustrated.

2 Experience Feedback and Social Media: A Literature Review

Experience Feedback is a knowledge management initiative whose objective is to convey experiential knowledge or lessons learned applicable to an operational, tactical, or strategic level such that, when reused, this knowledge positively impacts on the results of the organization [4]. The lessons learned from problem-solving include: lessons about the domain, lessons about how to find information that is useful to the problem-solver, and the information about the resources that are useful in particular contexts [18]. Several researchers identified that narratives and story telling give the richest opportunities for articulating and sharing tacit and experiential knowledge [5] [16], especially when the lessons are *high-context and situation specific* [2]. Milton [2] stated that a story could support a lesson by providing valuable background and context, facilitating to understand the context when a new person reviewing the lesson, thereby guiding the person whether it applies within the new context or not.

In this perspective, videos seem to be a well-suited medium for supporting tacit knowledge transfer, because they bring rich context−not detached and compartmentalized like text [19]. A recent McKinsey study [20] found that video sharing is one of the most adopted social media tool in companies (i.e., top 3 with 38%). Videos are especially useful for scanning the external environment and capturing subtle and complex aspects of performed activities and to represent overviews of key dynamic processes [21]. Web 2.0-enabled capabilities facilitate video hosting services, which could allow individuals to upload video clips to Internet websites to capture and communicate stories with a richer and more dynamic content [22]. Additionally, Web 2.0 offers annotations, tagging, bookmarking, commenting, editing, and ranking functionalities [17] to increase the ability to share, network, find and discuss videos across dispersed boundaries. According to a 2010 survey among advanced manufacturing industries [23], social media tools (such as: social networking sites, video sharing, blogs, wikis and micro-blogs) are beneficial to share best practices and to quickly identify experts based on content they have uploaded on their profiles or conversations held on accessible social platforms. Wood et al. [21] investigated using videos to elicit and transmit the tacit nature of skilled practices and have created a wiki-based learning resource for novice craft practitioners, which offered a more flexible way of developing and refining their crafting skills. Further, Shariff et al. [24] added features to LL systems to allow users to upload media files, such as pictures and videos, to support a socialization process as well as to promote lessons reuse.

3 Methodology

The paper is based on a case study [25] performed in collaboration with an aero-engine component manufacturer, which develops and manufactures components for gas turbine-, aircraft- and rocket engines. The company usually acts as a design-make supplier to major aero engine manufacturers, in various product and technology development projects. The company works as an independent risk and revenue sharing partner, and assumes responsibility for certain engine components, from design, manufacturing, to maintenance services throughout the entire lifetime of an engine type. The company has recently implemented a Design Practice (DP) System to capture and structure product specific activities and related methods for each component against stage-gate product development process [26]. The system encompasses *flows, activities,* and *methods* to guide design and development work. The DP *flow* indicates which *activities* to be done, in which order, within a project phase, for a specific engine component. The documents related to *activities* and *methods* are stored in DMS (Document Management Systems) and searchable in DP system. The case study has been performed on DP system to identify solution alternatives to foster experience and lessons learned sharing across product lifecycle phases regardless of projects and organizational boundaries. Empirical data has been collected through observations at the company and interviews with DP system and product lifecycle stakeholders, which include engineers, system owner, business developer, design leaders, manufacturing and quality leaders, process owners, and product support leaders. The interviews and observations are focused on three things: First is to develop a richer understanding on current management of experience feedback along the product lifecycle phases. Second is to get feedback on the applicability of using video-based approach that is proposed by the authors. Third is to perform testing activities at the companies' facilities to verify the integration with the DP system. This paper is based on the case study results from testing the video-based approach and the conceptual scenarios that were discussed to support the DP system with continuous experience feedback.

4 As-Is Practice in Experience Feedback: An Example

Since the case company is moving forward to take over the product lifecycle responsibility, the product support team is dealing with operational problems of components wherein they have not been involved during the design of these components. The team is therefore increasingly searching for past experiences or the answers to the decisions that have been taken previously. For instance, what we have agreed with the customer? Why? Who took certain decisions on what basis?

Figure 1 illustrates an example for identifying past experiences when a product support personal received a problem from the customer. If it is an easy or known problem, the personal knows whom to contact to resolve the problem or get some help to know the references to old reports in the DMS. If it is an ill-defined problem, then there are mainly three options available to resolve the situation, including: asking seniors or colleagues in their department, searching in the DMS, or raising the issue in the weekly department meeting. If any senior is familiar with the problem, then he/she can send some old reports or else recommend a person X that could be helpful. The person X could send some reports in case he/she understands the problem by phone or email, otherwise, he/she may request for a meeting to discuss the issue further. The meeting might be helpful to identify some past experiences. If not the knowledge seeker will inform the project team that there was no past experience available to the given problem and there is a need to come up with a new solution by performing an analysis. Alternatively, the person can search for the past experiences in the DMS. However, in the DMS, one can only search with the title names if he/she knows what to look for in the DMS. For example, if one can type the word "milling" in the search title, then he/she will get all the documentation that have the title name milling. The person has to open all the documents to check if there is any relevant document.

If there were any document outside of his/her working context, then he/she wouldn't have the access to open it. In that case he/she needs to make a request to access them. Once the personal gets the access, he/she reads the documents. If there is any relevant document, then the personal usually gives a call to the person who wrote that document or the people who were working in that project to make sure that this past experience would applicable in his/her context.

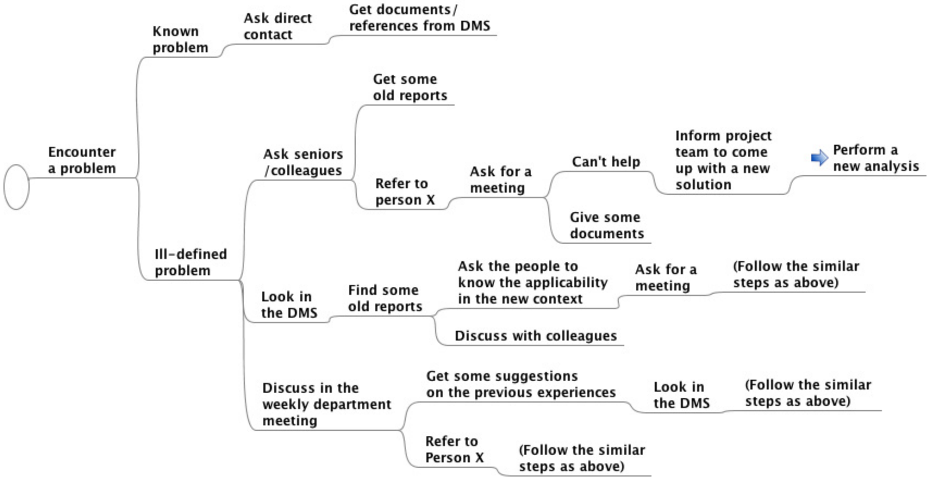


Fig. 1. An example for identifying past experiences in the product support phase

Figure 2 illustrates how the experience feedback is usually happened in the above example. In case the problem is a smaller issue, the product support personal documents a short analysis report. If it is a damage or non-conformance, then the personal has to dig into the archives in correspondence with the supplier and the customer and summarize the results in a "summary report", including answering questions such as why the problems were occurred? What they were discovered? What decisions were taken?

From this report, 10-15 lessons learned are identified in order to make a list of actions to the different departments to avoid repeating the same mistakes again in the next products. The audit department usually makes the follow up and is informed to different managers to make actions in their respective departments as shown in Figure 2. According to the informant most of these lessons are useful in the pre-study and concept study to inform the designers: "*you should think about this if you design a part that goes in to casting process*". If the lesson might have to do with the definition work, then it needs to go to product definition department to make a new DP in case there is no DP available, otherwise it adds to the checklist in the design review process. If the lesson is regarding the casting manufacturing process, then it can result in an alert report, which can be sent out to all casting suppliers with the recommendations. Eventually, this "summary report" is stored in the DMS with references to other reports. However, people that are working in the same project can only access to this

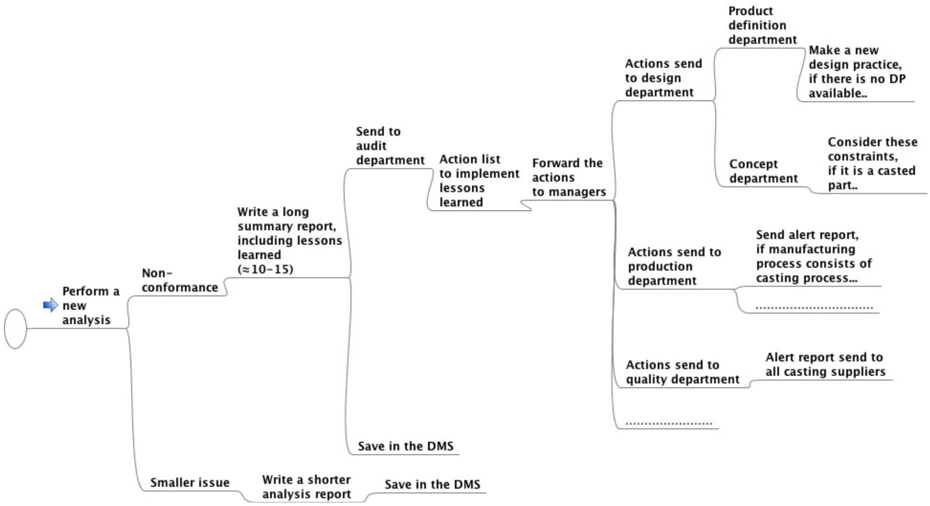


Fig. 2. Experience feedback process from the product support phase for the above example

document. Other people can see that there is a document, but they cannot open it. "*I don't know how these lessons learned that we identified is actually spread to other projects and departments*" described the informant. By commenting on identifying experiences he said that: "*of course this knowledge is only comes to me because I am the one is asking for it. It should be stored some where. So everyone could see it, right?*". The problem in documenting the lessons learned report from the projects is highlighted by one of the informants: "*[I think] no one really wrote those reports anyway. Because they thought it is not so important…we are so busy writing the reports we need to, for the clients. They require certain numbers and types of reports. That's what we focus on. This lessons learned template is something you have to do when you get sometime over…I would say [that] those reports have a low priority*".

The above example evidently illustrates the difficulty in documenting, identifying and accessing the past experiences and is emphasizing the importance of personal networks and social connections in the experience feedback process.

5 Experience Feedback Using Social Media: An Approach for Capturing Lessons Learned through Videos

The preliminary experimental results at case company identified that videos are beneficial for capturing lessons learned (LL) as they can capture the context of dynamic problem situations and that reduces time-consuming manual processes while capturing lessons in a continuous manner compared to a more text-based approach of documenting LL. However, capturing an LL video is not merely about making a video with some stories from a project. The LL video must be factual, technically correct, valid and applicable to specific tasks and processes. Hence, the authors have developed a method for capturing LL videos as a means to provide the structure and to lower the threshold for the people who want to share their lessons. The method to structure the LL videos contains seven steps as shown in Table 1. Each step has a set of guiding questions to support the users in formulating their message in a clear, concise, and informative manner for each section of the LL video as shown in Table 1.

The video-based LLs process consists of six stages, including: (1) Identifying the LL during an activity, (2) Preparing and formulate a LL story using the steps and guidelines in the below LL template, (3) Recording the LL video, storing and sharing with proposed tags and secrecy level settings, (4) Validating and disseminating the LL with secrecy level and tags settings, (5) Searching and retrieving the LL using the tags, and (6) Reusing the LL in new activities.

Table 1. Layout of lessons learned capturing template in the proposed video-based approach

No	Steps	Guidelines	Notes
0	LL Statement	Shortly summarize the main points about this lesson and why it is important for others to know.	
1	Working Context	**Describe the background of the task:** Name of person, job role, product type and project name? What is the operational level of the task within the product development process? Who are the stakeholders?	
2	Task Description	**Briefly describe the task:** How was the task planned/ executed? What key parameters or tools were used? What are the conditions when the task was executed?	
3	What Went Wrong or Well?	**Describe problems/successes that you came across during the activity:** What was the problem/favorable outcome? Where/How did you identify the problem(s)/favorable outcome? What is the effect of the problem(s)/success on task execution?	
4	Lesson Learned	**Describe the lesson that you learned:** What are the root-causes of problem/success? What steps have you undertaken to solve the problem or to find the success? How can the problem be avoided or how can the success be repeated?	
5	Lesson Learned Measures	**Describe the measures to the improved solution of the problem(s):** How can your LL improve the problem area or success area? How would you quantify the change/ improvement compare it with pre-existing solutions?	
6	Applicability and Delimitations	**Describe the applicability or delimitations of the lesson learned:** Who are the potential beneficiaries of your lesson? Where can the lesson be applicable? What is the level of quality? What additional activities are necessary? What are the limitations of your lesson?	

The LL contributor records the LL video and proposes several tags on the basis of job role, project name, product type, lifecycle phase, discipline, area of impact, stakeholders and validator, to make the LL searchable. Further, contributors can propose the name of a validator or specialist in the LL area for approving their LL video in a rapid manner. Additionally, the contributors can propose a “secrecy level” to their LL from scales 1 to 4 to enhance privacy and confidentiality for sharing sensitive lessons from the projects across boundaries. Based on the case observation, the study identified 4 secrecy levels. Following the LL contributor request for approval of their LL video, the proposed validator gets the alert message to review the LL. The validator can go through with the dissemination settings proposed by the LL contributor and approve it with minor or major changes. The knowledge seekers search for the LL videos based on the tags defined in the system and can add their reflections, comments and rankings after their usage of LL.

YouTube® (www.youtube.com) has served as a video repository during the first round of experiments and as a portal for testing basic tagging and annotation functionalities. A number of other video hosting services have been further analyzed to identify functionalities able to cope with the needs emergent from the empirical study. These include annotating, tagging, commenting, bookmarking, ranking/rating, aggregating and embedding functionalities. Based on the gathered user needs, all the required features were drawn and mapped against the list of functionalities. Eventually, this led to the conceptual mock-up of video-based LL sharing portal with the following interfaces shown in Figure 3.

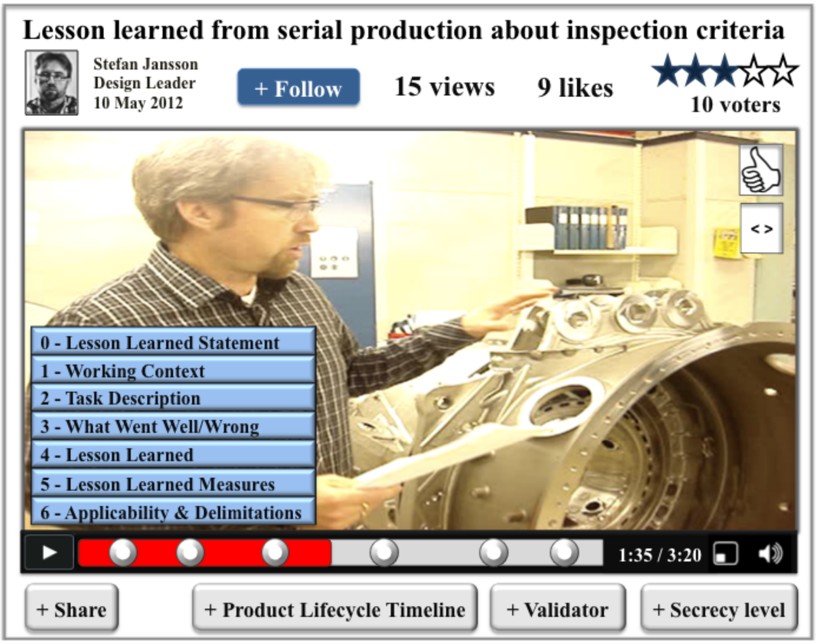


Fig. 3. Conceptual mock-up of Video-based LL sharing portal with functional interfaces

As seen in Figure 3, the LL video displays annotations of LL template topics/steps as an overlay on top of the video. The observations showed that this way of representing the LL videos allows the knowledge seekers to browse for interesting topics of LL instead of going through whole video. Additionally, the experimental observation also considered having "browsing points" on the video status bar, which symbolize the 7 topics in the captured LL story. The observations also revealed that these capabilities built on top of the LL video could allow the users to browse and absorb many LL videos in a shorter time span. The empirical observations highlighted several bookmark links to be considered in the platform, including, but not limited to, "share", "product lifecycle timeline", "validator" and "secrecy level". For instance, the "Share" bookmark link can facilitate an LL contributor to quickly add video clips to the project blogs, intranet, departmental sites, and so on.

6 Benefit of the Approach for Industrial Use

According to the previous research [6], design teams like to access the past experiences at a component level. However, the As-Is practices are majorly ad-hoc, project- based which does not support the designer to access the past experiences at a component level with a richer context. The company is changing the process flows within DP system based on LL reports, eventually missing the rationale why they have changed a certain process. As observed during the study, DP system lacks support for handling the lessons learned from various projects, especially concerning lessons from the downstream processes such as manufacturing, serial production, product support and maintenance. Furthermore, the study found that the lessons with high-context such as casting and welding operations are harder to explain and report in the text-based document. Video-based LL approach could allow product lifecycle stakeholders to capture the lessons with an illustrated story and share it to the product lifecycle timeline per each component as shown in Figure 4. Within the DP system, this practice could allow designers to access related LL from various projects on the same page together with the best practice documents. In this way, videos can carry a learning point that is specific, actionable recommendation to the component designers in the early phases, enabling to access more context-specific lessons compared to the traditional project-specific lessons learned documents. Such practice can help continuous capturing and disseminating of the lessons learned from the downstream processes, which could help the design teams accessing properties governing lifecycle behavior in the early conceptual stage per each component.

Another technology enabler for developing social ties across organization is to leverage conversations around LL videos. The study found that adding commenting functionalities related to the LL videos allow other people in the organizations go through the video and add their relevant comments to the LL story. In addition, adding "like," rating, follow the user and "embed" social features in the portal enhances the bottom-up and social networking capabilities across boundaries. Based on preliminary experiments, the LL video-based approach, in this way, can capture the rich context of lessons learned and feed that back to early design practices, thereby leveraging cross-functional sharing and networking across borders.

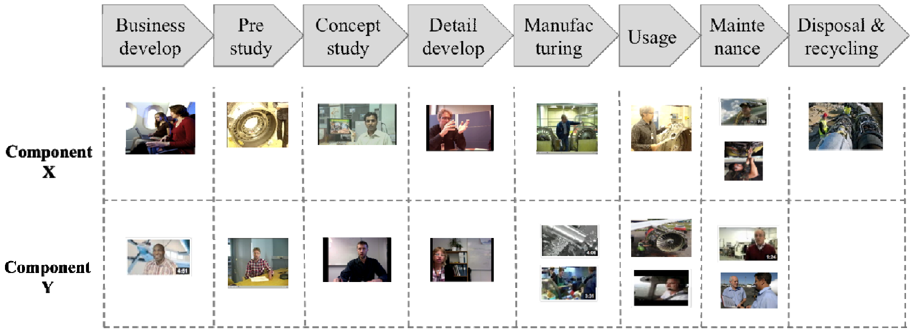


Fig. 4. The conceptual view of sharing video LL from product lifecycle phases to DP system

Based on the proof of concept validation at industrial environment, the study proposes a conceptual mock-up of video-based LL social platform—with using social media technologies—for capturing and disseminating the experiences across boundaries. The major functions considered in the platform are video portal, network profiles and discussion space, including the basic interfaces such as search, tag cloud and dashboard (See Figure 5). A *Video Portal* is intended to contain a variety of LL videos, which are classified under the approved tags by the validators. When designers who are seeking for specific experiences from past projects can access the relevant videos based on the tags. As they click on the relevant video, they can view the video with annotations of LL topics, the entire tags and comments as shown in Figure 5.

Further, the *Network Profiles* is intended to contain the profile pages of LL contributors. Every LL contributor can create their profile pages and user name when they uploaded their first LL video to the platform. In profile pages, every user can see their LL videos and save other relevant LL as their favourites on basis of their job roles and working projects. In the network profile, every user asks to enter their skills and later these skills are tagged into the system as "expertise". Additionally, the users can see their social ties, recent activities as well as subscribe to the favourite feeds they are interested in. This will enhance the social networking capabilities across different departments. Another functionality considered is a *Discussion Space*, which is in nature more of a blog and wiki combination. Blogs can be used to capture and leverage conversational knowledge across boundaries. For instance, blogs can be used to discuss the past experiences and LL search results before the gate meetings. The wiki functionalities in the blog can enable to combine different LL videos at the end of each stage-gate and to create a summary of LL practices as a Wiki page from the specific project. The *Search* function is intended to allow the knowledge seekers to search for the relevant LL from previous projects by entering the keywords. The platform can also recommend relevant tags for the user based on the key words they have entered in the platform. While searching for past experiences, the search function will be able to show the LL videos, network profiles and the discussion pages relevant to the key search word. Moreover, the learno-meter, a *Dashboard,* is intended to visually displays the quantify numbers of LL capturing and reuse for estimating the performance of the tool. Finally, the *Tag Cloud* in the platform is intended to gather various tags created in the system (i.e., tags from LL videos, network profiles and discussion pages) and present the visual display in an abstract manner. This way of structuring knowledge in a bottom-up manner could assist both management and operation levels to see what is the current 'hot' topic in the organization as well as within the platform.

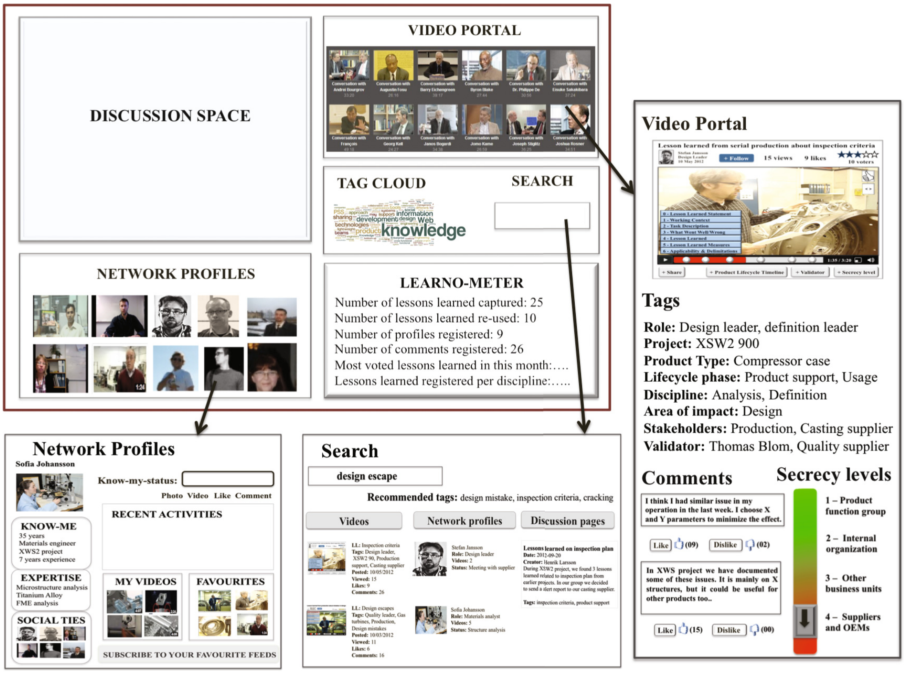


Fig. 5. The conceptual mock-up of a proposed video-based lessons learned social platform

7 Concluding Remarks and Future Work

This paper has proposed a video-based approach–using social media technologies–as a way to lower the threshold for continuous capturing and sharing lessons learned (LL) from the product lifecycle phases to the design practices, supporting front-loading in product development by enabling experience feedback from product life-cycle phases. The approach encompasses a LL capturing template, guidelines, process description and technological enablers. The approach is based on a 7-step template, which is intended to facilitate the capturing of contextual information and tacit know-ledge compared to what is already available in literature. Preliminary verification activities have shown such a solution improves the preparation and formulation of LL in a story format compared to other traditional templates and recording means. The study identified that the video-based approach is beneficial to give manufacturing, operational and maintenance inputs to early phases of design practices at a component level. In the future, the study will extend to the development of a full-scale prototype system, using open-source video sharing applications. The prototype will serve the purpose of testing the viability and performances of approach by experimental means, observing and analyzing through a range of experiments how social media mechanisms can support designers by enabling experience sharing across product lifecycle phases in emerging product development trends such as PSS.

Acknowledgments. We are grateful to Luleå University of Technology and the case company for the financial support through the FFI Robust Machining programme and are extending our gratitude to the respondents of the interviews and observations.

References

1. Senge, P.M.: The Fifth Discipline: The Art and Practice of the Learning Organization. Doubleday Currency, New York (1990)
2. Milton, N.: The Lessons Learned Handbook: Practical Knowledge-Based Approach to Learning from Experience. Chandos Publishing Ltd., Oxford (2010)
3. Thomke, S., Fujimoto, T.: The effect of "front-loading" problem-solving on product development performance. J. Product Innovation Management 17(2), 128–142 (2000)
4. Bergmann, R.: Experience Management: Foundations, Development Methodology, and Internet-Based Applications. Springer, Heidelberg (2002)
5. Goffin, K., et al.: Managing lessons learned and tacit knowledge in new product development. Research-Technology Management, 39–51 (July-August 2010)
6. Vianello, G.: Transfer and Reuse of Knowledge from the Service Phase of Complex Products. Ph.D. dissertation. Technical University of Denmark, Copenhagen, Denmark (2011)
7. Tukker, A., Tischner, U.: New Business for Old Europe: Product-Service Development, Competitiveness and Sustainability. Greenleaf Publishing Ltd., Sheffield (2006)
8. Harrison, A.: Design for Service - Harmonizing Product Design with a Services Strategy. In: ASME Turbo Expo 2006: Power for Land, Sea and Air (GT 2006), Barcelona, Spain (2006)
9. Isaksson, O., et al.: Development of Product-Service Systems: Challenges and opportunities for the manufacturing firm. J. Engineering Design 20(4), 329–348 (2009)
10. Chirumalla, K., Bertoni, A., Ericson, Å., Isaksson, O.: Knowledge-Sharing Network for Product-Service System Development: Is it Atypical? In: Shimomura, Y., Kimita, K. (eds.) The Philosopher's Stone for Sustainability, vol. 122, pp. 109–114. Springer, Heidelberg (2013)
11. Baxter, D., et al.: A Knowledge Management Framework to Support Product-Service Systems Design. J. Computer Integrated Manufacturing 22(12), 1073–1088 (2009)
12. Andersson, P.: Support for Re-use of Manufacturing Experience in Product Development: From an Aerospace Perspective. Ph.D. Luleå University of Technology (2011)
13. Abramovici, M., Lindner, A.: Providing product use knowledge for the design of improved product generations. CIRP Annals- Manufacturing Technology 60, 211–214 (2011)
14. Clarkson, J., Eckert, C.: Design Process Improvement: A review of current practice. Springer, London (2004)
15. O'Dell, C., Hubert, C.: The New Edge in Knowledge: How knowledge management is changing the way we do business. John Wiley & Sons, New Jersey (2011)
16. Williams, T.: How do organizations learn lessons from projects – And do they? IEEE Transactions on Engineering Management 55(2), 248–266 (2008)

17. Bertoni, M., Chirumalla, K.: Leveraging Web 2.0 in New Product Development: Lessons Learned from a Cross-company Study. J. U. Computer Science 17(4), 548–564 (2011)
18. Leake, D.B., Bauer, T., et al.: Capture, storage, and reuse of lessons about information resources: Supporting task-based information search. In: Aha, D.W., Weber, R. (eds.) Intelligent Lessons Learned Systems, pp. 33–37. AAAI Press, CA (2000)
19. Yllrisku, S.P., Buur, J.: Designing with Video. Springer, London (2007)
20. Bughin, J., Byers, A.H., Chui, M.: How Social Technologies are extending the organization. McKinsey Quarterly (November 2011)
21. Wood, N., Rust, C., Horne, G.: A Tacit understanding: The designer's role in capturing and passing on the skilled knowledge of master craftsmen. J. Design 3(3), 65–78 (2009)
22. Cha, M., et al.: I tube, you tube, everybody tubes:analyzing the world's largest user generated content video system. In: ACM Internet Measurement Conference, New York (2007)
23. Chui, M., et al.: The Social Economy: Unlocking value and productivity throughsocial technologies. McKinsey Global Institute (July 2012)
24. Sharif, M.N.A., Zakaria, N.H., Ching, L.S., Fung, L.S.: Facilitating knowledge sharing through lessons learned system. J. Knowledge Management Practice (March 2005)
25. Yin, R.K.: Case Study Research: Design and Methods. SAGE Publications (2009)
26. Cooper, R.G.: Perspective: The Stage-Gate® Idea-to-Launch Process—Update, What's New, and NexGenSystems. J. Product Innovation Management 25(3), 213–232 (2008)

The Requirement Analysis and Knowledge Management Methodologies in a Product Service System

Haihua Zhu[1], James Gao[2], and Dongbo Li[1]

[1] School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing 210094, China
[2] School of Engineering, University of Greenwich, Chatham Maritime, Kent ME4 4TB, UK
tianshasky@hotmail.com, j.gao@gre.ac.uk, db_calla@yahoo.com.cn

Abstract. Manufacturing enterprises are making more efforts in providing high value added services in addition to their traditional product business. A service-centric product service system (PSS) is present in this paper which is used as a decision support tool and offers a means of supporting decision-making for maintenance, repair and overhaul (MRO) solution finding. Requirement analysis technologies are used to identify the final important rating and the technical targets of engineering characteristics (ECs), and reduce the redundant ECs. An ontology-based knowledge representation is developed to represent, accumulate and collect knowledge and experience emerged during the MRO services, which realizes the knowledge originated from the service process and served operations. An initial attemp has been made to demonstrate the role of PSS as a decision support tool for MRO in the aerospace manufacturing business.

Keywords: PSS, MRO, Requirement Analysis, Knowledge Management, Aerospace manufacturing.

1 Introduction

Companies that direct their efforts toward meeting their customer requirements (CRs) produce higher-quality products, provide customized services, ensure a higher degree of customer satisfaction, and earn more revenue. All these benefits are achieved by minimized internal conflicts, cut down turn around time, and made the greater market penetration. The concept of Product Service System (PSS) has been proposed and investigated to better exploit the potential benefits of integrating product development with related services. Practical industrial cases implementing PSS have been investigated in recent years. For example, William [1] applied PSS in the automotive industry. Meier and Krug [2] proposed a PSS solution to the integration of the development and supply of products and services. Mittermeyer [3] applied PSS in health care. Qu [4] applied PSS to serve as a production process. In the aerospace industry, maintenance, repair and overhaul (MRO) services are normally provided during product usage. Given that an airplane is a durable product with a life span of over 30 years, opportunities abound for the application of PSS in aviation maintenance, repair and

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 473–484.
DOI: 10.1007/978-3-642-30820-8_40

overhaul. The profitability of the aviation industry is not just from the sale of aircrafts, but also from maintaining them for an anticipated lifespan. This research will focus on applying PSS in the aviation industry to specifically support the MRO services.

In the current practice of manufacturing industry, MRO services seriously depend on individuals' experience, which makes the services unstable and uncontrollable. It is realized that knowledge obtained from previous projects is hosted by individual experts, and in turn, individual experts use previous knowledge into new MRO services and obtain new knowledge from them. This makes knowledge sharing and reuse in the service team and related personnel inefficient and ineffective, and thus makes the project risky. To solve such problems during product service activities, the needs of knowledge representation in the process of product services are discussed in this paper, and an ontology-based knowledge representation method for product service process is proposed. To better manage the ontology, a solution for ontology management is developed for ontology definition and building, and evaluation of semantic similarities of concepts among ontology domain. The logical structure and details of the knowledge involved in the product service process are described by ontology building. An ontology-based knowledge representation framework has been developed for the reuse of knowledge unambiguously, which realizes the knowledge originated from the current and previous service processes.

Some of the service offering approaches used in service business include full services, solution selling and total care solutions [5]. The PSS proposed in this research can be regarded as a kind of outsourcing service, which is designed to support decision making in MRO services. In the current industrial environment, manufacturing enterprises are asked to respond rapidly and adjust dynamically to external market and customer requirement changes. The PSS development is a systematic and cross-functional design activity [6]. Although product design and service design focus on different aspects, both product and service should be considered to satisfy the requirements of customers. Quality function deployment (QFD), as an effective customer-driven design tool, has been used successfully to translate CRs into ECs in product or service design. It can be translating CRs into ECs in PSS development. Rough set theory is a relatively new and intelligent knowledge discovery tool. It is widely used to find data dependencies, evaluate the importance of attributes, reveal data patterns, reduce the number of redundant objects and attributes, and seek the minimum subset of attributes [7-10,]. In this research, the Rough set theory approach has been mainly used to reduce the number of redundant ECs, which created by translating from CRs. The analytic network process (ANP) approach has been used to prioritize ECs in order to overcome the shortcomings of the traditional QFD models [11-13]

The main aim of this project is to develop a PSS, and apply it in the aerospace manufacturing industry focusing on the MRO services. To meet the customer requirements emerged during the use phase of product, a framework of PSS based on the requirement analysis is put forward, which integrates Quality Function Development (QFD), rough set theory, ANP approach and ontology-based knowledge reasoning methods. The mapping relationships between customer requirements and engineering characteristics are identified based on QFD-ANP analysis, as well as the weight of characteristics. An ontology-based knowledge reasoning method is used to find the semantically similar generalized product service cases. The PSS configuration scheme set is obtained by optimizing and assessing the selected cases. The reference service solutions for the specific customer requirements will be created using the proposed PSS. The proposed methodology will be developed using web technology to provide lifecycle services and supports, which can be easily accessed through the internet at all times and places. An initial attempt is made to describe the potential value of the PSS in the aerospace manufacturing industry and also to describe how to provide lifecycle services and supports in industry based on the proposed web-based PSS framework.

2 Current Limitations and Objectives of This Research

PSS was first proposed by Goedkoop [14] who described a PSS as a system of products, services, networks of 'players' and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models. The general category of PSS includes product-oriented PSS, use-oriented PSS, and result-oriented PSS [15, 16]. Many systemic and scientific frameworks for modeling PSS have been proposed. However, most researchers only focused on product-orientated PSS. Only a few reported use-orientated PSS and result-orientated PSS, where service is considered as the core part whilst physical products are only carriers for service delivery.

Due to the increasing interests on environmental problems and government regulations for recycling and reusing, considering product lifecycle factors on service activities as well as customer requirements is increasingly more important than in the past. However, only a few QFD works have considered product lifecycle requirements into the process of QFD in spite of its importance [17]. Moreover, most researchers only consider quantitative correlations among engineering characteristics in original QFD. Even though some engineering characteristics have a positive or negative effect on each other, the original QFD method oversimplifies this correlation in the prioritization of engineering characteristics.

In this research, a requirement-oriented PSS will be developed using requirement analysis and knowledge management methodologies, which is suitable for use-orientated PSS and result-orientated PSS. The customer and product lifecycle factors will be incorporated in this research, and exert their significant impacts to the implementation and performance of PSS. The positive and negative effects among different engineering characteristics will be analyzed; a systemic decision-making approach will be used to identify the relative prioritization of engineering characteristics.

3 The Proposed Methodology

Currently, manufacturing enterprises are making more efforts to provide high value added services in addition to their traditional design and manufacturing business, engender a higher degree of customer satisfaction, and earn more revenue. A requirement-oriented PSS has been developed using requirement analysis and knowledge management technologies. The proposed PSS will be regarded as a decision support tool and offer a means of supporting decision-making for MRO services solution in this research. The reference service solutions for the specific customer requirements will be created using the proposed PSS. Figure 1 is the general approach of providing supports and services by the Web-based PSS, which can be divided into 4 steps which are described below.

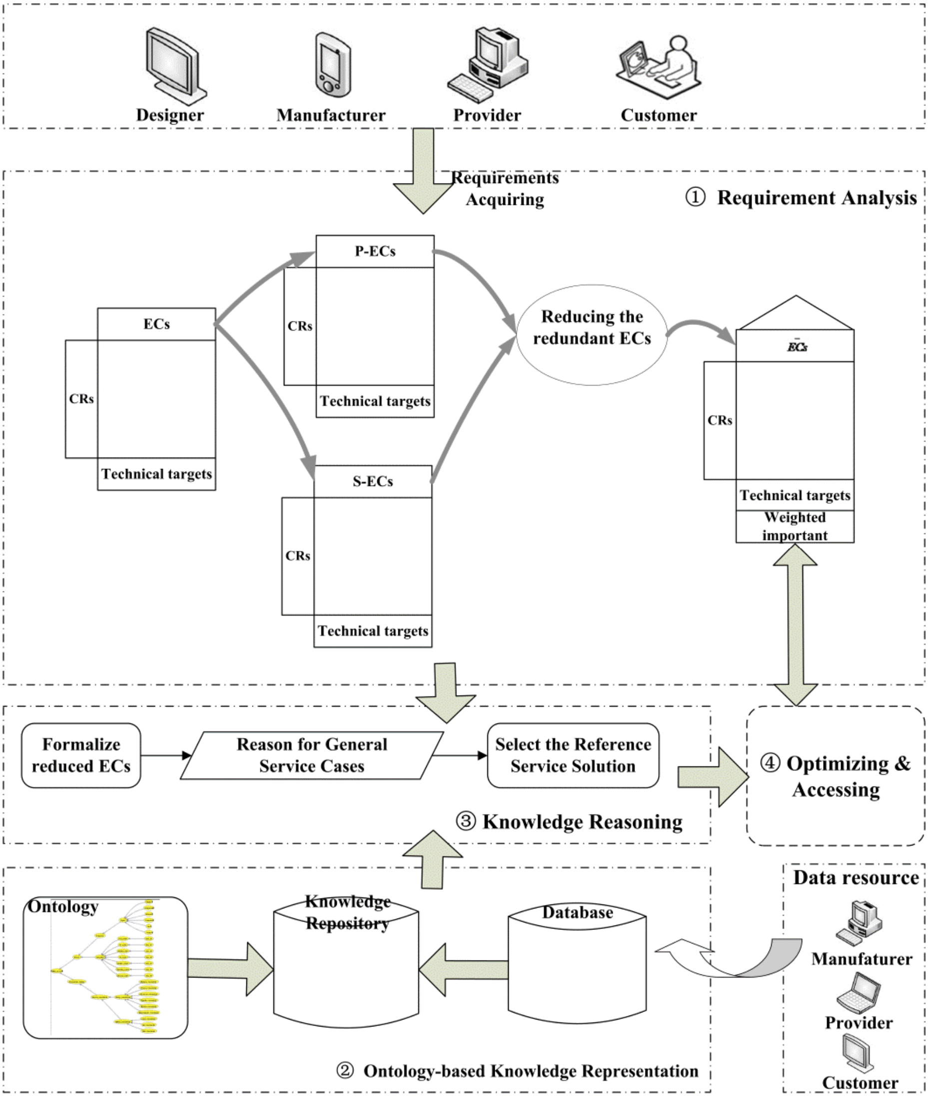


Fig. 1. General approach of providing supports and services by the proposed PSS

- Step 1: Requirements management: to acquire the requirements, and identify satisfactory ECs using requirements analysis methodologies. The redundant ECs will be reduced, and the important weight of reduced ECs will be defined accurately.
- Step 2: Service knowledge representation based on ontologies: Service ontology is build to represent, accumulate and store knowledge and experience emerged during service activities. Ontology-based knowledge representation is proposed to collect and formalize service cases and store them as knowledge in the knowledge repository.
- Step 3: Knowledge reasoning by ontology-based knowledge representation: the knowledge-based method is used here to help and support users for service solution finding. When the service activities are formalized by referring to the predefined ontologies, the formalized services will be reasoned in the knowledge repository to find semantically similar generalized service cases.
- Step 4: Optimizing and accessing: the technical targets which are identified by requirements analysis will be used to evaluateand access the reference service solutions and find the optimal solution for the specific requirements.

4 Technologies for Implementing the Proposed PSS

Three key techniques used in the proposed PSS are introduced in depth in this section, i.e., how to determine the final important ratings of ECs by analyzing the requirements; how to represent the MRO activities and the relationships between them by ontology; how to reuse the service knowledge which are collected from service cases, and use the reasoning method to find the similar generally service cases in the knowledge repository.

4.1 Requirement Analysis

It is not easy to identify satisfactory engineering characteristics because the information in the early stage of product service system planning is subjective, qualitative, and even uncertain to engineers. As a well-known planning and problem-solving methodology, QFD is used to support product service system design in this research. A step by step proceduce, starting from requirements acquiring until the prioritization stage, is described below.

Acquire customer voices or requirements from customer and market. The mentioned requirements here are including internal requirements and external requirements. The former consists of the requirements emerged during different phases of product life cycle, e.g., design, manufacturing, usage, disposal. The external requirements are not only customers' requirements, but also providers' and partners' requirements. The methods of acquiring are mainly including survey, interview, self-report, observation and so on. For complete or near complete sentences, begin with a capital letter and end with a full stop. Acquire customer voices or requirements from customer and market.

Identify general requirements and the relationship among these requirements. Firstly, three distinct types of information must be identified from requirements acquiring, e.g., Jobs, Outcomes, Constraints. Jobs represent what the customers are trying to get done when using the product or MRO service. Outcomes indicate what the customers are trying to achieve when performing these jobs. Constraints describe the roadblocks that stand in the way of them performing a specific job. After identifying general requirements, there may be three kinds of relationships between any two requirements: a positive relationship, a negative relationship, and a non-relationship, respectively. Then, the positive and negative effects between these requirements will be analyzed, and the important weightings of CRs will be calculated by ANP method.

Develop ECs from CRs based on House of Quality (HoQ) model in QFD. HoQ model is primarily used to describe the relationships between and within CRs and ECs. The functional requirements (FRs) will be identified by analyzing the customer requirements (CRs). Then, the FRs in the functional domain will be translated into engineering characteristics (ECs) using QFD approach, including product-related ECs (P-ECs) and service-related ECs (S-ECs). A set of ECs candidates will be determined, some of the ECs candidates may be redundant, and the conflict relationship between the ECs candidates may also exist. Therefore, the further selection from the ECs candidates is essential.

Reduce the redundant ECs. To identify the most important characteristics and remove the unnecessary ones in the EC set. Rough set theory as a relatively intelligent knowledge discover tool is used to evaluate the important of ECs, reduce the number of redundant ECs, and seek the minimum subset of ECs. The new EC set, which produced by attribute reduction, can fully characterize the knowledge, such as EC set is called a reduct. The reduct can be thought of as a sufficient set of engineering characteristics.

Determine the relative weightings between CRs and the reduced ECs. A relationship between CRs and ECs is defind as "a decision matrix". A decision matrix is created combining the result of the computation with calculated CRs. QFD method is used to obtain the importance weights of ECs based on CRs and relationships modeled in the HoQ. In order to accurately define the importance weights of ECs, the inter-dependency relationships between CRs and ECs (including P-ECs and S-ECs), the inter-dependency relationships between P-ECs and S-ECs, and the inner-dependency relationships among these three clusters should also be taken into consideration in QFD analysis.

Calculate the overall weight of each ECs. To define the importance weights of ECs accurately, ANP method is used to form a network considering the interactions at different levels. Moreover, the relative weights of each EC will be calculated by ANP method.

Determine the final important rating of ECs. The final weights of ECs are obtained based on QFD and HoQ. The technical targets of ECs are also determined. The most important ECs will be formalized by referring to a set of predefined ontology, and reasoned in the knowledge repository of the proposed PSS to find semantically similar generalized MRO service cases. The technical targets will be used to evaulate and access the reference service solution and find the optimal solution for the specific requirements.

4.2 MRO Services Knowledge Representation

Advanced computing methods and related technologies are changing the way engineers interact with the information infrastructure. Knowledge management (KM) is widely used in service activities, and helpful to enhance enterprises' service capabilities. As the basis of KM, knowledge representation formalisms and methods perform a decisive role in KM.

As an appropriate representation scheme, ontology is adopted to effectively define the knowledge hierarchies in service activities and the relationships between them. Ontology describes the concepts in a domain of interest and the relationships that hold between those concepts [18, 19], as well as providing powerful tools for querying and information retrieval and automatic causality extraction using semantic similarity [20, 21]. Ontology is also used to address the semantic shortcomings and matchmaking difficulties associated with semantic Web technology [22, 23]. In this research, service ontology is developed to represent the semantic information and relationships between functional modules and process modules. Moreover, the relationship information between service functions and processes will be represented by ontology to provide the inputs, outputs and constraints for MRO processes design. The service engineering characteristics and product engineering characteristics are classified by knowledge representation to fit the ontology structure. The solution for ontology management is shown in Figure 2, which mainly involves ontology defining and modeling, and semantic similarity evaluation.

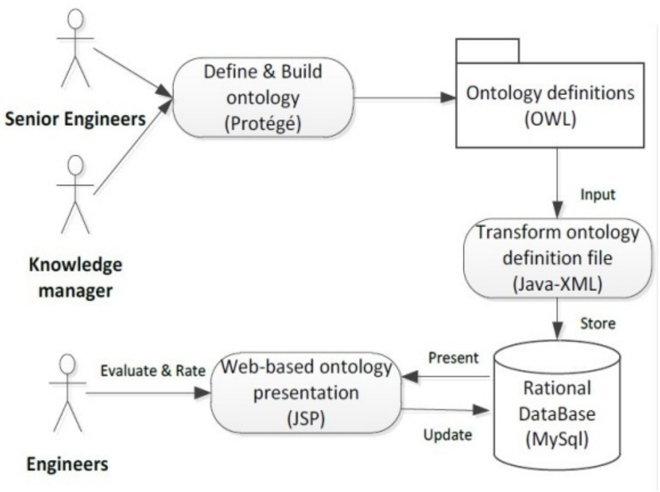


Fig. 2. Solution for Ontology Management

Ontology Defining and Modeling. The concepts used in the MRO process will be defined by knowledge manages and senior engineers. The mentioned concepts here, involve two parts, i.e. the predefined part and extended part. The former one can be considered as general engineering concepts, which is normally in higher level of abstraction. The extended part means the specifically concepts, which is used in the company and generated based on the predefined concepts.

Suppose that the formalization of ontology can be described as: O=(S, RS, I). O represents the ontology; S represents the collection of all concepts, each concept in S can be regard as a class, and the class is inherited by subclass; I represents the instances of the class; RS represents the relationship between every two concepts, i.e. part_of, has_part, Sibling_of, attribute_of, has_attribute, instance_of, has_instance, and so on. Protégé is adopted as an ontology editor to formalize predefined ontology in computer language, which was developed by Stanford University and used in the academic area for ontology development. By using the tool, the ontology is formalized with OWL2 specifications. Physically it is stored in a XML file. The ontology definition file is processed and transformed using java technologies. The transformed ontology will be stored in a rational database, and be used with other parts of the system.

Evaluation of Semantic Similarities of Concepts. The main aim of this step is to evaluate and rate semantic similarities between concepts. The rated ontology will be used in the knowledge repository management, and used to find the solution and support decision making in the other parts of the system. The evaluating and rating work will be conducted by engineers in the related departments. The rules of evaluation and rating are described below, which are carried out in two steps: (1) Evaluate and rate semantic similarities between the parent concept and its child concepts. (2) Evaluate and rate semantic similarities between sibling concepts.

Suppose that S represents a set of services: S = {S1, S2, S3 … Sn}. Where S1 consists of a set of MRO services and their functions. P represents the process of MRO service: P = {P1, P2, P3, …, Pn}. F represents the function of MRO service: F = {F1, F2, F3, …, Fn}. SP represents the sub-process of service, P1 consists of {SP11, SP12, SP13, …, SP1n}. Since P1 is the parent of SP11 and SP12, S1 is the parent of P1 and F1, P1 and F1 are siblings, which are described as: SP11 $\in$ P1; SP12 $\in$ P1 and P1 $\in$ S1; F1 $\in$ S1. Suppose that the number of engineers who are going to evaluate and rate the similarities between concepts is m. Each engineer will be given the credibility by knowledge manager according to their engineering experience, which represented as C = {C1, C2, C3, …, Cm}, more experienced engineers have higher credibility. Taking an example of rating semantic similarities between S1 and P1. The final result of semantic similarity Sim (S1, P1) can be represented as Equation (1). The similarity of the sibling classes (F1 and P2) can be represented as equation (2).

$$\mathrm{Sim}(S_1, P_1) = \frac{\sum_{i=1}^{m} C_i \times Sim(S_1, P_1)_i}{\sum_{i=1}^{m} C_i} \tag{1}$$

$$\mathrm{Sim}\,(F1, P2) = \left\{ \frac{\sum_{i=1}^{m} C_i \times Sim\,(F_1,\ S_1)_i}{\sum_{i=1}^{m} C_i} \times \frac{\sum_{i=1}^{m} C_i \times Sim\,(S_1,\ S)_i}{\sum_{i=1}^{m} C_i} \times \frac{\sum_{i=1}^{m} C_i \times Sim\,(S,\ S_2)_i}{\sum_{i=1}^{m} C_i} \times \frac{\sum_{i=1}^{m} C_i \times Sim\,(S_2,\ P_2)_i}{\sum_{i=1}^{m} C_i} \right\} \quad (2)$$

Ontology-based Knowledge Representation. To represent, accumulate and store knowledge and experience emerged during the MRO services, an ontology-based knowledge representation framework has been proposed to collect and formalize service cases from engineers' everyday work and store them as knowledge in the knowledge repository, as shown in Figure. 3.

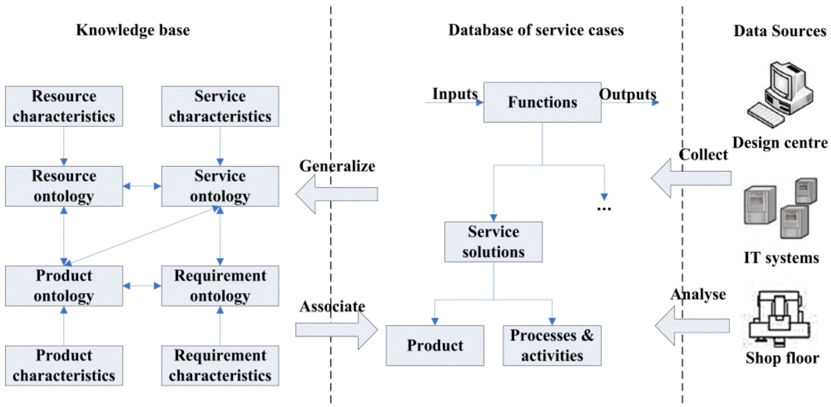


Fig. 3. The Framework of Ontology-based Service Knowledge Representation

The proposed system is developed for the reuse of knowledge unambiguously, which realizes the knowledge originated from the service process and served service process. In this system, service cases are collected from various sources including different information systems and functional departments. The service cases are formalized in a hierarchical way, which clarifies the functions the service case is to address. Moreover, the service cases can be further decomposed into components and characteristics. Therefore, the predefined ontology can be used to tag each element of the functional model and then the service case with tagged semantic meaning can be stored in the knowledge repository. The knowledge representation method will be applied to enable the proposed PSS that can provide users with various functions that are searching, sharing, and reusing information in the distributed environments.

4.3 A Knowledge-Based Method Support for Service Solution Finding

A knowledge-based method is used here, to help and support engineers for service solution finding. When the mission and objectives of MRO service are identified by requirement analysis, the MRO service will be formalized by referring to the predefined ontology. Then the formalized MRO service will be reasoned in the knowledge repository to find semantically similar generalized service cases. Therefore, specific service cases that are associated with generalised service cases can be retrieved. These selected service cases will be used as reference solutions for the current CRs.

The aim of formalizing MRO activities is to formalize the service function model and the component where the service occurs. In this research, formalizing service activity is not only formalizing the service activity itself, but also formalizing inputs, outputs, resources, constraints, relationships between service functions and service processes. Figure 4 shows the MRO service model formalized by the pre-defined ontology. Product ontology defines the type of product and consists of system ontology and component ontology. A product is composed of several subsystems such as flight control system, fuel system, electrical system, propulsion system and oxygen system, and each sub-system is composed of many components. Service ontology defines the methods, processes, activities, and organization in the MRO services. It can be divided into function ontology and process ontology. Flow ontology defines the type of the flow. The characteristic ontology defines the properties of the product and service activities.

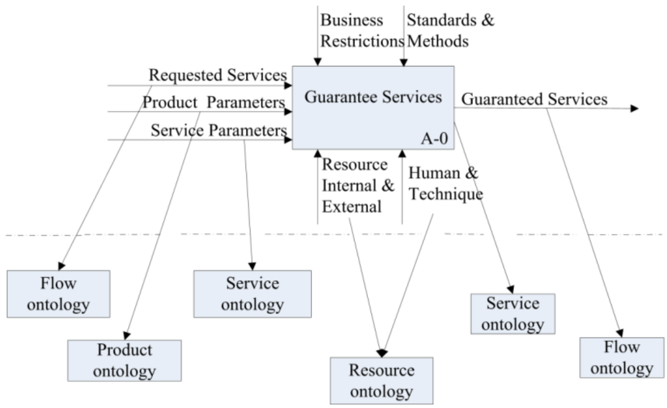


Fig. 4. Formalization of the MRO Model

An ontology-based knowledge reasoning method is proposed to find semantically similar generalized service cases. The MRO activity is decomposed into inputs, outputs, resources, constraints, relationships between service functions and service processes, each of them will be tagged with predefined ontology. The reduced characteristics of components and services which are identified by requirements analysis will be considered as important factors, and are also formalized with predefined ontology. After formalizing concepts for each parts of the decomposed service activity, the semantic similar service case will be retrived by knowledge reasoning. These selected service cases will be used as reference solutions for the current CRs.

5 Conclusions and Further Work

This paper presented on-going research into the development of a Web-based Product Service System using requirement analysis and knowledge management technologies. A service-centric PSS have been proposed which is suitable for result-orientated PSS and use-orientated PSS. The proposed PSS is used as a decision support tool and offer a means of supporting decision-making for MRO solution finding. QFD-ANP are used to identify the relationship among CRs, FRs and ECs, as wll as the final important rating and the technical targets of ECs. Rough set theory is used to reduce the redundant ECs. Furthermore, Ontology-based knowledge representation has been developed to represent, accumulate and collect knowledge and experience emerged during the MRO services. Predefined ontologies have been stored in the knowledge repository of the proposed PSS. The most important ECs which are determined by requirements analysis, will be formalized by referring to a set of predefined ontology, and reasoned in the knowledge repository of the proposed PSS to find semantically similar generalized MRO service cases. The technical targets will be used to evaulate and access the reference service solution and find the optimal solution for the specific requirements. The emphasis of further work will be on the development of the proposed PSS for evaluating and accessing the effectiveness of the operation, and applying the proposed PSS in the real industrial company. In the next stage of this research, integrating with other enterprise systems will be developed to acquire knowledge regarding contributions that previous cases made to related requirements.

References

1. Williams, A.: Product service-systems in the automotive industry: A Case for Micro-factory Retailing. Journal of Cleaner Production 14, 172–184 (2006)
2. Meier, H., Krug, M.: Managing the capacity of industrial product-service-systems. Journal of PPS Management 11, 48–51 (2006)
3. Mittermeyer, S.A., Njuguna, J.A., Alcock, J.R.: Product–service systems in health care: case study of a drug–device combination. International Journal of Advanced Manufacturing 52, 1209–1221 (2011)
4. Qu, T., Chen, X.D., Zhang, Y., Yang, H., Huang, G.Q.: Analytical target cascading-enabled optimal configuration platform for production service systems. International Journal of Computer Integrated Manufacturing 24(5), 457–470 (2011)
5. Kumar, R., Panesar, S.S., Markeset, T.: Development of technical integrity management services - A concept. Journal of Quality in Maintenance Engineering 15(3) (2009)
6. Geng, X., Chu, X., Xue, D., Zhang, Z.: An integrated approach for rating engineering characteristics' final important in product-service system development. Computers and Industrial Engineering 59(4), 585–594 (2010)

7. Cheng, C.H., Chen, T.L., Wei, L.Y.: A hybrid model based on rough sets theory and genetic algorithms for stock price forecasting. Information Sciences 180(9), 1610–1629 (2010)
8. Feng, F., Liu, X.Y., Violeta, L.F., Young, B.J.: Soft sets and soft rough sets. Information Sciences 181(6), 1125–1137 (2011)
9. Khoo, L.P., Zhai, L.Y.: A prototype genetic algorithm-enhanced rough set-based rule induction system. Computers & Industrial Engineering 46, 95–106 (2001)
10. Nepal, B., Yadav, O.P., Murat, A.: A fuzzy-AHP approach to prioritization of CS attributes in target planning for automotive product development. Expert Systems with Applications 37(10), 6775–6786 (2010)
11. Büyüközkan, G., Ertay, T., Kahraman, C., Ruan, D.: Determining the importance weights for the design requirements in the house of quality using the fuzzy analytic network approach. International Journal of Intelligent Systems 19(5), 443–461 (2004)
12. Karsak, E.E., Sozer, S., Alptekin, S.E.: Product planning in quality function deployment using a combined analytic network process and goal programming approach. Computers and Industrial Engineering 44(1), 171–190 (2003)
13. Partovi, F.Y., Corredoira, R.A.: Quality function deployment for the good of soccer. European Journal of Operational Research 137(3), 642–656 (2002)
14. Goedkoop, M.J., van Halen, J.G., te Riele, H., Rommens, P.J.M.: Product Service Systems, Ecological and Economic Basics. Vrom EZ, The Hague (1999)
15. Cook, M., Bhamra, T., Lemon, M.: The transfer and application of product service-systems: From academia to UK manufacturing firms. Journal of Cleaner Production 14(17), 1455–1465 (2006)
16. Morelli, N.: Product-service systems, a perspective shift for designers: A case study: the design of a telecentre. Design Studies 24(1), 73–99 (2003)
17. Zhang, Y., Wang, H.P., Zhang, C.: Green QFD-II: a life cycle approach for environmentally conscious manufacturing by integrating LCA and LCC into QFD matrices. Int. J. Prod. Res. 37(5), 1075–1091 (1999)
18. Gruber, T.: Toward principles for the design of ontologies used for knowledge sharing. Int. J. Human Comput. Stud. 43(5), 907–928 (1995)
19. Ravendra, S., Krist, V., Gernaeyb, R.G.: An ontological knowledge-based system for the selection of process monitoring and analysis tools. Computers and Chemical Engineering 34, 1137–1154 (2010)
20. Li, Z., Raskin, V., Ramani, K.: Developing ontology for engineering information retrieval. In: Proceedings of the 2007 ASME IDETC/CIE Conference (2007)
21. Kim, S., Bracewell, R.H., Wallace, K.M.: A framework for automatic causality extraction using semantic similarity. In: Proceedings of the 2007 ASME IDETC/CIE Conference (2007)
22. Berners-Lee, T., Hendler, J., Lassila, O.: The Semantic Web. Sci. Amer. 284(5), 34–43 (2011)
23. Maio, C.D., Fenza, G., Loia, V., Senatore, S.: Knowledge structuring to support facet-based ontology visualization. International Journal of Intelligent Systems 25(12), 1249–1264 (2010)

IPS²-KOP: IPS² Knowledge-Based Service-Oriented Lifecycle Management Platform

Michael Abramovici, Hoang Bao Dang, and Mario Wolf

Chair of IT in Mechanical Engineering, Department of Mechanical Engineering,
Universitaetsstrasse 150, Bochum, NRW, Germany
{michael.abramovici,bao.dang,mario.wolf}@itm.rub.de

Abstract. Besides the need for data availability and highly dynamic processes, IPS² is characterized by a very high degree of interaction between manufacturer, wholesaler, and customer with fluctuant intensity of requirement adaptations and changes within the IPS² network in various ways. In this paper, we will introduce an IPS² knowledge-based lifecycle management platform (IPS²-KOP) based on the principles of service oriented architecture (SOA) to solve the problem of streamlining processes and interfaces between collaborators. The coherence of the given data builds a valuable source for knowledge-based information retrieval, and therefore, new valuable data can be created and stored to supply the knowledge-based assistance systems, which support for example decision makers with real-time analysis.

Keywords: SOA, Industrial Product-Service System, IPS², Architecture, IPS²-top domain ontology, KOP, Lifecycle Management Platform.

1 Introduction

Industrial product-service systems (IPS²) are defined as a bundle of physical products and corresponding services for customer oriented solutions [1], [2], [3], [4], [5], [6]. As an example of this relatively new distribution and business model, imagine an agricultural machine is acquired as a service with a guaranteed 95% availability.

A core feature of IPS² is the mutual determination of product and service components along the IPS² lifecycle phases (planning, development, implementation, and operation) [2]. In addition, IPS² is characterized by a very high degree of interaction between manufacturers, wholesaler, and customer, with a fluctuant intensity of requirement adaptations [7], [3].

Throughout an IPS² lifecycle, a lot of product and service related data is generated from different IT-systems, processes and domains. In classical PLM systems, all of this data is gathered and managed only at the manufacturer's side for internal use only, which is not sufficient for IPS². Therefore, a lifecycle management approach for IPS² (IPS²-LM) based on the PLM concept has been developed [7]. The classical PLM approach has been extended to manage IPS² relevant information, from planning through development to recycling phases. Furthermore, the IPS²-LM provides

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 485–493.
DOI: 10.1007/978-3-642-30820-8_41

domain-specific roles with required information and supports dynamic collaboration between IPS² network partners and customers. This IPS²-LM concept is planned to be technically implemented in IPS²-KOP (see figure 1).

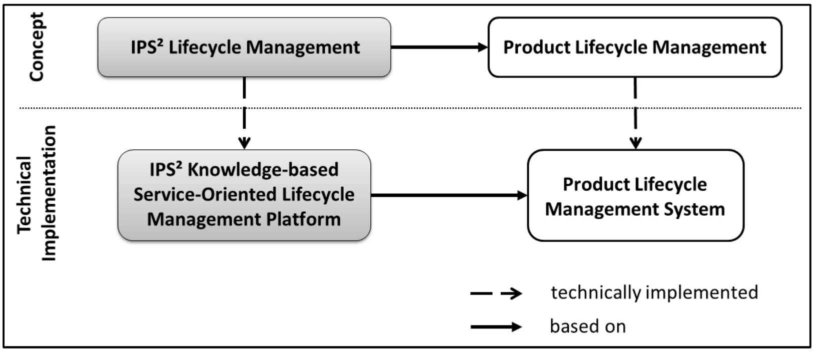


Fig. 1. IPS²-KOP and related key aspects

This paper will introduce the IPS²-KOP concept as well as relevant technologies needed for its implementation.

The 'Introduction' section describes the relationship of the proposed concept and related key aspects. Section 2 reviews related work, which is relevant for the development of the IPS²-KOP concept. Section 3 gives an overview of basic requirements regarding the IPS²-KOP concept. Section 4 describes the IPS²-KOP concept, which is based on the SOA paradigm and adapted for IPS². The prototype is described in section 5. The last section presents the conclusion and lines of future work.

2 Related Work

This section presents an overview of available technologies and current research work, and describes the distinction between the new approach and the existing solutions.

2.1 State of the Art

A number of PLM vendors recently released web-based PLM solutions like PTC's Windchill [1], AutoDesk's Autodesk PLM360 [2], Aras' PLM software [3], Dassault's ENOVIA V6 [4], Siemens' Teamcenter[5]. All these PLM solutions support engineering data, process and project management as well as an online engineering collaboration.

[1] http://www.ptc.com
[2] http://www.autodeskplm360.de/
[3] http://www.aras.com/
[4] http://www.3ds.com
[5] http://www.plm.automation.siemens.com

However, these solutions mostly focus on traditional (physical) products and only support predefined static processes and activities in product design environments. In addition, these PLM solutions are restricted to the use of web service protocols such as SOAP[6], utilizing UDDI[7] and WSDL[8], and do not support semantic approaches.

2.2 State of Scientific Research

Service oriented architecture (SOA) already became a widely used design principle in industrial PLM solutions (as listed in section 2.1). In contrast, possible extensions of SOA with semantic methods are so far still a matter of research. A marketable and widely accepted concept remains to be established. In order to distinguish the architecture introduced in this article from existing approaches to semantic SOA, we shortly summarize the current state of research regarding this aspect.

According to [8], problem solving methods as a core concept of artificial intelligence are the key to enable goal-directed discovery and invocation of services in SOA. In the depicted concept, users describe their requirements independent of existing services; then, these tasks are solved by means of logical reasoning based on the semantic description of requirements and services. In comparison to [8], the articles [9] and [10] focus mostly on designs and algorithms as well as methods, i.e. the core functional SSOA (semantic SOA) tasks of discovery, process mediation and combined discovery and composition.

Mistry and colleagues [11] add a novel aspect to semantic SOA by introducing a new way of improving the quality of service discovery. In the proposed architecture, the ontology of service providers is enhanced by analysis and learning from service consumer requests, thus rendering the process of service discovery more efficient.

To summarize, these articles conclude that semantic extensions of SOA are vital to enable logical reasoning, which then forms the basis for a complete or partial automation of service discovery, mediation, composition, and invocation.

Based on the SOA paradigm, different platforms for the integration of multidisciplinary domains have been suggested. In the field of mechatronics, projects such as MIKADO [20] and VIVACE [21] as well as research from Bellalouna [18] and El Khoury [19], among others, aimed at providing integrated platforms for mechatronic product development, which enable interdisciplinary information and systems management. However, VIVACE focused mostly on simulation and computation; thus, it does not offer a truly interdisciplinary platform. Other approaches fulfilled the aspect of multidisciplinarity by integrating methods, systems and tools of different domains (mechanics, electrical and information engineering). In order to implement these concepts, technologies such as WS-BPEL and STEP have been applied. Although these approaches support interdisciplinary domains, they only focus on physical products and can therefore not be applied to IPS², as the service component of IPS² cannot be represented appropriately.

---

[6] SOAP: Simple Object Access Protocol.
[7] UDDI: Universal Description, Discovery and Integration.
[8] WSDL: Web Services Description Language.

Besides the projects mentioned above, several web-based PLM-platforms are currently under development or were recently started. Projects like L.I.S.A., CESAR [12] or I-CONIK [13] are incorporating some paradigms on which our approach is focused, using service orientation and semantics for improved usability. As these projects focus on automotive industry products, they also lack the service-component of IPS².

3 Basic Requirements

In order to consider all the described specific aspects of IPS² the new Lifecycle Management platform has to meet the following basic requirements:

Flexible Metadata Model
The data kernel of the developed LM platform is a metadata model, which should integrate not only product data but all the relevant heterogeneous IPS² data along their whole lifecycle. This metadata model should be extended by new classes and attributes during the IPS² operation without changing the existing core metadata models.

Semantic Data Content
The IPS² lifecycle metadata model should incorporate all the data necessary for knowledge-based search, retrieval, analysis or diagnosis operations. For this purpose an additional knowledge-based model should be considered within the IPS² lifecycle database. Furthermore the knowledge-based model should facilitate the semantic integration of heterogeneous data sources. It should provide the user with aggregated information, thus forming the basis for intelligent decision support.

Support of Static and Dynamic Workflows
Static standard PLM processes like release or change processes have to be supported. In addition the new LM platform should consider IPS² specific components. Moreover the IPS² management should support dynamic processes, which have to be defined and executed in real time, enabling an immediate reaction to unpredicted events during the IPS² operation (i.e. changes in the IPS² network). The static and the dynamic IPS² workflows should coexist within the IPS² LM platform.

System Flexibility
The new IPS² LM-platform has to be hardware independent, portable and integrable in order to assure a long term trouble-free operation. Due to unpredictable changes of the system environment and of the customers during the IPS² operation, the IT system architecture of the IPS² LM platform should be agile and flexible, in order to allow the manufacturer and service providers to fulfill their overall contract.

4 The IPS²-KOP Platform Concept

Over the last years, the term service-oriented architecture (SOA) has grown to a widely known symbol of modern software design with a whole lot of advantages to classic approaches when compared to highly dynamic environments. The main motivation of using SOA as a design pattern is using functions of different software-providers while maintaining a loose coupling between clients and servers and offering platform independent services to all the receiving clients [14] to support real-time definition and execution of dynamic workflows.

Considering the described advantages, the IPS²-KOP concept has been developed based on SOA, which was extended with an IPS² top domain Ontology and dynamic workflow capabilities. This basic platform has been adapted to specific IPS² needs. It considers following bottom-up layers (see figure 2):

External Sources

The external sources layer contains domain specific applications which provide automatic processing, management and controlling of information and data within their special fields, for example PDM, EES, SCM. In our platform concept, these applications should be considered as a source of IT resources which make their data and functions available in encapsulated form (as services) via appropriate interfaces.

Data Layer

At the core of this concept are information models, which cover all data models being used in the systems and tools deployed in the product life cycle. To solve this task, the data layer makes use of an LM metadata model [17] and IPS² top domain ontology. The IPS² top domain ontology is used to describe and index a domain of knowledge and the relations between its content. The IPS² top domain ontology extended semantically static LM metadata models. At the same time, the IPS² top domain ontology integrates heterogeneous data between domain-specific ontologies and systems from operative levels (see Figure 2: external sources layer), thus providing the user with new semantic information which is based on information stemming from domain-specific ontologies and generated by predefined rules and axioms.

Service Layer

The service layer distinguishes between classical and knowledge-based services. Apart from internal services, the functions and data of domain specific applications are provided as standardized services within the service layer. Services comprise a standard description of application specific functions including the corresponding input and output data as well as additional information with regard to the execution and usage of the offered functions.

Workflow Layer

Within the workflow layer, the defined workflows coordinate and control multiple activities across all domain specific applications. The activities use the needed services from the service layer to perform their tasks. Besides classic workflows, dynamic workflows are also incorporated. Dynamic workflow management (described in more detail in [15]) is a goal-oriented process management method which aims at replacing fixed, sequentially planned processes with dynamic and adaptive ones, thus allowing for real-time responses in specific situations. They also provide the process management with recommendations for decision making in the view of the further occurring process steps.

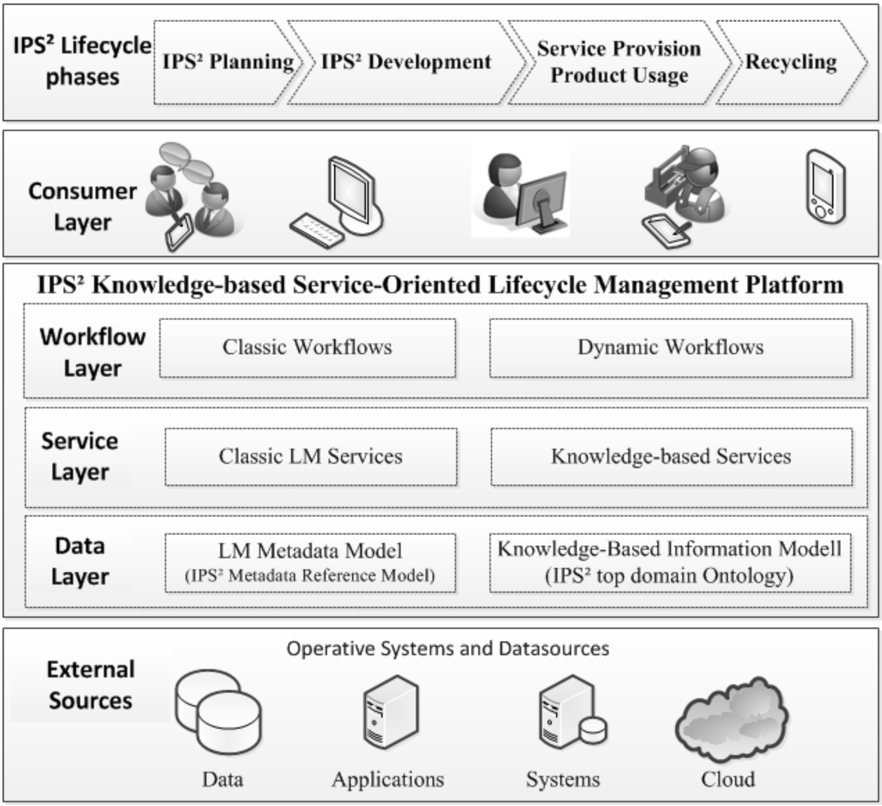


Fig. 2. IPS²-KOP concept

5 Prototype

The prototyping of the IPS²-KOP concept is currently in process. Creation of a whole new system for IPS² is time-consuming and unnecessary, as there are commercial solutions available which can be extended to fulfill the requirements of the IPS²-KOP concept. Using well-tested software like PTC Windchill as a basis for further development enables the implementation of new modules of IPS²-KOP and focus on refining them. Figure 3 shows an extension of the PLM system Windchill [16] with new IPS²-KOP modules and IPS² top domain ontology module.

Windchill itself offers graphical user interface, certain types of web services and, through its Info*Engine, interfaces to several enterprise systems. Because of these advantages, the prototype focuses on semantic services and dynamic processes, while using the metadata model for IPS². In a first step, the IPS² metadata model has been implemented in Windchill, enabling it to manage IPS²-relevant data. In the near future, necessary interfaces and the IPS² top domain ontology will be implemented, thus supporting knowledge-based methods and services.

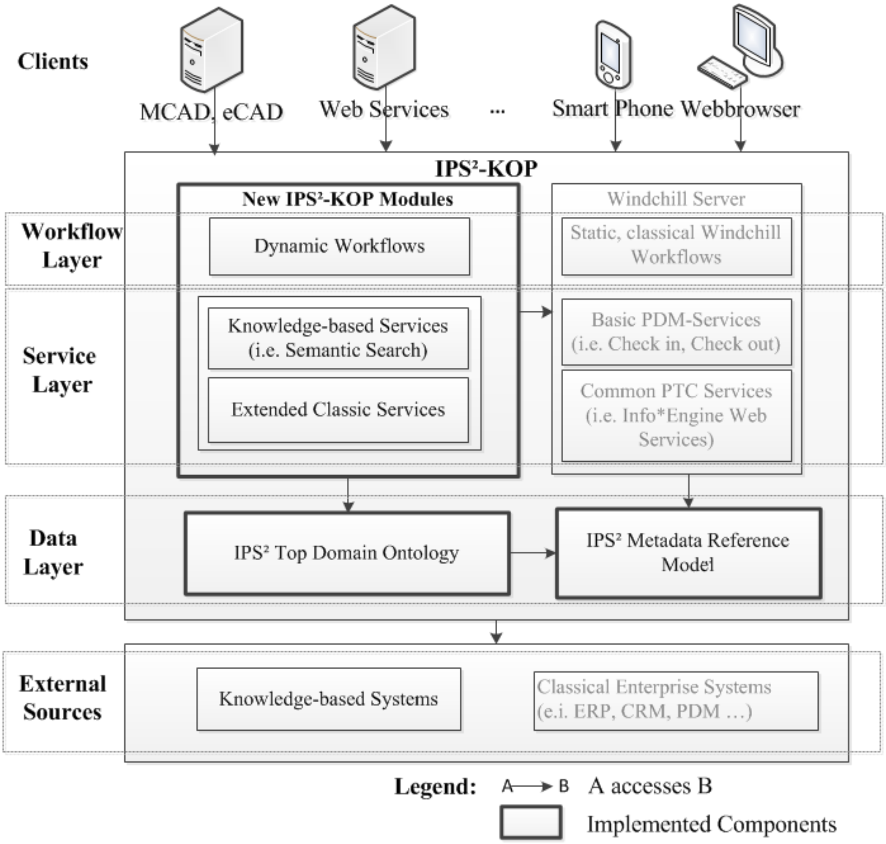


Fig. 3. IPS²-KOP prototype concept based on the commercial PDM system PTC Windchill

6 Conclusion and Future Work

This paper introduced a knowledge-based lifecycle management platform for IPS² which is based on the principles of SOA. In IPS², involvement of network partners and customers across the IPS² lifecycle is one of the most important factors determining the success of this business model. The proposed IPS²-KOP concept fully supports the required intensive collaboration with different business partners and customers.

In order to enable knowledge-based methods (e.g. semantic search, semantic information retrieval) and to support dynamic changes of business processes, an IPS² top domain ontology has been developed. The ontology includes a semantic description of various IPS² concepts and integrates interdisciplinary information and knowledge from different systems.

An additional advantage of the IPS²-KOP concept is its interoperability. While proprietary software may yield advantages in a homogenous network, within a heterogeneous network open standards for communication are preferable.

In near future the presented prototype will be extended with implementations of intelligent operations (*Knowledge-based Operation*: e.g. Change in business model for a single customer) utilizing the IPS² top domain ontology and workflows (*Dynamic Workflow*: e.g. Change in supply chain induces adhoc changes in other domains) as well as intelligent KPI-based decision support (*Knowledge-based Service*: e.g. Evaluation of sustainability).

Acknowledgements. We express our sincere thanks to the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) for financing this study within the Collaborative Research Center Transregio 29 (CRC/TR 29) on Industrial Product-Service Systems – dynamic interdependencies between products and services in the production area.

References

1. Backhaus, K., Becker, J., Beverungen, D., Frohs, M., Knackstedt, R., Müller, O., Steiner, M., Weddeling, M.: Vermarktung hybrider Leistungsbündel. Das ServPay-Konzept. Springer, Berlin (2010)
2. Meier, H., Uhlmann, E., Kortmann, D.: Hybride Leistungsbündel, Nutzenorientiertes Produktverständnis durch interferierende Sach- und Dienstleistungen. In: wt Werkstattstechnik Online 7/8 year 95. Springer VDI (2005)
3. Meier, H., Uhlmann, E.: Integrierte Industrielle Sach- und Dienstleistung. Springer, Berlin (2012)
4. Mont, O.: Clarifying the concept of product-service system. Journal of Cleaner Production 10(3), 237–245 (2002)
5. Thomas, O., Nüttgens, M., Loos, P.: Hybride Wertschöpfung. Mobile Anwendungssysteme für effiziente Dienstleistungsprozesse im technischen Kundendienst. Springer, Berlin (2010)
6. Beverungen, D., Knackstedt, R., Hatfield, S., Biege, S., Bollhöfer, E., Krug, C., Wienhold, D., Müller, P., Stelzer, C., Köbler, F., Blinn, N.: Hybride Wertschöpfung – Integration von Sach- und Dienstleistung. Publicly Available Specification. Beuth, Berlin (2009)
7. Abramovici, M., Schulte, S.: Lifecycle Management für hybride Leistungsbündel(HLB). In: wt Werkstattstechnik Online 7/8. Springer VDI (2006)
8. Vitvar, T., Mocan, A., Kerrigan, M., Zaremba, M., Zaremba, M., Moran, M., Cimpian, E., Haselwanter, T., Fensel, D.: Semantically-enabled service oriented architecture: Concepts, technology and application. Service Oriented Computing and Application 1(2) (2007)
9. Moran, M.J.: Semantic Service oriented architecture- Component Model, Reference architecture and evaluated prototype. DERI- National University of Ireland, Galway (2011)
10. Stollberg, M., Wahler, A., Fensel, D.: Semantic SOA Überblick und Wertschöpfungspotenzial. STI International, Vienna (2008)
11. Mistry, S.K., Kamal, M.H., Mistry, D.: Semantic Discovery of Web Services through Social Learning. In: The 2012 Iberoamerica Conference on Electronics Engineering and Computer Science, pp. 167–177. Elsevier Ltd. (2012)

12. Virtual Vehicle Magazine 2-2009: Multidisziplinäre Integration Gesamtsystem Fahrzeug. Kompentenzzentrum Das Virtuelle Fahrzeug, Österreich (2009)
13. Factories of the Future, Brussels (2011), http://cordis.europa.eu/fp7/ict/micro-nanosystems/docs/ict-fof-project-summaries-2010-2011_en.pdf
14. Zeppenfeld, K.: SOA und Webservices. Springer, Berlin (2009)
15. Abramovici, M., Bellalouna, F., Goebel, J.C.: Towards adaptable industrial product-service systems with an adaptive change management. In: 2nd CIRP IPS^2 Conference 2010, Linköping, Schweden (2010)
16. Javvadi, L.: Services Oriented Architecture in PLM. MphasiS White Paper (2011), http://www.mphasis.com/pdfs/WhitePapers/Services%20Oriented%20Architecture%20in%20PLM.pdf
17. Abramovici, M., Neubach, M., Schulze, M., Spura, C.: Metadata Reference Model for IPS^2 Lifecycle Management. In: Proceedings of the 1st CIRP IPS^2 Conference, pp. 268–272. Cranfield University Press, United Kingdom (2009)
18. Bellalouna, F.: SOA-basierte Integrationsplattform für eine integrierte und interdisziplinäre Entwicklung mechatronischer Produkte. Berliner Kreis Tagungsband-Jahretagung 2008, Münschen, pp. 151–175 (2008)
19. El-Khoury, J.: A Model Management and Integration Platform for Mechatronics Product Development. Royal Institute of Technology, Stockholm (2006)
20. Hayka, H., Lüddemann, J., Stark, R.: Zuverlässigere Gestaltung mechatronischer Produktentstehung, ZWF 2008 / 103, pp. 714–719, Carl Hanser Verlag, Münschen (2008)
21. Fischer, F., Van Nguyen, T., Guellec, P., Harms, M.: EDM: a Framework for Virtual Aircraft Data Management. In: Proceedings of the 15th Symposium Product Data Technology Europe, Toulouse, France, pp. 23–35 (2006)

Effectiveness of Color-Coded CAD Models Value Visualization in PSS Conceptual Design

Alessandro Bertoni and Marco Bertoni

Product Innovation, Division of Innovation and Design, Luleå University of Technology, Luleå, Sweden
{alessandro.bertoni,marco.bertoni}@ltu.se

Abstract. The paper presents the results of testing activities aiming to verify the effectiveness of an approach that uses color-coded 3D CAD models to visualize value in the conceptual design stage of PSS. The paper describes setting and findings of a series of PSS Design Experiments involving 8 design teams composed by students participating to the Master Programme in Product Development. Through the application of protocol analysis to the recorded design sessions, the paper compares the behavior of those teams using color-coded CAD models, against those using color-coded numerical tables. The design teams using color-coded models have been found to dedicate significantly more time in the analysis of the value information provided, and to follow a more structured approach in problem analysis and solving.

Keywords: Product Service Systems, Protocol Analysis, Conceptual Design, Color-coded CAD models.

1 Introduction

Conceptual Design is one of the most critical steps in the product development process [1]. At this stage, designers take decisions that determine a large share of the final value of the product [2], often dealing with requirements that are vague, poorly defined or not existing. This problem is exacerbated when designing PSS, because the design space becomes wider and the analysis of the future solutions goes beyond merely product-related characteristics, encompassing service and lifecycle aspects outside the horizon of the engineering team [3]. Lacking of a holistic perspective, designers tend to follow their *'normal specification'* and optimize the system locally, making decisions based on their own preferences [4].

A Stage-Gate® approach [5] is commonly adopted to cope with the issues generated by long and complex development processes to facilitate projects from idea conception to product launch. However, as far as the system grows in complexity, it becomes less straightforward to understand which solution is the most value adding. Hence decisions at the gate become more difficult and working guidelines during the stages less clear. Innovative methods and tools are needed to stimulate the discussion about the system-level contribution of a component design, to eventually trigger

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 495–506.
DOI: 10.1007/978-3-642-30820-8_42

better decisions. One of the major issues in this domain relates to the capability of representing value-related information in a way to foster such a collaborative process.

Value-related information relates to the operational life of future design concepts, and encompasses dimensions that complement a purely technical and requirements-related perspective. The literature provides several examples of the multifaceted aspects that influence the value of a forthcoming solution. Kowalkowski and Kindström [6] represent the value of PSS as the merging of three dimensions: Product, Service and Relationship. Declining these dimensions at a lower level of granularity, product-based value encompasses aspects such as cost and quality, but also environmental impact and sustainability [7]. Service-based value encompasses aspects such as operation cost, customisation benefits, service consistency [6] or ilities [8], capturing for instance, by the capability of a system of to maintain its functions in the presence of changes. Relationship-based values includes proactivity, trust, long-term commitment and shared norms and mind-sets [6], thus encompasses more intangibles aspects, such as knowledge, emotions or experiences [9-11]. Building on these concepts, Bertoni et al. [12] propose six layers of categorization in an effort to summarize all the aspects relevant for the value assessment of a PSS in the aerospace industry, namely: Performance attributes, risk, profitability, operational performances, ilities and intangibles. In a nutshell value-related information can be seen as a way to represent the system characteristics, i.e. a way to represent the multifaceted factors and interactions which have an impact on the design and the behavior of the product and therefore on the design decision-making process

At the 3rd CIRP IPS2 Conference, the authors presented an approach to support decision-making at the gate, by increasing the decision makers' awareness about the value of a set of PSS alternatives [13]. The paper proposed an approach for displaying the value contribution of a part/assembly through color-coded 3D models in a CAD environment, which were exemplified in a case study related to the development of an aero-engine sub-system. The models aimed at improving the design teams' awareness on the problem to be solved, leveraging the way value-related information was considered during conceptual design.

This paper presents the results of a testing activity performed to verify such hypothesis. The researchers have applied protocol analysis to evaluate the performances of eight design teams working on the same design task, four using value reports in the form of color-coded 3D models, and four using value reports in the form of color-coded QFD-like tables. Eventually, conclusions are drawn about the effectiveness of the proposed visualization approach for PSS design.

2 Research Method

The research has been conducted within a European Commission's Seventh Framework Programme (FP7) project named CRESCENDO (Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation – http://www.crescendo-fp7.eu/) between May 2009 and October 2012.

The research adopts protocol analysis, in the form of Gero and Mc Neill [14], to investigate the behaviors of the designers during the design episodes. Protocol analysis has its roots in the "think aloud" method, which was introduced by Ericsson and Simon [15] and further detailed by van Someren et al. [16], where designers are literally asked to think aloud, so to record the verbalization for later analysis. The protocol technique extends the think aloud method through the use of a domain-dependent coding scheme based on generic models of designing and a robust coding methodology [14]. This approach makes possible to observe the temporal aspect of the design process [17] and to capture designers' behaviors as a sequence of activities.

Protocol Analysis considers the designer's activity as composed by a sequence of actions, each typically lasting for a few seconds. During the course of the work, designers engage in the design problem calling up a series of micro strategies, which can be recorded, grouped, categorized and analyzed [6]. The testing activity has been conducted in a laboratory environment involving students from a second year master in mechanical engineering.

3 PSS Dimensions for Conceptual Design

The PSS dimensions have been defined emerging from the PSS Layer method first developed by Müller et al. [18], and later adopted by Sakao [19]. The method defines nine dimensions, namely: Lifecycle activities, Needs, Values, Deliverables, Actors, Core Products, Periphery, Contract and Finance. Such layers served as a guidance to define a set of PSS dimension to be used in the protocol analysis. Within the present study, 5 of the original dimensions were better defined and renamed in order to avoid inconsistencies and to limit the risk of mistaken interpretation by the encoders. Namely Deliverables and Customer Value were reworked into Usage Phase and Service, to detail how the design teams intend to deliver value, either by directly impacting the usage phase of the product or by creating synergies or benefits in the servicing activities. Core Product was reworked into Engineering Characteristics, to better capture hardware-related instances, making explicit that this dimension was limited to technical specification. Eventually, Knowledge Reuse and Design Rationale were added and Actors and Contract removed, to analyze the impact of the visualization approach on the use of knowledge in PSS conceptual design, where discussions about contract specifications are premature and actors involved are not yet defined. The 9 PSS dimensions used for the analysis are defined as follows:

- *Needs* captures the discussion related to the definition or clarification of customers' and stakeholders' needs. It also considers the discussion related to the information made available from the previous assessment, as it represents a way to clarify the needs of the forthcoming solution. (e.g.: '…yes, but what is the need we focus on when we want it inside?...´)
- *Knowledge Reuse* captures the discussion related to the personal knowledge of the designers that was recalled during the experiment in order to fulfill the design task. (e.g.: ´The plastic may melt if you put something on it, so I think is not the best´)

- *Design Rationale* refers to explicit documentation, discussions, argumentations or reasons behind decisions made when designing a system or artifact. (e.g.: ´Why was it better with plastic?´)
- *Engineering Characteristics* captures the discussion related to the structure, mechanical characteristics, technical features or material related to the PSS hardware. (e.g.: ´…if we take away the welding and try to make it more…´)
- *Usage Phase* includes all the statements related to the operating phase of the product when the customer is physically using the artifact. (e.g. ´If you look at what is here, if you talk about ergonomics, it should be easier to use´)
- *Service* embeds all those statements related to activities activated by the customer's request to benefit of the product, but that are not directly visible by the customers, such as transportation or in-site assembly. (e.g.: ´It would take a lot of less time instead of pushing it into the garden…´)
- *Lifecycle Activities* contains all those statements related to the lifecycle of the product, from the production to the dismissal, with the exception of the statements concerning Usage Phase and Service. (e.g.: ´We can have a foldable one that is easier to store, but then is harder to assemble´)
- *Periphery* captures the statements about support equipment, technical periphery, tools and infrastructure related to the PSS execution system, similarly to what defined by Muller et al. [18]. (e.g.: ´I am thinking not roll it into the truck, but having a small crane that can..´)
- *Finance* includes all the discussions about cost-related aspects, either related to production, maintenance or servicing of the PSS. (e.g. ´Perhaps the burners are the most expensive part, those ones…´)

To facilitate the analysis at an higher level of granularity, the dimensions have also been grouped based on their area of relevance: Knowledge Reuse and Design Rationale referred to the Knowledge field, while Lifecycle Activities, Usage Phase, Periphery and Service have been grouped into the Service System field. The grouped categories are those not considered as main evaluation metrics for the experiment, and the decision to group them is driven by the necessity to make the result more readable. A description of the key metrics of the experiment is provided in section 4.3.

4 Experiment Set-Up

The testing activity was conducted in a laboratory environment at the university facilities. The rooms during all the experiments were equipped with the same material, i.e., papers, pencils, pens, tape and prototyping materials; the walls of the rooms were empty and no whiteboards were available. The equipment for both audio and video recording were available at DO. Eight experiments, in four different sessions took place between January and February 2012. A pilot session also took place in December 2011 and served the purpose of verifying and adjusting the variables for the study. All the sessions featured the same schedule. The task was explained in a 20 minutes meeting where the company, its PSS offer, and the rating system for the value assessment were presented. Each design team had then 25 minutes to analyze the report and come up with a new design. Additional 15 minutes were given to prototype a solution to be later presented to the other groups. The presentations lasted for 10 minutes, including short question and answer sessions. The last 15 minutes were spent to fill in individual questionnaires focusing on the use of the value assessment report. The analysis in this study has been limited to the problem analysis and idea generation phase (25 minutes).

4.1 Assignment and Instructions

The experiment featured a fictional design problem, which considered a barbeque equipment manufacturer aiming to shift its business focus, from selling the equipment through its retail network to provide it as a PSS solution. Despite the approach being first developed in the aerospace industry [13], it was preferred not to use the example of an aerospace component, since students might have perceived it as too complex and difficult to related to their direct knowledge. In the new scenario the ownership of the product stays with the manufacturer, which has to take care of all the service-related aspects, e.g. maintenance, cleaning, delivery and storage. The participants were asked to redesign the grills to make them more value adding in a situation where they are rented and delivered "just in time" to the customer.

The design sessions involved 26 students, who were split in 8 design teams of either 3 or 4 persons. The participants were allocated randomly to the teams with the only concern to uniformly assign the international students in order to use English as the only language. No particular method for PSS design was taught to the students prior to the experiments, in order not to influence the design session. Information about the company previous products was available to all the participants. Especially two different designs were described: The "old BBQ solution" (the old, outdated design) and "the actual BBQ solution" (the As-Is design). The two solutions had a similar structure based on six main components: A frame, a case, a grill, a lid, two supports, and a gas cylinder. The actual BBQ solution differed from the old one in terms of shape, materials and components, as it also featured an air system.

The value assessment reports, distributed to all the teams, represented the "knowledge baseline" for the redesign activity. The reports contained information about the capability of the old and actual design to fulfill the customer value scale, providing value-related information to the designers. The old and As-Is designs were compared against a set of value dimensions and value drivers, which were intended to translate stakeholders expectations and needs into understandable and actionable design objectives. Five value dimensions were defined, each of them built up by two to five specific value drivers. The 5 value dimensions were defined as: Operational Performances (i.e. Warming speed, Cooling speed, Ergonomics, Heat distribution, Safety), Service (i.e. Reparability, Cleaning, Mean time between failure, Assembly time, Logistic (i.e. Packaging, Weight, Size, Foldability), Production costs (i.e. Material cost, Manufacturing cost, Assembly cost), Intangibles (i.e. Brand acknowledgement, Environmental impact). In total six papers in an A3 format were provided in each report. Each paper reported the results of the benchmarking of a specific value dimension with its related value drivers, while the sixth paper reported an aggregate view of the 5 value dimensions without the detailed value drivers.

4.2 Implementing the Visualization Approach in the Design Problem Scenario

The value contribution of the ´Actual BBQ’ was assessed by the authors using the same 1-9 scale proposed by the value visualization approach [5], considering the ‘Old BBQ’ as baseline. In case the ´Actual BBQ´ was found more value adding than the old solution for a given driver, a score form 6 to 9 was assigned. In the opposite case a score between 1 and 4 was assigned. A score of 5 meant that no difference was found between the old and the As-Is solution. A color scale from red to white to dark green was associated to the numerical scale. White was associated to the neutral value (5), nuances of red to scores from 1 to 4 (pink=4, red=1), nuances of green to scores from 6 to 9 (light green=6, dark green=9).

Color-coded tables

	Reparability	Cleaning
Cover	7	7
Case	5	3
Frame	2	3
Support	3	7
Grill	4	8
Air system	3	3
Gas Cylinder	4	3

Color-coded 3D models

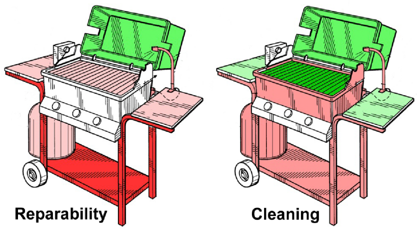


Fig. 1. Color-coded tables vs. color-coded 3D models

The value assessment report featured two alternative visualizations (Figure 1). Four teams received value-related information in a QFD-like format, i.e. the results of the benchmarking were visualized as numbers from one to nine in an excel table, and each table cell was filled with the corresponding color. The other 4 teams received the value assessment results as color-coded 3D models. In this case the report did not show any number, but the benchmark information were directly visualized as components colors in the printout of the BBQ CAD model. To avoid bias during the experiments the students were not aware of the difference in the value visualization between the teams.

4.3 Evaluation Metrics

The shift toward the design of PSS forces designers to make decisions based on a wider set of customer and stakeholder needs and expectation [20]. Being able to identify such needs earlier at a conceptual stage would save time and rework in later phases of the development process [20]. Therefore the author identified in the increase of the total time spent on discussing needs a success criterion for the evaluation of the visualization approach. Moreover research has shown that when a sample design is available to designers, the range of ideas produced in a conceptual design session suffers by design fixation [21]. Building on this finding, the discussion of specific engineering characteristics of the future products in the very initial phase of a conceptual design was considered as a proxy to evaluate the early fixation on a specific preformed idea of product to be developed, making designers' scarcely considering the new aspects related to the service dimension. By consequence the decrease of the total time spent in discussing engineering characteristics in the first quarter of the experiments has been identified as a success criterion to be investigated.

5 Data Analysis

The experiments were transcribed and codified separately by two encoders. This was done to grant the coding consistency. The percentage of agreement between the encoders after the first round of coding was of 65.2%. This result showed the necessity of describing with major detail the definition of the PSS dimensions into consideration. A second coding activity was later performed jointly by the two encoders, which led to the final version of the coding presented in the paper.

The scheduled duration for the idea generation and report analysis phase was of 25 minutes, however small discrepancies, up to 2-3 minutes, were found during the transcription. To overcome this problem the time spent on each PSS dimension has not been considered in absolute terms, but has been translated into percentage of the total time spent in the experiment.

5.1 High Level Results

Initially, the analysis has focused on the total time spent on each dimension during the experiment. The first column of Table 1 lists the 9 PSS dimensions considered for the analysis, plus an additional dimension that gathers all those statements that were not related to any dimension. The second column shows the average time percentage spent on each dimension by the teams with QFD-like value reports. The third column shows the average time percentage spent on each dimension by the teams with color-coded CAD models. Finally the last column shows the difference between column 2 and column 3.

Table 1. Percentage of time spent on each Value Dimension

DIMENSION	Tables	CAD	CAD-tables
Needs	13.45%	25.46%	**12.01%**
Knowledge Reuse	6.07%	6.28%	**0.21%**
Design Rationale	5.42%	3.50%	**-1.92%**
Engineering Characteristics	32.37%	28.75%	**-3.63%**
Lifecycle Activities	6.83%	4.33%	**-2.50%**
Usage phase	9.60%	4.07%	**-5.53%**
Periphery	2.53%	0.66%	**-1.87%**
Service	5.09%	7.53%	**2.44%**
Finance	5.34%	4.35%	**-0.99%**
No dimension	13.29%	15.07%	**1.78%**

Table 1 shows a relevant change in the behavior of the design teams. The teams using color-coded CAD models have spent 12% more of the total time in discussing about clarification and definition of needs, also related to the analysis of the previous value related information. This behavior causes the reduction of the time spent on all the other PSS dimensions with the only exception of the Service dimension, which has been discussed for the 2.44% more of the total time.

The analysis at this stage did not suggest the reasons for such behavior, neither it allowed analyzing in detail the behavior and the trends generated by the difference in the visualization. Therefore a second step of the analysis focused on the evolution of the topic of the discussion along the timeline of the session.

5.2 Analysis along Experiments Timeframe

To analyze in which sequence different activities were undertaken during the sessions, the experiments were temporally divided in four quarters. Each quarter lasted from 5 to 7 minutes according to the length of the experiment. It is worth notice that the time not allocated to any PSS dimension did not differ much between the two categories (see Table 1). For this reason such percentage of time were not considered in the analysis that follows.

Figure 2 displays the results of the analysis along the 4 quarters of the experiment, and shows that the teams using color-coded models initially approached the design problem strongly analyzing the needs (more that 50% of the time). As opposite teams with tabular reports dedicated to this task less that 15% of their time, focusing more on the engineering characteristics of the new product to develop. Concerning Finance and Knowledge no significant difference was found, while the aspects related to the Service System were deeper discussed by subjects with tables. The same trend related

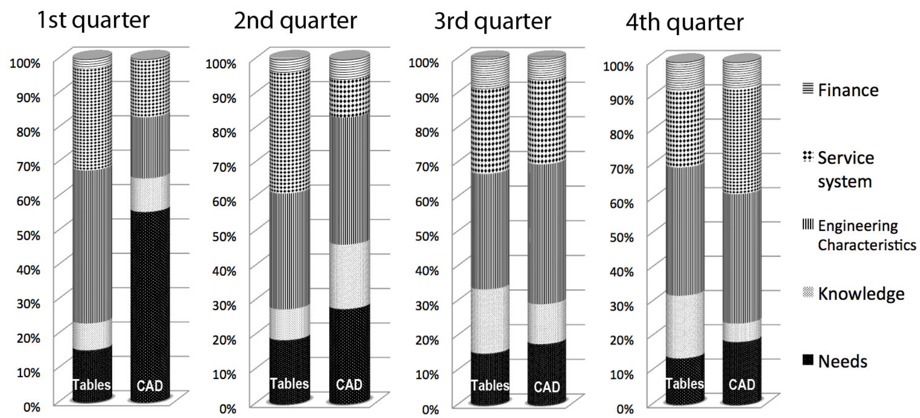


Fig. 2. Length (in percentage) of the time spent on each PSS dimension along the timeline

to the Service System was visible in the second quarter, where no relevant difference in behavior for teams with tables is recognized. CAD models teams instead switched their focus, reducing the time dedicated to investigate needs and spending an increasing time for Knowledge and Engineering Characteristics. In the third quarter a slightly increase in the Knowledge dimension for the teams with tables is visible, together with a continuous increase in the Engineering Characteristics dimension for the CAD model teams. In this quarter the teams with color-coded models started to significantly discuss Service System with more intensity. Finally in the last quarter the CAD models teams mainly focus on Service System and Engineering Characteristics, while the teams dealing with tabular reports did not show any significant change from the 3rd quarter. It has to be noted that after the first quarter, designers with color-coded models did not abandon the discussion about the needs, but kept focus on this dimension, conserving a percentage higher than the teams with tabular visualization all along the experiment.

6 Discussion

The results of the tests indicate that the use of color-coded CAD models drive the design team in a more detailed discussion of the needs of the solution to be developed. This finding is particularly relevant since the dimension Needs covers all the discussions related to the value assessment reports made available to the design team. Such finding strengths the hypothesis that the value visualization approach in color-coded CAD models enhances the awareness about the problem to be solved, leveraging the way value-related information is used in conceptual design.

From the analysis of the discussion along the timeline a clear trend seems to emerge. Teams using tabular reports did not significantly change their behavior during the experiment, i.e. the time spent on the PSS dimensions did not differ significantly in the quarters. As opposite teams with color-coded CAD reports followed a more structured approach. Initially they focus on the needs, and then they recalled previous knowledge and rationale to feed the discussion about the engineering characteristics of the hardware. In the third quarter the Service System dimension was emphasized concurrently to the technical discussion about engineering characteristics. The process is completed by the fourth quarter when the discussion about the Service Systems was brought up to more than 30%, equalizing those related to the engineering characteristics.

6.1 Discussion about the Method

The experiments have featured 26 participants from the Master Programme in Product Development. Protocol analysis is a widely know and proven approach, and despite some limitation [22] and the limited set of data, previous studies have shown the method to be applied also for a smaller number of experiments (see [19]). In authors' advice the sample represents the target population for the visualization approach, as they are soon becoming novice engineers in industry, and they will be actively involved in development projects featuring similar boundary conditions (intensity of teamwork, limitations in the knowledge baseline, deadlines) and problem statements. In terms of possibility of observing similar results in an industrial context, as highlighted by Coley [23], the main difference between experts and novices is that experts pay frequent attention to the reformulation of the problem, while this is completely ignored by the novices [24], which have been found to use a pattern of trial and error [25] although they seem to use similar working backward strategies [26]. These suggest that the results in an industrial contest might differ in absolute terms from what observed in the artificial scenario, although in relative terms the difference between the two settings might not be particularly evident. Furthermore, as recognized in the information visualization literature, most information visualization tools are still verified and validated in lab settings [27]. In spite of the drawbacks of artificial scenarios [28], a main advantage of conducting experiments with students in a laboratory environment is that industrial companies may not permit video and audio recording, and this restricts the amount and relevancy of the data collected.

7 Conclusion

The paper has presented the results of a set of experiments run in a laboratory environment aiming at analyzing the impact of color-coded 3D CAD models to improve communication and value-related information processing in PSS conceptual design.

The experiments have shown that design teams using such models have spent significantly more time, compared to teams using color-coded tabular reports, on analyzing the needs of the new solution in the light of the value information communicated to the design teams. Additionally the teams with color-coded CAD models have followed a more structured approach in analyzing the multifaceted aspects of the design problem into consideration. The experiments thereby confirm the hypothesis that color-coded 3D CAD visualization enhances the awareness of design teams on the problem to be solved, leveraging the way value-related information are used during conceptual design. Such finding suggests that the use of color coded CAD models to visualize the value of a forthcoming solution would improve the stage-gate process during early design, by triggering better decisions thanks to an improved understanding of the system level contribution of a component design.

Future work will focus on new codification of the existing recordings after the selection of categories targeting different aspects of the design activity. Finally additional experiments will be planned involving a larger number of product stakeholders and featuring cross-functional teams with different backgrounds.

Acknowledgments. The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 234344 (www.crescendo-fp7.eu/).

References

1. Roozenburg, N.F.M., Eekels, J.: Product Design: Fundamentals and Methods. John Wiley & Sons, West Sussex (1995)
2. Ullman, D.G.: The mechanical design process. McGraw-Hill, New York (2003)
3. Alonso-Rasgado, T., Thompson, G., Elfström, B.O.: The design of functional (total care) products. Journal of Engineering Design 16(6), 515–540 (2004)
4. Almefelt, L., Berglund, F., Nilsson, P., Malmqvist, J.: Requirements management in practice: findings from an empirical study in the automotive industry. Research in Engineering Design 17, 3 (2006)
5. Cooper, R.G.: Perspective: The Stage-Gate® Idea-to-Launch Process-Update, What's New, and NexGen Systems. Journal of Product Innovation Management 25, 213–232 (2008)
6. Kowalkowski, C., Kindström, D.: Value Visualization Strategies for PSS Development. In: Sakao, T., Lindahl, M. (eds.) Introduction to Product/Service-System Design. Springer, London (2009)
7. Goedkoop, M., van Haler, C., Riele, H., Rommers, P.: Product Service-Systems, ecological and economic basics. Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ) (1999)
8. Ross, A., Hastings, D.E., Warmkessel, J.M.: Multi-Attribute Tradespace Exploration as Front End for Effective Space System Design. Journal of Spacecraft and Rockets 41(1), 20–28 (2004)
9. Steiner, F., Harmor, R.: The Impact of Intangible Value on the Design and Marketing of New Products and Services: An Exploratory Approach. In: Proceedings of PICMET 2009, Portland, Oregon USA (2009)
10. Swartz, T.A., Bowen, D.E., Brown, S.W.: Fifteen years after breaking free: services then, now, and beyond. Advances in Services Marketing and Management 1, 1–21 (1992)
11. Vargo, S.L., Lusch, R.F.: The Four Service Marketing Myths: Remnants of a Goods-Based, Manufacturing Model. Journal of Service Research 6, 324–335 (2004)
12. Bertoni, M., Eres, H., Isaksson, O.: Criteria for assessing the value of Product Service System design alternatives: an aerospace investigation. In: Hesselback, J., Herrman, C. (eds.) Fuctional Thinking for Value Creation, pp. 141–146 (2011)

13. Bertoni, A., Bertoni, M., Isaksson, O.: Communicating the value of PSS design alternatives using color-coded CAD models. In: Hesselback, J., Herrman, C. (eds.) Fuctional Thinking for Value Creation, pp. 51–56 (2011)
14. Gero, J.S., Mc Neill, T.: An approach to the analysis of design protocols. Design Studies 19, 21–61 (1998)
15. Ericsson, K.A., Simon, H.A.: Protocol Analysis Verbal Reports as Data. MIT Press, Cambridge (1993)
16. van Someren, M.W., Bardard, Y.F., Sandberh, J.A.C.: The Think Aloud Method: A Practical Guide to Modelling Cognitive Processes. Academic Press, London (1994)
17. Mc Neill, T., Gero, J.S., Warren, J.: Understanding conceptual electronic design using protocol analysis. Research in Engineering Design 10(3), 129–140 (1998)
18. Müller, P., Kebir, N., Stark, R., Blessing, L.: PSS Layer Method - Application to Microenergy Systems. In: Sakao, T., Lindahl, M. (eds.) Introduction to Product/Service-System Design, pp. 3–30. Springer, London (2009)
19. Sakao, T., Paulsson, S., Mizuyama, H.: Inside a PSS design process: insights through protocol analysis. In: Proceedings of the 18th International Conference on Engineering Design, pp. 365–376 (2011)
20. Isaksson, O., Larsson, T., Rönnbäck, A.Ö.: Development of product-service systems: challenges and opportunities for the manufacturing firm. Journal of Engineering Design 20(4), 329–348 (2009)
21. Jansson, D.G., Smith, S.M.: Design fixation. Design Studies 12(1), 3–11 (1991)
22. Cross, N., Christiaans, H., Dorst, K.: Analysing Design Activity. Wiley (1996)
23. Coley, F., Houseman, O., Roy, R.: An introduction to capturing and understanding the cognitive behavior of design engineers. Journal of Engineering Design 18(4), 311–325 (2007)
24. Brand-Gruwel, S., Wopereisa, I., Vermettenb, Y.: Information problem solving by experts and novices: analysis of a complex cognitive skill. Computers in Human Behavior 21(3), 487–508 (2005)
25. Ahmed, S., Wallace, K.M., Blessing, L.T.M.: Understanding the differences between how novice and experienced designers approach design tasks. Research in Engineering Design 14, 1–11 (2003)
26. Ho, C.H.: Some phenomena of problem decomposition strategy for design thinking: differences between novices and experts. Design Studies 22, 27–45 (2001)
27. Ellis, G., Dix, A.: An explorative analysis of user evaluation studies in information visualization. In: Proceedings of the 2006 AVI Workshop on Beyond Time and Errors: Novel Evaluation Methods for Information Visualization, Venice, Italy, pp. 1–7 (2006)
28. Sedlmair, M., Isenberg, P., Baur, D., Butz, A.: Information visualization evaluation in large companies: Challenges, experiences and recommendations. Information Visualization 10(3), 248–266 (2011)

Functional Specification for IPS²-Execution Systems

Horst Meier, Friedrich Morlock, and Thomas Dorka

Chair of Production Systems, Ruhr-University Bochum, Universitätsstr. 150,
44801 Bochum, Germany
{meier,morlock,dorka}@lps.rub.de

Abstract. To support the Industrial Product-Service System (IPS²) provider during the delivery phase of IPS², an IPS²-Execution System (IPS²-ES) is needed for the planning, scheduling and organization of the required delivery processes and the partner network. To be able to build such an IPS²-ES, the requirements for this system have to be collected in a user specification document. Based on the given requirements, a functional specification has to be developed to serve as a basis for the design and the architecture of an IPS²-ES.

In this paper, an overview over a functional specification for an IPS²-ES is given. Since the requirements for the development of software systems for active collaborative research projects are continuously changing due to new results from own research or related projects, the agile software development process is proposed for the implementation of an IPS²-ES prototype.

Keywords: Industrial Product-Service System, IPS²-Execution System, functional specification.

1 Introduction

Industrial Product-Service Systems (IPS²) are means to provide customer value as, for example, described in [1] and [2]. This customer value is achieved by not only selling a product and offering services to a customer but by offering a system that integrates product and service shares. An integrated development of these two parts of the system as well as their mutually determined planning and delivery allow for the fulfillment of the customer needs [3].

The delivery of Industrial Product-Service Systems (IPS²) is a highly complex task. An IPS² provider has to take several responsibilities to provide the value agreed upon with an IPS² customer. In [4] the responsibilities are described and a system for supporting the provider in the delivery of IPS² is proposed. This system has to be able to manage fluctuations in a supplier network, provide strategic and operational planning methods, serve information about the IPS² delivery to all IPS² partners, and much more. The different software systems currently available on the market, among them Enterprise Resource Planning systems (ERP), Manufacturing Execution Systems (MES) and Service Management Systems (SMS), do not provide the features to support an IPS² provider in his specific tasks. Therefore, a new system called IPS²-Execution System is proposed. [4]

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 507–519.
DOI: 10.1007/978-3-642-30820-8_43

Although [4] already describes parts of the functionality of a so-called IPS²-Execution System (IPS²-ES), a formal specification to serve as a basis for the development of such a system is not given therein. Therefore, a user specification for an IPS²-ES is presented in this paper. Based on that, a functional specification is developed to serve as a basis for an implementation of the IPS²-ES.

2 State of the Art

For the development of an IPS²-Execution System, a specification document for the system has to be created to lay out the conditions for the implementation. According to [5], such a document is called "user specification" (this term will be used throughout this paper). However, the term is not used consistently in the corresponding literature. In [6] the document is named "tender specification", [7] refers to "system requirements" and [8] uses "Stakeholder Requirements Definition" and "system technical requirements" for the same document. The process of creating such a specification is called requirements engineering, as, for example, presented in [9] or [6].

[7] and [10] further detail the contents of the specification as: introduction to the project, description of the starting point (current status), tasks (desired status), interfaces, system technology requirements, requirements for starting up and operation, quality requirements and project execution requirements.

Each requirement represents a necessary attribute of the described system that is of value and utility to a customer or user. The attributes can describe capabilities, characteristics or quality factors. This provides the basis for the following development work. [9]

[9] and [11] distinguish several types of requirements. [9] first distinguishes between hardware and software requirements. Both are further detailed. The software requirements, which are most important for this paper, are divided into functional requirements and non-functional requirements. Also, the suggestions presented in [8] are referenced.

[11] presents a tree of classifications for requirements. Type, content, scope, detail level, reference point and many more are presented. The type classification also contains the functional and non-functional aspects in addition to the restriction of the solution space and domain requirements.

As a summary, the user specification describes what has to be done to develop the system and what purpose the system serves [6]. The requirements mentioned in the specification can be classified by different characteristics, e.g. describing functional or non-functional aspects of the system.

Based on the user specification, a technical implementation proposal document can be developed. This document is named functional specification (this term will be used throughout the paper) in [5]. [6] and [10] use the term performance specification while [7] just uses specification. In addition to the reviewed and extended contents of the user specification, the functional specification adds the system solution and the system technology (see [10] and [7]).

To be able to create a functional specification, the requirements given in the user specification have to fulfil several criteria as given in [9]. For example, each requirement should be correct, complete, consistent and feasible.

The functional specification describes how and with what (e.g. measures, tools, functionality, etc.) each requirement will be realized. The document is then used as a contractual description of the scope of the delivery and serves as a basis for the realization and preliminary and final inspections. [6]

3 User Specification for an IPS²-Execution System

As mentioned above, a user specification contains the following parts: introduction to the project, description of the starting point (current status), tasks (desired status), interfaces, system technology requirements, requirements for starting up and operation, quality requirements and project execution requirements. While an introduction to the IPS²-ES is given in [12] and [4], [13] elaborates on the role of the IPS²-ES in control of IPS². These papers can serve as an introduction to the project and the topics therein will not be repeated here.

The starting point for the development of an IPS²-ES is the research conducted on special topics of the IPS², for example on capacity planning [14], [15], adaptive resource planning [16], [17] and organizations for IPS² [18], [19]. Based on the information provided there and in [4], the tasks and interfaces as well as system technology, operation and quality requirements can be derived.

Since the required space for a detailed description of all requirements is not given in this paper, the requirements, including the necessary interfaces and tasks, will be presented only with a short description and references.

1) Technical Interfaces. This section describes the interfaces to external systems for sending and receiving different data or for using services.

A *Life Cycle Management System* (LCMS) for IPS² is the main source of information for the IPS²-ES. It supplies all information that is needed for the delivery of the IPS². Among those are descriptions of delivery processes, including their requirements, as well as the partner network involved in the delivery. [20], [21], [22]

The *IPS²-Control System* (IPS²-CS) controls each delivery process and reports unplanned demands to the IPS²-ES. It depends on the master plan created by the IPS²-ES and tracks all processes, supports workers in fulfilling the delivery process and monitors the IPS² condition. Hence, an interface to the IPS²-CS has to be implemented. Transmission of data should be done via the LCMS while the incoming data should be received directly from the IPS²-CS due to the real-time requirement 6.3. [13]

An interface to the Knowledge Management System (KMS) for IPS² should be established to retrieve past data, e.g. about previously executed delivery processes, and achieve continuous improvement of the IPS²-ES (see requirement 3). [23]

Each partner in the delivery network for an IPS² has potentially a *software system to support his business*. For example, this can be an ERP system to track the availability of offered products, an SMS that tracks the availability of service technicians or an

MES that keeps the information of machine (potentially IPS²) availability. This data is needed for the planning of IPS². Therefore, an interface to these business software systems needs to be created. Although several suppliers of these software systems are available and the software systems have different interface capabilities, a common interface to the IPS²-ES should be created to collect necessary data. [18], [24], [25], [4]

During the delivery of an IPS², several *external services* have to be used. Among these are the ordering of spare parts and the transportation of goods. In the IPS²-ES, the use of such services should be included in the planning. Therefore, an automated process for ordering spare parts or scheduling logistics over web services has to be integrated. [4]

2) Planning Method for IPS². This section describes the requirements for the IPS² planning methods needed for the delivery of IPS² in a distributed partner network.

Since the IPS² planning methods are very complex, an appropriate *data model* should be created to serve both as the model for the planning algorithm as well as the data exchange format with external business software systems. Only the necessary data for the IPS²-ES should be contained to avoid redundant data storage. [14], [4]

Strategic capacity planning is needed to support an IPS² provider in the determination of how many resources he needs in the future for the delivery of all IPS² he provides. This includes spare parts, tools and service technicians. Since not all resources are supplied by the IPS² provider, the data of external partners has to be included. The planning method should be based on the following literature: [16], [14], [15], [17]

Operational resource planning is needed whenever an unplanned demand occurs on short notice. The available resources have to be used to fulfil the unplanned demand without substantially affecting the already planned demands. The planning method should be based on the following literature: [16]

For the planning of IPS², several resources of different network partners, including the customers, are used to fulfil the demands of each IPS². Whenever capacity of one of the resources is low, a new network partner can be integrated in the network to supply the needed resources. Depending on the resulting network configuration, the IPS²-ES should *self-configure* itself to use the newly available partners and change the delivery plan accordingly. For example, the integration of a provider of logistic services that are fast and offered at a favourable price can have a considerable impact on costing factors of a delivery plan. [4]

External services should be used for planning algorithm, if available. For the calculation of the travel times of service technicians, travel route planning services (e.g. Google Maps API) should be used to provide most accurate details for the planning phase. Also, a possibility to integrate web services of providers of logistic services should be created. [26], [27]

3) High System Effect Performance. This section describes the system effect performance requirements for an IPS²-ES. A high system effect performance of the IPS²-ES is achieved, when the delivery of the IPS² is executed with optimized parameters like low costs, punctuality of delivery or a balanced utilization of resources. Due to the changes in the several different input parameters for the IPS²-ES, e.g. changed product models, different sets of resources, etc., a continuous improvement process has to be established.

To be able to *measure the performance* of the system, appropriate measurement techniques for the different parts of the application have to be implemented. This includes the measurement of partner performance, i.e. how good and how quick a partner fulfills the tasks (e.g. production, service, logistics) assigned to him, and measuring the quality of the delivery plan created by the planning algorithm, taking into account how long it has taken to generate the plan. Also, software metrics should be included, if necessary. This requirement is not final, since the effect parameters can only be derived from the IPS²-ES when it is built. The data acquired by the performance measurement should be provided to a KMS. Already *available knowledge data* should be used throughout the system to improve the performance. [23]

4) Web-Based Graphical User Interface. For the interaction of users via IPS²-ES, a web-based graphical user interface is required. The advantage of using a web-based user interface is that the application does not need to be installed on the client but is available independently of the user device. The client is provided with a configurable user interface where a user can define which parts of the application he wants to see and which services he wants to use (provided he has the required role, see requirement 6). Additionally, the IPS²-ES should provide a control center to manage the internal elements of the software system, including the adding of services and partners.

5) Information Provision. Throughout the delivery of the IPS², information has to be provided to the users of the system and to workers executing the delivery processes as planned by the IPS²-ES. The unhindered flow of data and the easy access to the system should be provided.

The LCMS provides detailed data about the IPS² product model including its delivery processes, spare parts and tools as well as information about the IPS² network partners. For each of the participants in a delivery process (e.g. a service technician or a delivery man), *specific data has to be provided*, e.g. about the delivery process or used spare parts and tools. This data can be retrieved from the LCMS and can contain, among others, technical data or process plans. With this, the IPS²-ES can help to prepare for each delivery process. On the other hand, the IPS²-ES should provide an aggregated view over the IPS² for each of the customers. This is realized by the web-based user interface presented in requirement 4). [4]

To allow for an information flow for participants of an IPS² delivery process, a *communication platform* should be established. Beyond the data provided in requirement 5), participants can use the platform for task-based information exchange and coordination. Also, customers of IPS² can get into contact with the IPS² provider if they need to clarify topics about the delivery plan for their IPS². This especially supports the socio-technical aspect of the IPS². [4]

6) Non-functional Requirements. This section describes the non-functional requirements for the IPS²-ES, i.e. they target the system as a whole, not only the functionality provided by the system. [11]

The *availability* of the IPS²-ES has to be as high as possible. If the system breaks down, planning functionality and information exchange for delivery processes, both crucial parts of the IPS²-ES, cannot be used anymore, which will have a great impact on the delivery of the whole IPS². An architecture allowing for failover should be targeted. A cloud computing solution could offer this functionality. [12]

Due to the heterogeneity of the user group, the system should be as self-explaining as possible and provide high *usability*. Trained IPS² managers should be able to retrieve their special data while untrained users can easily work occasionally with the system. Using a manual should be the last resort to help in using the system. An online help function that refers to the part of the system the user is working with should provide answers to urgent questions. Easy-to-understand labels, simple graphics and a consistent look should make it simple to adapt to. Depending on the user group, the different parts of the system may require more or less understanding of the IPS²-ES. The design process should be guided by software ergonomic standards. [28]

Due to the fact that the IPS²-ES is part of a large-scale complex system, it has to be able to react in a certain timeframe to allow for control of the whole IPS² in the delivery and use phase. This *real-time constraint*, however, does not have a fixed time horizon. Depending on the urgency of unplanned demands, the requirement is that the system provides a viable solution in an adequate time. The definition of the concrete real-time requirements will be based on the first planning prototype. [29], [13], [30]

Several platforms for the hosting of applications are available. To be independent of a specific supplier, the IPS²-ES should be *platform-independent*. This means, it should be possible to install the software on all major server platforms, including cloud environments and physical standalone servers. Also, the installation requirements should be very low so that the IPS²-ES can be moved from one platform to another without high effort during the prototype phase. If possible, the installation requirements should be none and the client side should be browser-independent. [12]

Two key factors of the IPS² are the *openness and the extensibility* of the system. Both allow for an easy integration of new IPS² partners and new web service providers, e.g. for logistics or order processes. New services, new functionality and new partners should be integrated into the system automatically and existing services should be able to self-configure their behavior according to the set of available service offerings. [4]

The *maintenance* efforts for the system should be kept at a minimum. Since the system itself is highly automatic, manual intervention should be avoided, if possible. Newer versions of services should be automatically integrated as required in 6.5. Errors should be reported to the responsible person with the place of its occurrence and the state the software was in at the moment the error occurred. To reduce errors and bugs, unit tests for the system should be implemented.

The visibility of data should be restricted according to different user roles to provide *security*. IPS² customers may only see the data connected with their IPS² and service technicians or delivery men may only see the information required for the execution of their task in the delivery process. By doing this, the know-how from different partners is protected. If possible, data should be handled anonymously. The three levels of visibility presented in [4] should be taken into account.

7) Documentation. This section describes the requirements for the documentation of the IPS²-ES.

As *general documentation* for developers, the code has to be written in a readable style. Unit tests should allow for an understanding of what every part of the system is meant to do. Where needed or appropriate, additional comments should be given in the code itself and in the unit tests. A guide should give an overview over the general system architecture. For users, context-sensitive online help should be made available. For administrators, an installation and configuration guide should be available. For the developers of new services and for new IPS² partners, *a guide with principles for the integration of services* into the IPS²-ES should be made available. This document should be created during the development of the prototype. Best practices and the most common errors should be collected there and serve as a reference for future development.

4 Functional Specification for an IPS²-Execution System

Based on the user specification, a functional specification can be created. The given requirements in the user specification have to be fulfilled by the proposals of the functional specification. The following section will describe guidelines for the implementation of an IPS²-ES to fulfil the given requirements. A solution approach for each requirement is presented below.

1) Technical Interfaces. The interface to the LCMS will be implemented via web services. New delivery plans are transmitted to the LCMS directly after they have been created and required data is retrieved from the system whenever needed. An observer pattern will be implemented for notifications from the LCMS about new IPS² product models or change in the partner network. In addition to that, the IPS²-CS will be connected directly as required by implementing the interface proposed in [13]. To connect to the partners' business software system, an intermediate layer will be introduced. Each business partner will be represented in the IPS²-ES as a virtual organization unit (VOU) that provides the required data. The mechanism for transferring the data from and to the external system is encapsulated in the unit, depending on whatever interface the partners' software systems require. Hence, the organizational structure presented in [18] will be implemented in the IPS²-ES and a visualization of the organization can later be implemented. External services will be represented inside the IPS² with a thin wrapper layer to allow consistent communication inside the IPS² while hiding service implementation detail.

2) Planning Method for IPS². The planning method proposed in [16] will be adopted for the IPS²-ES. If it is required, some aspects of the algorithm will be altered, e.g. to use available data from generated knowledge. The implementation of VOU as mentioned above will serve as a basis for the self-configuration. All data from the VOU will be made available to the planning algorithm by implementing a plug-in framework that makes services and therefore the business software systems of the partners available as soon as they are added to the system (e.g. with a framework like [31]). A data model will be developed together with the planning algorithm in an incremental approach. [14] already provides an approach for a data model, which will serve as a guideline.

3) High System Effect Performance. A performance measurement method for the IPS²-ES will be developed. Software metrics and key performance indicators will be reviewed in order to find the set of parameters that have an impact on the IPS² delivery. Rating data for IPS² partners and their resources will be generated by means of the KMS. This data can later be used to optimize the delivery plan by the use of highly rated partners and resources.

4) Web-Based Graphical User Interface. For the application's portability (see requirement 6) and browser independence, the asynchronous web application framework Google Web Toolkit (GWT, [32]) will be used. With this framework, several web applications (called WApps in the IPS²-ES) will be created, each with a separate concern. An additional web application will be developed to serve as a user desktop, which is similar to the operating system of a state-of-the-art smartphone. Using this desktop WApp as their entry point into the system, the user can define his own set of applications to build his own distinct view on the IPS²-ES. The set of available WApps for each user is restricted by the roles assigned to him. The loose coupling of the WApps and the separation of concerns allows an exchange of single parts of the IPS²-ES without having to change the system as a whole. Each WApp will be designed for browser independence.

5) Information Provision. A WApp will be built which supports both the provision of required data from the LCMS as well as the communication of the parties involved in a delivery process. Each user of the WApp can automatically see all the delivery processes assigned to him, ordered chronologically, and can then select one of the processes. For each process, the available data can be retrieved from the LCMS. Partners involved in a delivery process can also exchange data and messages (with support of asynchronous messaging) through this WApp. Inside the WApp, partners will be automatically linked based on common delivery processes.

6) Non-functional Requirements. Usability will be taken into account while designing each WApp. User feedback from workshops will be integrated to finally provide an intuitive user interface with consistent process steps and convenient functionality. Due to the fact that the IPS² operation resource planning algorithm is based on metaheuristics, a guarantee for the real-time requirement cannot be granted. However, finding a viable plan will be supported by using multiple computing resources from a cloud system. A parallel execution of multiple planning instances will be evaluated (e.g. using island models, [33]), if necessary. Using a cloud computing environment will also provide the required availability. To cover the *portability* requirement, the Java programming language [34] will be used. With Java and GWT, no installation (apart from a web browser) is required by the client and the installation on the server is simplified to installing a web application archive, which is only a file copy process. The introduced concepts of the WApps and a plug-in framework, as mentioned above, will provide the basis for an extensible and open system. Based on these concepts, all services, interfaces and other parts of the systems will be designed and developed. This is also valuable for the maintainability requirement, because parts of the application can be easily exchanged without stopping the IPS²-ES, so it does not affect its availability. The system will be built according to its tools and material approach presented in [35], which allows for a quick understanding of the system architecture. Hence, new developers can easily understand the IPS²-ES and add or change functions or services. For each WApp a log file will be written. Errors will be reported to the responsible person via email together with the latest log files to allow an investigation of the problem. Users will be informed by means of a system-wide approach through their WApp so that they may additionally ask for assistance from a support team. A security system based on roles will be implemented to decide which user can see which content. By restricting the access to whole WApps through roles, unauthorized access to data will be additionally avoided.

7) Documentation. The documentation will be generated as required. The primary source of documentation for developers will be the code with the corresponding unit tests. An additional system architecture overview will be delivered in a separate document in addition to the installation and configuration notes. For the system extension guideline, the process of multiple service implementations will be evaluated to serve as a basis.

The functional specification as described above will be used to implement an IPS²-ES prototype. During the implementation, the requirements can be refined and the functional specification adopted. To achieve this, agile software development will be applied. The following sections give an overview of what agile software development is and why it is suited to be used in a research context.

5 Agile Software Development and Implementation of an IPS²-Execution System Prototype

Software developments in research projects have special boundary conditions for the development process. Research leads to new knowledge and results, which need to be considered during the development process. This increase of knowledge is not alone to be considered inside the software project itself but also in other research projects. This can particularly be found in collaborative research projects where there are interfaces between several related projects. These interfaces are further developed, which leads to changes in research results such as IT-interfaces and software tools.

Large numbers of changes are not only visible in software research projects but also in industrial software development projects. In practice it is observed that the sequential development of the traditional software development is not able to handle many changes in customer needs. To solve this problem, the agile approach was invented [36]. The driver for the agile movement was the permanent need for change. The aim was to develop a strategy to deal with upcoming changes, not to avoid them [37]. For this, Cohn quotes a survey in which 92% of the interviewed persons confirmed a superior response to changes in agile projects. Beside the high willingness to adopt changes, many advantages can be achieved with an agile approach, for example a higher predictability or a faster development process [38].

In 2001 leading agile developers agreed on a consistent guideline which was composed into the agile manifesto [39], [37]. The agile manifesto with its values and principles is available on the internet (http://agilemanifesto.org/) [40].

The agile software development has a high impact on the functional specification document. Especially the agile value “Responding to change over following a plan” and the agile principle “Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage” are related to functional specifications. These support the above-mentioned boundary conditions and continuously changing requirements of software development in research projects and provide means of dealing with them. Agile values and principles are described in detail in agile methods [37]. One of the best known agile methodologies is Scrum [38]. Scrum is an iterative and incremental approach for software development. It uses a number of iterations for the development which are called sprints [41].

In Scrum, the traditional functional specification is listed in a changeable product backlog. The product backlog is the base for the development. At the beginning of a project, the product backlog consists of all known requirements. These requirements may change during a development process and the updates are reflected by the product backlog. [41]

Another important agile value that is closely connected to the changeability is the value of working software. An early software implementation and testing of prototypes enable new requirements and results [39]. By doing this, software development is a learning process [36]. This process is especially important for research projects.

As a summary, the agile software development has a lot of advantages for development in research projects. The early implementations enable early results and the changeable functional specification allows the consideration of new results from internal and external research. Hence, agile approaches are valuable methods for the development of an IPS²-ES.

6 Conclusions and Outlook

After a short introduction to the topic of IPS² and the IPS²-ES, an overview of a user specification of an IPS²-ES and an overview of a first functional specification for the development of a prototype have been presented in this paper. The requirements from the user specification have been briefly described and the technical solutions to the individual requirements presented in the functional specification.

These two specifications can now serve as a basis for the development of a prototype of an IPS²-ES to demonstrate the benefit the system offers for the delivery of IPS². Also, the development of the prototype can deliver new research results and allow for improved and more detailed specification documents. Risks in the development of the software system can be collected to serve as a guideline for future implementations of IPS²-ES. To be able to react to constantly changing requirements during the development and to have a working test system available as early as possible, the agile software development has been proposed.

Acknowledgments. The authors would like to thank the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG, www.dfg.de) for funding their research within the project Transregio 29 "Engineering of Industrial Product-Service Systems" (www.tr29.de).

References

1. Aurich, J.C., Clement, M.H. (eds.): Produkt-Service Systeme: Gestaltung und Realisierung. Springer, Berlin (2010)
2. Durugbo, C., Bankole, O.O., Erkoyuncu, J.A., Tiwari, A., Alcock, J.R., Roy, R., Shehab, E.: Product-Service Systems across Industry Sectors: Future Research Needs and Challenges. In: Sakao, T., Larsson, T., Lindahl, M. (eds.) Proceedings of the 2nd CIRP IPS^2 Conference on Industrial Product-Service Systems (IPS^2), pp. 535–542. Linköping University, Linköping (2010)
3. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems - IPS2. CIRP Annals - Manufacturing Technology 59(2), 607–627 (2010), doi:10.1016/j.cirp.2010.05.004
4. Meier, H., Dorka, T.: Robust Manufacturing through Integrated Industrial Services –The Delivery Management. In: Windt, K. (ed.) Robust Manufacturing Control, pp. 190–201. Springer (2012)
5. DIN Deutsches Institut für Normung e.V.: Projektmanagement - Projekmanagementsysteme - Teil 5: Begriffe (Project management - Project management systems - Part 5: Concepts), 2009th edn. Beuth, Berlin 03.100.40(69901-5) (2009)
6. VDI Verein Deutscher Ingenieure: Vorgehensweise bei der Erstellung von Lasten-Pflichtenheften (Procedures for the compilation often derand performance specifications), 2001st edn. Beuth, Berlin 03.120.10; 25.040.00; 55.220(2519-1) (2001)
7. VDI Verein Deutscher Ingenieure: Lastenheft/Pflichtenheft für den Einsatz von Automatisierungssystemen (System requirement/specification for planning and design of automation systems), 2006th edn. Beuth, Berlin 25.040.01, 35.240.50(3694) (2006)
8. International Organization for Standardization/International Electrotechnical Commission (ISO/IEC): Systems and software engineering - Software life cycle processes, 2008th edn. (12207) (2008)
9. Young, R.R.: The requirements engineering handbook. Artech House, Boston (2004)
10. VDI Verein Deutscher Ingenieure: Lasten-/Pflichtenheft für den Einsatz von Förder- und Lagersystemen (Tender/performance specification for the use of convey anceand storage systems), 2001st edn. Beuth, Berlin 03.120.10; 25.040.00; 55.220(2519-2) (2001)

11. Partsch, H.A.: Requirements-Engineering systematisch: Modellbildung für softwaregestützte Systeme. Springer, Heidelberg (2010)
12. Meier, H., Funke, B., Dorka, T.: Cloud Computing für eine integrierte Leistungssteuerung. Industrie Management 2012(1), 49–52 (2012)
13. Meier, H., Uhlmann, E., Raue, N., Dorka, T.: Agile Scheduling and Control for Industrial Product-Service Systems. In: Teti, R. (ed.) 8th CIRP International Conference on Intelligent Computation in Manufacturing Engineering, Ischia (Naples), Italy, July 18-20. Elsevier (2012) (accepted paper, in print)
14. Hübbers, M.: Modell zur Kapazitätsplanung von Dienstleistungsressourcen in Leistungssystemen, 1st edn. Apprimus-Verl., Aachen (2011)
15. Krug, C.M.: Framework zur strategischen Kapazitätsplanung hybrider Leistungsbündel. Schriftenreihe des Lehrstuhls für Produktionssysteme. Shaker, Aachen (2010)
16. Meier, H., Funke, B.: Planungsmethoden für den Betrieb hybrider Leistungsbündel. In: Meier, H., Uhlmann, E. (eds.) Integrierte Industrielle Sach- und Dienstleistungen. Vermarktung, Entwicklung und Erbringung hybrider Leistungsbündel, pp. 163–190. Springer, Heidelberg (2012)
17. Meier, H., Funke, B., Boßlau, M.: Flexible Resource Planning in the Context of Dynamic IPS^2 Business Models. In: Hesselbach, J., Herrmann, C. (eds.) Functional Thinking for Value Creation. Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, pp. 165–170. Springer, Heidelberg (2011)
18. Völker, O.: Erbringungsorganisation hybrider Leistungsbündel. Shaker, Aachen (2012)
19. Meier, H., Völker, O., Funke, B.: Industrial product-service systems (IPS^2). Paradigm shift by mutually determined products and services. The International Journal of Advanced Manufacturing Technology 52(9), 1175–1191 (2011), doi:10.1007/s00170-010-2764-6
20. Abramovici, M., Jin, F.: A New Approach to Executive Information Management as Part of IPS^2 Lifecycle Management. In: Sakao, T., Larsson, T., Lindahl, M. (eds.) Industrial Product-Service Systems (IPS^2). Proceedings of the 2nd CIRP IPS^2 Conference. Linköping University, Linköping (2010)
21. Abramovici, M., Neubach, M., Schulze, M., Spura, M.: Metadata Reference Model for IPS^2 Lifecycle Management. In: Roy, R., Shehab, E. (eds.) Proceedings of the 1st CIR IPS2 Conference on Industrial Product-service Systems (IPS2). Cranfield University, Bedford (2009)
22. Aurich, J.C., Schweitzer, E., Fuchs, C.: Life Cycle Management of Industrial Product-Service Systems. In: Takata, S., Umeda, Y. (eds.) Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses, pp. 171–176. Springer, London (2007)
23. Seliger, G., Gegusch, R.: Automated knowledge generation in the PSS use phase. In: Product Service Systems. Dynamic Interdependency of Products and Services in the Production Area. International Seminar on PSS, Bochum, Germany, January 21-22, pp. 25–30. Shaker, Aachen (2008)
24. Bauer, J.: Produktionslogistik mit ERP-Systemen. In: Böge, A. (ed.) Handbuch Maschinenbau. Grundlagen und Anwendungen der Maschinenbau-Technik, pp. 1461–1472. Vieweg+Teubner, Wiesbaden (2009)
25. Kletti, J.: Manufacturing Execution Systems (MES). Springer, Berlin (2007)
26. Google Inc.: Google Maps API, `https://developers.google.com/maps/`
27. Alt, R., Gizanis, D., Österle, H., Gründel, K.: Logistik WebServices zur Unterstützung des Distributed Order Management. In: Hampe, J.F., Schwabe, G. (eds.) Mobile and Collaborative Business 2002. Proceedings zur Teilkonferenz der Multikonferenz Wirtschaftsinformatik 2002. Lecture Notes in Informatics, pp. 69–84, Köllen, Bonn (2002)

28. International Organization for Standardization (ISO): Ergonomics of Human System Interaction, 2006th edn. (9241) (2006)
29. Schuh, G., Meier, C., Brosze, T., Kompa, S.: Echzeitfähige Produktionsplanung und-regelung. ZWF 106(12), 907–911 (2011)
30. Filip, F.-G., Leiviskä, K.: Large-Scale Complex Systems. In: Nof, S.Y. (ed.) Springer Handbook of Automation, pp. 619–638. Springer, Heidelberg (2009)
31. OSGi Alliance: OSGi™ - The Dynamic Module System for Java™, `http://www.osgi.org`
32. Google Inc.: Google Web Toolkit, `https://developers.google.com/web-toolkit/`
33. Luke, S.: Essentials of metaheuristics: A set of undergraduate lecture notes. Lulu (2009)
34. Oracle Inc.: Java, `http://www.oracle.com/technetwork/java/index.html`
35. Züllighoven, H. (ed.): Object-oriented construction handbook: Developing application-oriented software with the tools & materials approach. Morgan Kuafmann. Dpunkt.verlag, Amsterdam, Bosten (2005)
36. Eckstein, J.: Agile software development with distributed teams: Staying agile in a global world. Dorset House Pub., New York (2010)
37. Dogs, C., Klimmer, T.: Agile Software-Entwicklung kompakt: Grundlagen agiler Software-Entwicklung; detaillierte Darstellung der wichtigsten agilen Methodiken; eXtreme-programming, Crystal, Scrum u.a., 1st edn. Mitp, Bonn (2005)
38. Cohn, M.: Succeeding with Agile: Software Development Using Scrum. Addison-Wesley (2009)
39. Bleek, W.-G., Wolf, H.: Agile Softwareentwicklung: Werte, Konzepte und Methoden, 1st edn. Dpunkt-Verl., Heidelberg (2008)
40. Cockburn, A.: Agile Software Development: The Cooperative Game. Addison-Wesley (2007)
41. Schwaber, K.: Agile project management with Scrum. Microsoft Press, Redmond (2004)

General Data Model for the IT Support for the Integrated Planning and Development of Industrial Product-Service Systems

Holger Bochnig, Eckart Uhlmann, Hoài Nam Nguyễn, and Rainer Stark

Institute for Machine Tools and Factory Management, Technische Universität Berlin, Pascalstr. 8-9, 10587 Berlin, Germany
{bochnig,uhlmann}@iwf.tu-berlin.de,
{h.nguyen,rainer.stark}@tu-berlin.de

Abstract. The approach of Industrial Product-Service Systems (IPS²) focuses on providing added value by integrating products and services. The complexity of their multi-disciplinary planning and development calls for methods and tools to support this integrated process. Therefore, the authoring tool "IPS² assistance system" has been developed, which represents an extensible framework and supports the entire IPS² planning and development process. For the implementation of this authoring tool, a general data model of IPS² is needed which helps with the management and exchange of phase-specific and discipline-specific data and results.

For the generation of this model, the phases of the planning and development of IPS² are examined based on a generic IPS² development process. The results of each phase (discipline-specific data) and their relations to each other are then defined and included in the data model.

Keywords: IPS² development, IPS² data model, IPS² authoring tool, Industrial Product-Service Systems, IT support.

1 Introduction

Industrial Product-Service Systems (IPS²) consist of integrated, interacting product and service elements and create an additional benefit throughout their lifecycle for customers and suppliers in the context of industrial applications [1-3].

Machine tool manufacturers often sell add-on services with the physical product, i.e. the machine tool. The influence of service aspects in the design and the use of the product are not considered, however, even though the revenue generated by industrial services is increasing. Thus, potentials are created by the integration of products and services over the entire lifecycle [4], [5].

IPS² represent customized solutions and allow a flexible adaptation to changing requirements of both customers and suppliers by the resulting solution space [6]. The extension of the solution space increases the organizational complexity, because the

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 521–533.
DOI: 10.1007/978-3-642-30820-8_44

time dimension of the service elements contained in the Industrial Product-Service Systems sets special requirements for tools and methods of the IPS² provider [7].

IPS² product and service elements depend on and influence each other and, therefore, need to be developed together as an integrated system. This puts high demands in regard to technical knowledge from different domains (esp. in both fields of product design and service engineering) as well as to the process complexity and organizational complexity. Also, it is necessary to take the interdependencies between products and services into account with concurrent and iterative development (sub) processes until contradictions are eliminated and the best solution is reached.

Moreover, a holistic view on the lifecycle of the IPS² should be applied in order to obtain the best solution, because the use phase moves into focus of the IPS² provider. The responsibility of the provider and the business relation with the customer do not end after shipping the product. All of these facts show that IPS² development is more demanding in contrast to conventional product design or service engineering [7].

While IT support for product design has been available for decades, IT tools for service engineering still have a relatively young history, and the integrated development is just emerging in the research field. IPS² development requires many different partial models resulting from various domains and development phases. However, smooth collaboration requires access to the latest development data across the entire value chain. Also, homogeneous environments are a success factor for development projects. They enable efficient data exchange and synchronization of project members and between different disciplines.

In order to support IPS² developer during the entire planning and development process, the authoring tool "IPS² assistance system" has been developed [8]. For the implementation of this authoring tool, a general data model of IPS² is needed which helps with the management and exchange of phase-specific and discipline-specific data and results.

2 IT Support System for the Integrated IPS² Development as a Scope for the General Data Model

The IT-based authoring tool "IPS² assistance system", developed at the Institute for Machine Tools and Factory Management of TU Berlin, supports the integrated planning and development processes of Industrial Product-Service Systems. This software system guides and supports the developer along the integrated development processes of products and pertinent services while constantly considering their mutual interdependencies starting at the earliest development phase. In order to reduce the complexity of the development task, the developer is provided with product-service module (PSM) libraries and technology databases containing aggregated knowledge about products, services, processes and pre-developed module solutions.

The partial models (specific models used in the respective planning and development phases) have to be combined within a consistent user interface. Since IPS² development aims at customized solutions, the aspect of customer interaction has to be taken into account by providing interfaces to the customer. The software system also has to be designed to permit an iterative development process. Feedback of changed or extended requirements needs to be included in the following development cycle in order to approach or reach the best solution for the customer. Finally, the architecture of the IPS² assistance system needs to be extensible in order to include other partial models.

Figure 1 depicts the software architecture of the IPS² assistance system, which has a modular structure and serves as a framework for the integration of software modules and partial data models that correspond to the respective process steps. So far the following software modules have been implemented: identification of customer and provider needs and their transformation into requirements, the IPS² configuration module together with the product-service module library and compatibility information database. A top-down approach has been applied to the task, so that after examining the creation of IPS² from pre-developed product-service modules, the research is now focusing in more detail on the creation of the product-service modules, consisting of product and service elements, and the detailed interdependencies between these elements [9]. For this framework, the general data model of IPS² has been developed in order to manage and standardize the exchange of phase-specific and discipline-specific data and results in the established industry standard XML.

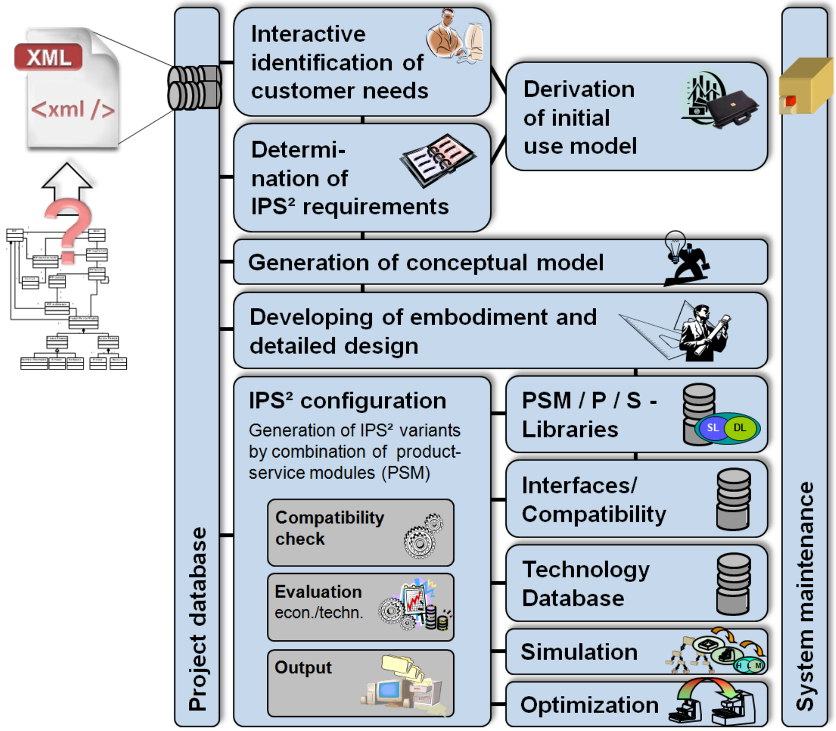


Fig. 1. Modular software architecture of the IPS² assistance system [9]

3 Process for the Planning and Development of Industrial Product-Service Systems

For the development of physical products as well as IT systems, a number of methodologies exist which define the development process from abstract to detailed levels. Widespread methodologies are the VDI guideline 2221, the methodology of Pahl/Beitz and for software the V-Model [10-12]. The development and delivery of services are not well specified. In [13] a very rough and abstract phase model for service development is introduced. Service classes in the engineering field are defined in [14] and service delivery described in [13]. A concept for service design with a lifecycle context is outlined in [15]. Detailed process models for service development are missing at present.

In the IPS² domain, many generic development concepts and approaches with different focuses have been proposed. For instance, among others, Sakao and Shimomura have proposed a generic method which has its focus on service design [16]. In the field of Eco-Design, a design process for PSS eco-innovation has been proposed [17].

In this paper, the generic IPS² development process proposed by Müller [18] will be used as a basis to derive an IPS² development process, which sets the scope for the generation of the general data model.

Although the generic IPS² development process fulfils its purpose as a communication basis by describing IPS² related issues, it is not suitable to serve as a basis to derive a general IPS² data model, because it does not contain any specific results of development phases. Therefore, an extended process for the planning and development of IPS² has been developed, which contains milestones and results of development phases (Figure 2). The process has been divided into four phases (planning, concept modeling, specification and modularization, embodiment and detailed design) with detailed description and results of its execution. This increases the understanding for a flow of this specific development process. Between the phases, milestones have been defined. They serve as orientation points, at which results of phases are reviewed and decisions are made whether or not to start the next phase. Iterative feedback loops are not shown in the figure for simplicity reasons.

3.1 Planning of Industrial Product-Service Systems

The planning of IPS² starts with an acquisition of customer needs and values in the planning phase. The integration of the customer in the planning and development is a key point for providing IPS², which in most cases is a customized solution. Apart from customer specific factors (e.g. competences, business strategies, production processes) also external factors like legislation, infrastructure, market, competitors, etc. have to be considered at this stage.

As a next step, IPS² requirements are derived from the customer needs. While needs, expressed explicitly or implicitly, describe the problem of the customer, requirements are solution-neutral descriptions of the behavior of an IPS² both from a customer and provider view [19].

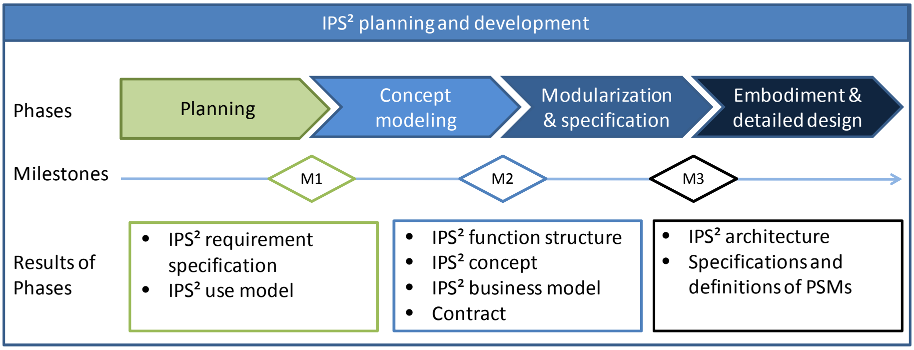


Fig. 2. Simplified IPS² planning and development process derived from [18]

Simultaneously, a use model is determined that benefits both the customer and the IPS² provider. A use model describes the usage of the IPS² and the resulting requirements in a specific business case.

3.2 Concept Modeling of Industrial Product-Service Systems

From the inputs, the IPS² requirement specification and the IPS² use model, a function structure and a concept model are generated in the concept modeling phase. The function structure is a representation of the intended behavior (the functions) of an IPS² and its modules without specifying an IPS² module (product or service), which should fulfill the function. For example, a function "temperature monitoring" describes a functional behavior of an IPS², which provides the exact temperature of a product element that is needed for maintenance.

A concept model includes a function model and principle solutions of an IPS². It describes the structural interaction between them and their logical functionality [20]. A principle solution for the function described above could be a temperature sensor together with an analysis tool.

At the same time a customer specific business model is developed based on the IPS² use model. A business model is defined as a business relationship between provider and customer as well as any third parties over the lifecycle of an IPS². It describes benefits, yield mechanisms, risk allocation, and an ownership of all parties in the IPS² network and the organizational implementation [21]. For example, an availability oriented business model resulting from an availability oriented use model, determines a maintenance contract in order to ensure the functional availability of a machine tool over an agreed period of time [22]. Additionally, responsibilities are defined for machine tool failure.

3.3 Modularization and Specification of Industrial Product-Service Systems

Based on the concept model, product-service modules can be defined and specified for an IPS². The concept of subdividing an IPS² into PSMs is borrowed from systems engineering, which defines a system as a composition of various subsystems for better handling. This means IPS² is a system, a PSM is a subsystem. A PSM consists of product and service elements in variable proportions and fulfils one or more functions. Thus, a PSM can take three forms: PSM composed of both product and service elements; PSM with product elements only, and PSM with service elements [8].

In addition to the specification and definition of PSMs, it is necessary to develop important aspects of integration of PSMs into IPS² like ICT infrastructure as well as synchronization processes. Together, they build an IPS² architecture.

3.4 Embodiment and Detailed Design of Industrial Product-Service Systems

In this phase variants and possible solutions are generated and evaluated. Existing PSMs from a PSM library are assessed in the IPS² configuration step with respect to their suitability for the new IPS². PSMs not yet included in the PSM library, must be developed in parallel development processes. The methodology resembles the development of the IPS² on a higher level. Each PSM requires planning (derivation of requirements for PSM), concept modeling (generation of concepts for PSM), specification and modularization (second level). Finally, product and service elements of the PSMs are drafted and designed. Typically, the embodiment and detailed design of PSMs is discipline-specific, for which the market offers many software tools (e.g. CAD for technical systems, IDE for software development, process modeling for service descriptions). For integrated development, however, the interdependencies between the IPS² elements must be considered.

4 Requirements to the IPS² Data Model

The partial models of the planning and development phases, and thus also the software modules of the IPS² assistance system that support the respective phases, differ substantially. They form a very heterogeneous system with diverse data formats. In order to enable efficient data exchange and improve communication between development phases, a general data model of IPS² for the authoring tool IPS² assistance system is needed. A data model defines the structure and intended meaning of data [23]. The general IPS² data model should

- support the entire planning and development process across all process phases,
- allow for development of a concrete IPS² instance for a particular customer,
- allow the management of data for IPS² authoring,
- represent all the different elements of IPS²,
- allow the modeling of the interdependencies between the IPS² elements (essential due to the focus on an integrated development),
- allow for combining IPS² elements to modules and thus a modularization of IPS²,
- carry along results across phase borders,
- be generic, not domain specific,
- allow traceability of results from preceding phases and process steps,

- preferably be simple, not too complex,
- be flexible and extensible,
- contain different views on the model and
- allow links between partial models.

5 General Data Model for Industrial Product-Service Systems

5.1 Data Structure of the General IPS² Data Model

Based on the requirements defined in section 4, the general data model is being developed (Figure 3). The first step is to identify the model elements. Primarily, the elements will be intermediate results of the entire planning and development process, which are generated during the aforementioned phases. In particular such results are of interest which are necessary inputs for subsequent phases, because of the focus on supporting the planning and development and allowing the traceability of results across all phases.

The root element is the particular IPS² instance that needs to be developed. It is derived from a specific inquiry or order of a customer. The IPS² model element serves as a container for the following elements, which are associated directly or indirectly with this IPS² instance.

The needs and the IPS² requirements specification from the planning phase form the direct basis for all development steps. The results of the development phases must at any time meet the needs of the customer and provider, which should constantly be checked. The IPS² use model is another result of the planning phase. It is included in the IPS² business model, which is further developed in the concept modeling phase.

Business model, contract, IPS² function structure and IPS² concept are essential elements from the concept modeling phase. A revenue model is added to the IPS² use model. Together with the value configuration they form the IPS² business model [22]. The contract creates an institutional framework, which regulates the rights, duties and responsibilities and establishes the business relation between the IPS² provider and the customer [21]. The contract model element is gradually completed from a basic structure to the final contract. The IPS² function structure has a hierarchical composition with higher-level and lower-level functions. This is modeled by the self-referring relationship.

During the modularization and specification phase at system level, an IPS² architecture is derived from the concept, and principle solutions are merged into product-service modules. The IPS² architecture describes how the PSMs integrate with each other and form the IPS² as a whole.

The PSMs are subsequently designed and detailed in the drafting and design phase and consist of product and service elements. Components of product elements can have a mechanic, electric/electronic or a software based nature. The discipline-specific development results like 3D-CAD models, EDA (Electronic Design Automation) models, simulation models and source code as well as platform-specific executable programs are stored here as product elements. The service elements

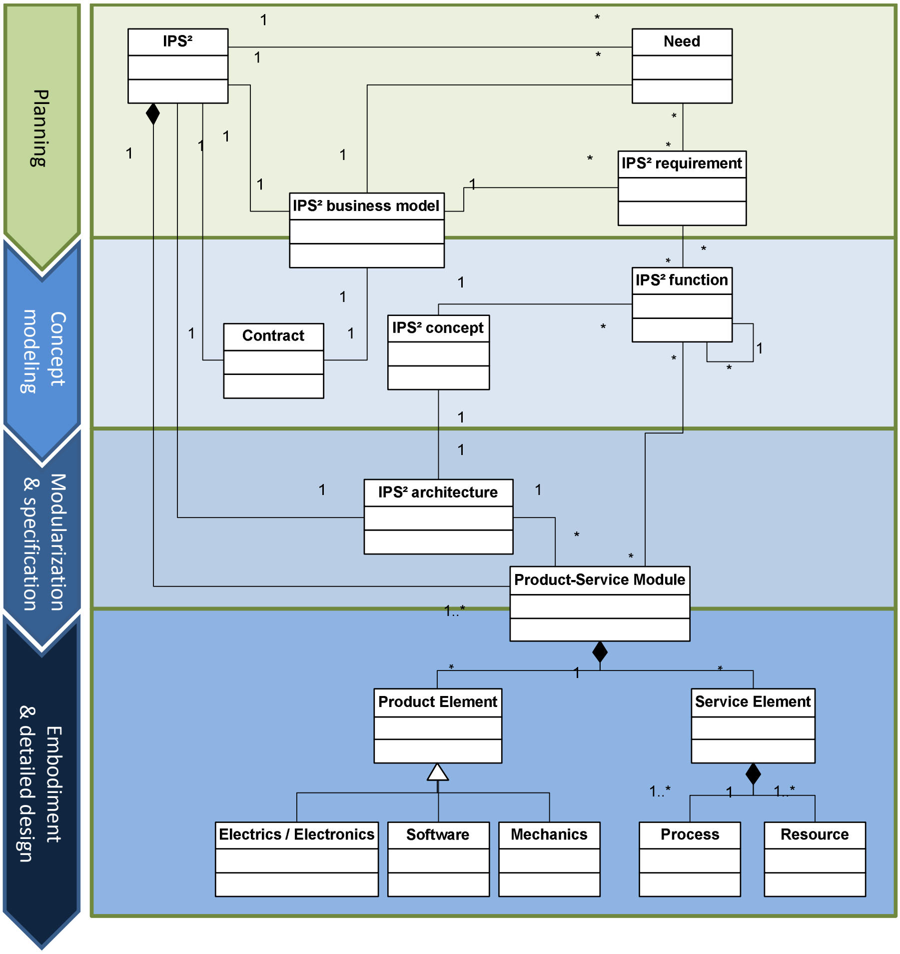


Fig. 3. The general IPS² data model

consist of processes (which include process steps and their sequence) and resources (which can be personnel, tools, consumables or auxiliary equipment).

The model elements are connected by relationships, which add semantics to the UML model. The following types of relationships have been used in the general IPS² data model: association, composition and generalization.

An association relationship is a structural relationship between two model elements, which shows that objects of one element connect objects and can navigate to objects of another element. A composition relationship is a type of aggregation and represents a relationship between an element that is a part of or subordinate to another element. A generalization relationship indicates that a specialized child element is based on a general parent element [24].

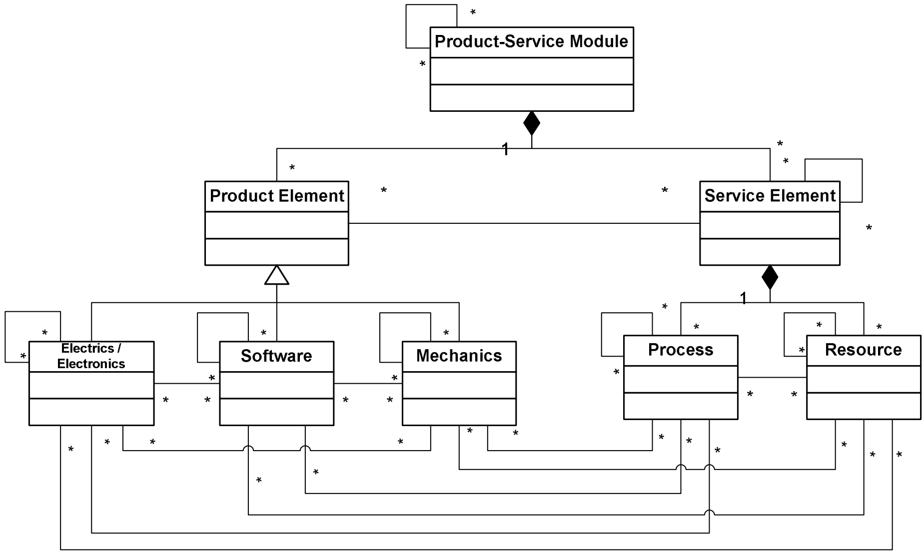


Fig. 4. Interdependencies in the general IPS² data model

In general the associations used in the model result directly from the order of the planning and development steps. Additionally, crosslinks have been inserted to incorporate multiple partial models or results from one phase and from parallel process steps.

The composition at the IPS² model element denotes the modularization concept of IPS². IPS² consist of one or more product-service modules, which in turn are composed of product and service elements. The latter are formed by the set of process and resource. The composition relationship has been used in this case because the development of a particular IPS² instance is concerned. Therefore, the model elements represent concrete instances of results of each phase and are valid only for this particular IPS² instance.

The product element is the generalization of the disciplines mechanics, electrics/electronics and software. Thus, a PSM can consist of and fulfill its function by components from the three disciplines and/or processes that are executed by or with the help of resources. This reflects the substitutability between solution variants for one function, which can be product-centric or service-centric or even consist of only one element type.

5.2 Interdependencies between IPS² Elements

The integrated development of IPS² makes it necessary to describe the interdependencies between IPS² elements. These interdependencies can be found at different levels within an IPS². The highest level is that of product-service modules. The next level is represented by the product and service elements. The third level consists of the discipline-specific components as well as the processes and resources. The attributes of these components, processes and resources are on the last and most detailed level. In this context attributes are characteristics or properties of the components, processes and resources like object mass, duration of a process step and qualification of a technician.

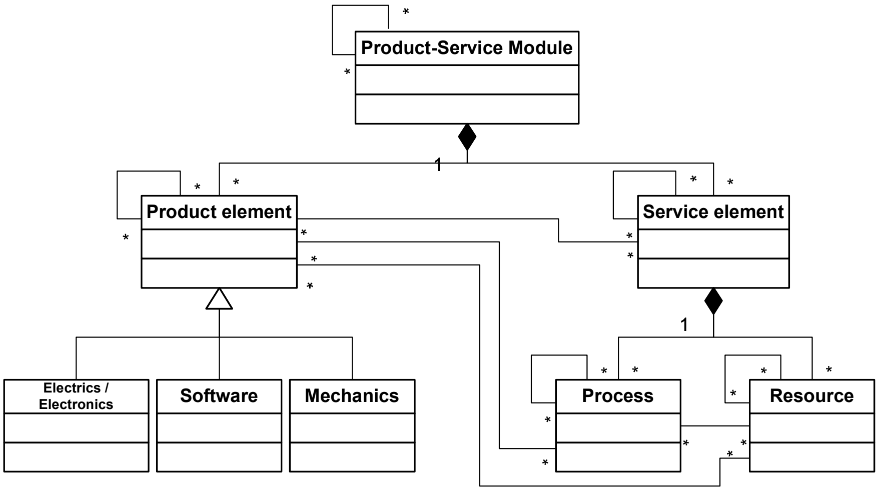


Fig. 5. Simplified model of interdependencies in general IPS² data model

Interdependencies can exist either within each of these levels or across these levels. In figure 4 the association relationships represent the identified interdependencies within the levels. The inter-dependencies across levels have been omitted in favor of better clarity. The composition relationship in the model also implies interdependencies across levels. If the components or parts of the elements belong to a whole, they need to be compatible with each other, and there exists a dependency between the whole and the part.

Different types of interdependency relationships can be assigned. At the higher levels the interdependencies can be described by the relationships "requires" and inversely "enables". For example, condition monitoring (PSM level) may be a requirement for preventive maintenance (PSM level). In turn, sensors have to be integrated into the mechanical product (element or component level) for this purpose. Another example is that an inspection service (element level) together with its process and resources (component level) is needed for wear testing a roller bearing (component level). Also, a technician (resource/component level) needs a certain qualification (attribute level) for a maintenance process, which he can obtain by training (element level).

The interdependency relationships on detail level can be described as interdependencies between the attributes of the components, processes and resources. For this, the relationship types "identical", "not less than" and "not more than" have been identified. For instance, a wrench needs to have the same size like the hexagon screw to be removed. The lifting of a heavy object during the manual execution of a process is another example. The maximum permitted weight of the product varies and depends on the use of a lifting device. Finally, the minimum qualification of service technician depends on the specific type of a product.

The interdependency relationships in figure 4 have been modeled extensively. In order to reduce the complexity of the model, a simplified model has been derived. In figure 5 the generalization relationship has been used to save the detailed relationships between process and resource on one side and the discipline-specific components on the other side as well as their self-references. Due to the generalization concept, one relationship each from the process and resource elements, and one self-reference at the product element, suffice to describe the same relationships.

6 Conclusion and Outlook

For the integrated development of complex systems, such as IPS², new methods and tools are needed. However, IT support for the integrated development of IPS² is hard to find and no standards exist for the exchange of IPS² data within an IPS² authoring tool during the entire planning and development phases.

To overcome these difficulties, a general data model has been developed and implemented in the authoring tool “IPS² assistance system”, which supports the entire IPS² planning and development. The data model includes partial models from all the phases of IPS² planning and development. Furthermore, it describes possible interdependencies between product and service elements in detailed as well as in simplified form.

As a next step the general IPS² data model shall be customized and detailed for specific industry cases and tested with various information standards, documents and models in the respective industry sector. It can be extended to integrate existing IT systems into the IPS² assistance system. For this purpose interfaces for data exchange need to be implemented.

Acknowledgments. We express our sincere thanks to the Deutsche Forschungsgemeinschaft (DFG) for funding this research within the Collaborative Research Project SFB/TR 29 on Industrial Product-Service Systems – Dynamic Interdependency of Products and Services in the Production Area.

References

1. Meier, H., Uhlmann, E., Kortmann, D.: Hybride Leistungsbündel: Nutzenorientiertes Produktverständnis durch interferierende Sach- und Dienstleistungen. wt Werkstattstechnik Online 95(7/2005), 528–532 (2005)
2. Tan, A.R., McAloone, T.C.: Characteristics of strategies in Product/Service-System Development. In: Andreasen, M.M. (ed.) 9th International Design Conference - Design 2006, Dubrovnik, Croatia, pp. 1435–1442 (2006)

3. Matzen, D., Tan, A.R., Andreasen, M.M.: Product / Service-Systems: Defining a coherent terminology. In: Meerkamm, H. (ed.) Design for X. Beiträge zum 16. Symposium, Neukirchen, pp. 27–38. Erlangen (2005)
4. Nyhuis, P., Fronia, P., Pachow-Frauenhofer, J., Wulf, S.: Wandlungsfähige Produktionssysteme. wt Werkstattstechnik Online 99(4), 205–210 (2009)
5. Fleischer, J., Meier, H., Kaiser, U., Krings, R., Niggeschmidt, S.: Verfügbarkeitsoptimale Dienstleistungskonfiguration. wt Werkstattstechnik Online 98(7/8), 601–606 (2008)
6. Uhlmann, E., Bochnig, H.: IT-gestützte Anforderungsgenerierung für hybride Leistungsbündel. wt Werkstattstechnik Online Jahrgang 100(Heft 7/8), 578–583 (2010)
7. Uhlmann, E., Bochnig, H.: Computer Aided IPS^2 Development. In: Meier, H. (ed.) Industrial Product-Service Systems. Dynamic Interdependency of Products and Services in the Production Area. 2nd Int. Seminar on IPS^2, pp. 31–36. Shaker, Aachen (2009)
8. Uhlmann, E., Bochnig, H.: Assistenzsystem zur Ausgestaltung hybrider Leistungsbündel. In: Meier, H., Uhlmann, E. (eds.) Integrierte Industrielle Sach- und Dienstleistungen. Vermarktung, Entwicklung und Erbringung hybrider Leistungsbündel, pp. 89–111. Springer, Heidelberg (2012)
9. Uhlmann, E., Bochnig, H.: PSS-CAD: An Approach to the Integrated Product and Service Development. In: Shimomura, Y. (ed.) Proceedings of 4th CIRP International Conference on Industrial Product-Service Systems, Tokyo (in press)
10. Verein Deutscher Ingenieure: Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte: Systematic approach to the development and design of technical systems and products. VDI 2221. Verein Deutscher Ingenieure, Düsseldorf (1993)
11. Pahl, G., Beitz, W., Feldhusen, J., Grote, K.-H.: Engineering Design: A Systematic Approach, 3rd edn. Springer, London (2007)
12. Industrieanlagen-Betriebsgesellschaft mbH: Das V-Modell, `http://v-modell.iabg.de/`
13. Deutsches Institut für Normung e.V. (ed.): DIN-Fachbericht 75 - Service Engineering: Entwicklungsbegleitende Normung (EBN) für Dienstleistungen. Beuth, Berlin (1998)
14. Verein Deutscher Ingenieure: Ingenieur-Dienstleistungen und Anforderungen an Ingenieur-Dienstleister: Engineering services and requirements for an engineering service provider: VDI 4510. Beuth, Berlin (2004)
15. Aurich, J.C., Fuchs, C., DeVries, M.F.: An Approach to Life Cycle Oriented Technical Service Design. CIRP Annals - Manufacturing Technology 53(1), 151–154 (2004)
16. Sakao, T., Birkhofer, H., Panshef, V., Dörsam, E.: An effective and efficient method to design services: empirical study for services by an investment-machine manufacturer. International Journal of Internet Manufacturing and Services 2(1), 95–110 (2009)
17. Chen, J.L., Huang, S.-C.: Eco-Innovative Design of Product Service Systems by using the Substance-Field Analysis Method. In: Hesselbach, J., Herrmann, C. (eds.) Functional Thinking for Value Creation. Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, pp. 63–68. Springer, Berlin (2011)
18. Müller, P., Stark, R.: A generic PSS development process model based on theory and an empirical study. In: Andreasen, M.M. (ed.) 11th International Design Conference - Design 2010, Dubrovnik, Croatia, May 17-20, vol. 1, pp. 361–370. Zagreb (2010)
19. Uhlmann, E., Bochnig, H., Stelzer, C.: Characterization of Customer Requirements in IPS^2 creation. In: Sakao, T. (ed.) Proceedings of the 2nd CIRP IPS^2 Conference on Industrial Product-Service Systems (IPS^2), Linköping, pp. 399–405 (2010)
20. Sadek Hassanein, T.: Ein modellorientierter Ansatz zur Konzeptentwicklung industrieller Produkt-Service Systeme. Shaker, Aachen (2009)

21. Rese, M., Meier, H., Gesing, J., Boßlau, M.: HLB-Geschäftsmodelle: Partialmodellierung zur Systematisierung von Geschäftsmodellen "Hybrider Leistungsbündel" (HLB). wt Werkstattstechnik Online Jahrgang 101(7/8), 498–504 (2011)
22. Tukker, A., Tischner, U. (eds.): New Business for Old Europe: Product-service development, competitiveness and sustainability. Greenleaf, Sheffield (2006)
23. West, M.: Developing High Quality Data Models. Elsevier Science & Technology (2010)
24. Olivé, A.: Conceptual Modeling of Information Systems. Springer, Berlin (2007)

A Computational Support for Abduction in Product-Service Systems Design

Hitoshi Komoto, Shinsuke Kondoh, and Keijiro Masui

Advanced Manufacturing Research Institute, National Institute of Advanced Industrial Science and Technology, Namiki 1-2-1, Tsukuba, Ibaraki, 305-8564, Japan
{h.komoto,kondou-shinsuke,k-masui}@aist.go.jp

Abstract. Design of services at the use stage of products is crucial for the manufacturing industry to increase value delivery to product users through the life cycle. The paper proposes an approach to computational hypothesis formation regarding these services to meet given goals and quality criteria as specifications. The hypothesis formation procedure, which consists of analysis, suggestion, and transformation of service-related business models, represents the reasoning of designers by abduction, and implemented on a service CAD tool. The representation of a business model suitable to support the procedure is proposed and it is compared with related work about service modeling.

Keywords: service modeling, abduction, computer-aided design.

1 Introduction

Study of Product Service Systems (PSS) is concerned with design, analysis and implementation of business models from various (e.g., economic, environmental, and socio-cultural) perspectives. In the manufacturing industry, such business models are designed considering services offered during life cycle of a product (e.g., monitoring, repair, upgrading services, and consumable supplies) as well as reconfiguration of the product adapted to the services [2]. Some of the services maintain and enhance the functions of a product during the entire life span, while others deliver a variety of contents (e.g., information) to the users of a product, which is regarded as a channel of the service delivery.

Abduction [3] is a form of reasoning, by which new knowledge is hypothesized for the explanation of an observed fact. In natural science, scientists hypothesize a physical rule by abduction for the explanation of an observed behavior (e.g., gravity to explain free fall of objects on the earth). Past literature argued the role of abduction in design [4] and methods and tools to support design by means of abduction. For instance, Takeda et al. [5] formalized abduction in design. Shimomura et al. [6] reported an abduction-based design method for service design. As reported in the past literature, abduction in design is meant to hypothesize structural and behavioral concepts, which will be realized so as to meet specific functional and technical requirements. Therefore, the capability to support designers to hypothesize such concepts is regarded as a crucial function of methods and tools supporting abduction in design.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 535–546.
DOI: 10.1007/978-3-642-30820-8_45

The paper presents an approach to hypothesis formation performed at the design of a manufacturers' business model related to the use stage of a product. The goals of the presented approach are to (i) formalize a procedure for a designer to hypothesize the concepts of services related to a product that are suitable to the given requirements specified by an user of the product and (ii) propose a computational tool to support the procedure using the knowledge about products and services, which is separately defined and collected by the users and manufacturers of other products. By achieving these goals, the designer of such a business model can systematically search and find services that potentially enhance the value of the product used in the business model, as he¥she does in product design [7], and identify the characteristics of the product suitable to the services.

The rest of the paper is structured as follows. In Section 2, the paper briefly reviews the study of service and business modeling methods and computational tools accompanied with the methods. Section 3 proposes an approach to hypothesis formation, and the business model representation to support the approach. Section 4 reports a computational tool, which supports for the design of manufacturers' business models followed by the presented approach. Section 5 summarizes the paper.

2 Related Work

2.1 Service and Business Modeling Methods

Study of PSS for the manufacturing industry has proposed a number of methods to describe manufacturers' business models. They consist of products, services, and their interrelations. The previous conference proceeding [8] included some of the methods (e.g., [6, 9-13]). They are useful for various purposes, such as the organization of design knowledge, sharing of the knowledge among designers, and the development of design support tools.

The abovementioned methods are mainly based on the study of service modeling, because services are regarded as crucial elements of manufacturers' business models. Service models have been studied by researchers in the field of marketing [14, 15], operational management [16], service research [17], and service engineering [18-20]. These models are common in that services are regarded as activities or processes, while they are different one another mainly in terms of the types of related concepts expressed with services.

The representation of a business model presented in the paper is an extension of the service model proposed in the field of service engineering [18-20]. It defines service as an activity to deliver service content from a service receiver to a service provider with a service channel. It is chosen in this study due to the following reasons. First, it represents not only a business model but also its specifications, which is suitable to the qualitative evaluation of a business model and the hypothesis formation regarding services and relevant concepts with reference to given specifications (see Section 3). Second, it represents the details of service contents, channels, receivers, and providers included in a business model in terms of their parameters, which is useful to characterize each of these service elements. Third, it has been employed by tools to computationally support the design of service and business models (e.g., [6, 20, 21]).

2.2 Computational Tools

In parallel with the study of service and business modeling methods, tools to support the design of service and business models has been studied. Functions of these tools are various, including visualization, checklist-based evaluation [22], simulation-based evaluation [21], analysis of relations among actors (e.g.., service providers and receivers) [23], analysis of relation among their parameters [20]. Although a number of tools support the analysis and evaluation of service and business models, few tools support the design of these models.

As described earlier, abduction (or hypothesis formation) is a crucial reasoning in design. The paper proposes a formal procedure to computationally support the introduction of services in the life cycle of a product as hypotheses to meet the given specifications, while refining the characteristics of the product. The procedure is different from the abduction-based creative design procedure implemented in the Service CAD system [6]. The proposed approach is based on the search of new knowledge about products and services that meets the given unsatisfied specifications (see Section 3), while the Service CAD system searches new knowledge about products and services that are similar to existing ones by means of analogy. Both systems are similar in that they can utilize the knowledge about products and services defined in different domains (e.g., industrial sectors).

3 Formalization

This section formalizes a procedure of hypothesis formation in context of the design of a business model employed at the use stage of a product as well as the representation of such a business model suitable for the hypothesis formulation.

3.1 A Business Model

Fig. 1 shows the proposed representation of a business model, which is considered suitable to the hypothesis formation (see Section 1). A business model is defined by concept nodes and their relations (i.e., a network of concept nodes), which qualitatively characterizes the business. Each concept node belongs to the specification domain (e.g., WHAT to realize in the business) and the realization domain (HOW to realize the business). These domains appear in product models used for conceptual design (e.g., [24]), in which the specification domain is described in terms of the functions of a product, while the state, structure, and behavior (i.e., embodiment) realizing the functions are the part of a product model in the realization domain (Fig. 1 (a)). The specification domain of the presented model consists of the goal domain and quality domain, while the realization domain consists of activity domain and environment domain (Fig. 1 (b)). Thus, an instance of the proposed model consists of nodes belonging to these domains and their relations (Fig. 1 (c)).

Difference between the product model for conceptual (product) design and the proposed model for business model design is the treatment of dynamic property. In product design, the behavior of a product is often predictable by physical rule-based analysis and simulation techniques. Thus, a prediction with such techniques used in product design can approximate the actual behavior of a product. In contrast, a business model designer has difficulty in explaining the behavior (activity) of a product user by physical rules. Thus, he/she needs to explicitly define the behavior as well as decision makings regarding the behavior.

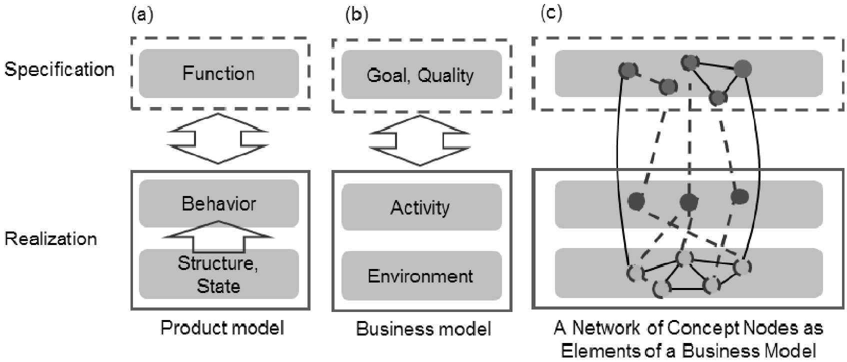


Fig. 1. The proposed representation of a business model for hypothesis formation

Fig. 2 shows the detail of Fig. 1 (c). Nodes constituting a business model, which belonging to the aforementioned domains are classified into six node types: goal, quality, activity, condition, element, parameter node types. In Table 1, the interpretation of eight relations among the nodes appeared in Fig. 2 is shown. The detail of the node types and relations is described in the next paragraph.

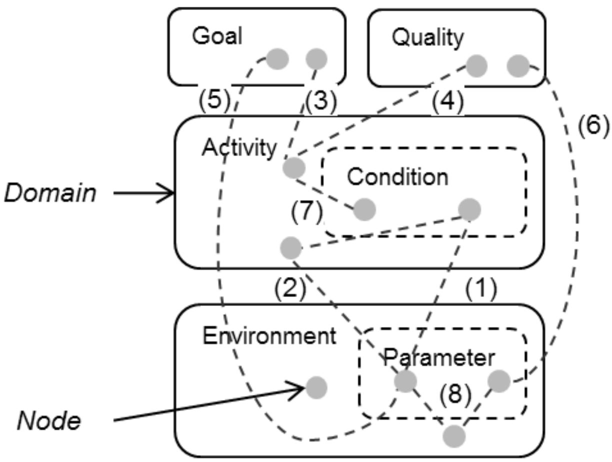


Fig. 2. Relations between nodes in the proposed representation

Table 1. Interpretation of relations between nodes

Index	Connected node types	Explanation
1	Condition Parameter	The relation indicates that an execution *condition* of an activity is defined by the value of a *parameter*.
2	Activity Parameter	The relation indicates that the execution of an *activity* causes the value change (state transition) of a *parameter*.
3	Activity Goal	The relation indicates that the execution of an *activity* results in the realization of a *goal*.
4	Activity Quality	The relation indicates that a *quality* criterion is measured at the execution of an *activity*.
5	Goal Parameter	The relation indicates that the realization of a *goal* is evaluated by the value change of a *parameter*.
6	Quality Parameter	The relation indicates that a *quality* criterion is measured in terms of the value of a *parameter*.
7	Element Parameter	The relation indicates that an *element* in the environment domain has a *parameter*.
8	Activity Condition	The relation indicates that an *activity* has an execution *condition*.

Environment. In design of a business model, a numbers of stakeholders and service channels are considered. The proposed representation treats these stakeholders and service channels as element nodes in the environment domain (or service environment [19]). Each element node has parameter nodes (Fig. 2 (7)) The execution condition of an activity node is defined by connected condition nodes (Fig. 2 (8)), which are connected with parameter nodes (Fig. 2 (1)). The state change of an element node is caused as a result of the execution of an activity node (Fig. 2 (2)). Furthermore, it defines the realization of a goal specified by a relation between an activity node and a goal node (Fig. 2 (5)). The parameters of stakeholders and service channels are related to the quality criteria specified by a set of relations between a parameter node and a quality node. The relations partly represent the parameter network including quality, service receiver parameters, service channel parameters, service content parameters [19].

Service Element Classification. Element nodes in the environment domain can be classified into service providers, service receivers, service channels, and service contents. They are not mutually exclusive. For instance, an intermediate agent has double characteristics of a service receiver and a service provider [19]. A car is considered as service content, when the ownership of the car is delivered. The same car is regarded as a service channel, when a taxi driver uses the car, which delivers mobility to customers of the driver. (In this example, mobility is the content of the service.) The multiple roles of stakeholders and service channels cause difficulty for designers to classify them into service elements in service environment. For this reason, the computational support introduced in the paper does not use such classification.

Goal and Quality. A goal (represented by a goal node) is realized by service or by state transitions of receivers [18]. This indicates that a goal node has relations with either a service (represented by an activity node) (Fig. 2 (3)) or a parameter node in the environment domain (Fig. 2 (5)). A quality criterion (represented by a quality node) is evaluated in terms of the parameters of channels and contents [6]. This indicates the necessity to describe the parameters of elements in environment (Fig. 2 (6)). State transition of environment may cause the change of quality. Thus, the timing of quality evaluation should be explicitly defined in the PSS conceptual model. The timing is defied by relation between an activity node and a quality node (Fig. 2 (4)). All goal nodes and quality nodes belong to the specification domain.

Activity. An activity is defined by its execution conditions and execution results. The execution conditions are represented by the relations between an activity node and a condition node (Fig. 2 (8)). The execution results are represented by relations between an activity node and a parameter node (Fig. 2 (2)), a goal node (Fig. 2 (3)), and a quality node (Fig. 2 (4)), which are interpreted as state transition, goal realization, quality evaluation, respectively. Finally, a service is represented by an activity node, which is included in specific patterns made of a set of the node relations. These patterns are shown in Fig. 3. The detail is described in the next subsection.

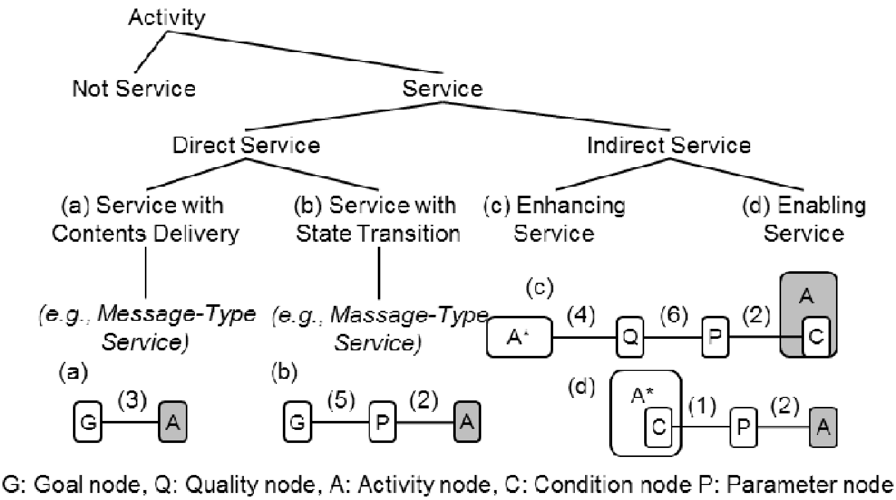


Fig. 3. Classification of an activity node

3.2 Classification of Activity

The proposed representation of a business model shown in Section 3.1 helps classify an activity into (1) a service with contents delivery, (2) a service with state transition, (3) an enhancing service, and (4) an enabling service. In Fig. 3 (a-d), the patterns to define each service class are shown. The colored nodes with label A are activity nodes regarded as services.

Service with Contents Delivery (Fig. 3 (a)). When an activity node is directly related to a goal node, it is regarded as a service to deliver contents to realize the goal represented by the connected goal node (Fig. 2 (3)). The class is used to define a service, whose influence on the state of service environment is unknown or unobservable. Thus, the description of services belonging to the class does not provide knowledge concerning the parameters of elements in environment. Examples of services belonging to this class are functional sales service (delivery of function) and message-type service (delivery of information) [19], if the consequences of these services are not explicitly defined in terms of the state of elements of environment. If so, these services are regarded as services with state transition, which is explained below.

Service with State Transition (Fig. 3 (b)). A service classified in the category is recognized in terms of state transition of environment. Therefore, there is no direct connection between an activity node and a goal node. Instead, they are connected through a parameter node. The same service can be described with both (1) service with contents delivery and (2) service with state transition. For instance, transportation service can be described as "service to deliver mobility (as service content)" and as "service to change the geographical state of passengers". When designers select the former service class, they emphasize the delivery of service contents. Otherwise, they choose the latter service class so that they can explain service in terms of state transition of environment.

Enhancing Service (Fig. 3 (c)). An enhancing service is defined by an activity node related to the parameter node (Fig. 2 (1)) related to a quality node (Fig. 2 (6)) related to an activity node (Fig. 2 (4)). For example, the comfort of tourists during stay at a hotel room can be enhanced by providing room cleaning service during the entire stay, assuming the comfort is associated with the cleanness as a parameter of the hotel room. In the example, the room cleaning service is labeled A, the cleanness of the room is P, the comfort of tourists is Q, and the stay is regarded as activity evaluating the quality A*, respectively.

Enabling Service (Fig. 3 (d)). An enabling service changes the parameter value of elements in environment (Fig. 2 (2)). The parameter is related to a condition node of an activity node (Fig. 2 (1)), which is regarded as one of the abovementioned service classes. In Fig. 3 (d), the activity node regarded as an enabling service is A, while the enabled activity node belonging to the other service classes is A*. For example, tourists to do scuba diving in a small island, they may need to rent scuba gears. They may also need to get license to do so at school. Renting scuba gears and receive education themselves do not provide experience in deep sea. However, they are necessary to have the experience. In the example, scuba diving is the service delivering experience as service content, while other activities are services enabling the service.

3.3 Analysis, Suggestion, and Transformation of PSS Design Knowledge

This subsection describes three types of supports for the design of a business model based on the presented representation. First, the representation provides logics to analyze a business model under development. Second, business models built in advance is selected to complement a business model under development. Third, the selected business model is transformed so that it fits to the context of the business model under development. These supports, as a whole, are regarded as an integrated support realizing abduction or hypothesis formulation on a business model under development.

Analysis. First, in the analysis, concept nodes shown in Table 2 are regarded as incomplete nodes due to lack of relations to other concept nodes. The relations in Table 2 are indexed following Table 1. Goal nodes in a business model that are related to activity nodes or parameter nodes included in the service with state transition class are *unrealized*. Quality nodes that are not related to any parameter node are *immeasurable*. Quality nodes that are not evaluated by any activity node are *unevaluated*. Parameter nodes, which are not connected with any concept node, are *unjustified*. Thus, the removal of all unjustified parameter nodes does not influence the interpretation of the current case.

Table 2. Description of incomplete concept nodes and missing relations

Concept type	Missing relations	Interpretation
Goal	(3) or (5)	Unrealized goal
Quality	(6)	Immeasurable quality
Quality	(4)	Unevaluated quality
Parameter	(1) or (2) or (5) or (6)	Unjustified parameter

Suggestion. After the analysis of all concept nodes defined a business model, incomplete nodes and missing relations are identified. After that, concept nodes and their relations to be added to the business model is suggested. The added nodes and relations are derived from other business models, which potentially connect the concept nodes in the business model. The suggestion procedure starts with selection of a concept node in the business model. The selected concept node is usually one of such insufficient nodes as unrealized goal, immeasurable quality, unevaluated quality, or unjustified parameter nodes. Then, other business models, which consist of a couple of a concept node and its relation, which replaces the missing relation in the business model, are regarded as candidate parts added to the business model.

Transformation. One of the suggested business models is adapted to the business model under development. However, the knowledge about the suggested business model is not directly adaptable. To do so, the binding between the conceptual nodes in the business model under development and the suggested business model is necessary. As a result of the binding, each concept node of the suggested business model becomes either one of the existing concept node in the business model underdevelopment or an independent node, which is newly added to the business model.

4 A Design Tool

This section shows a tool equipped with the formalization described in the previous section. The tool is based on Service CAD integrated with life cycle simulation [21]. The PSS conceptual model described in the paper is based on the model studied in the previous work [25]. In comparison with the previous work, this paper employs a simplified model described by an undirected graph. Therefore, the support in the paper is performed considering the relations between concept nodes but not the labeling and direction of the relation. Furthermore, the paper employs the classification of activity in order to develop the support.

Fig. 4 shows the screens dump of the tool, which mainly consists of the modeling pane to describe a business model, the browsing pane to look other stored business models, and the hierarchy of concepts to support binding between the business model under development and other stored business models. The concept hierarchy is used for the suggestion and transformation procedures.

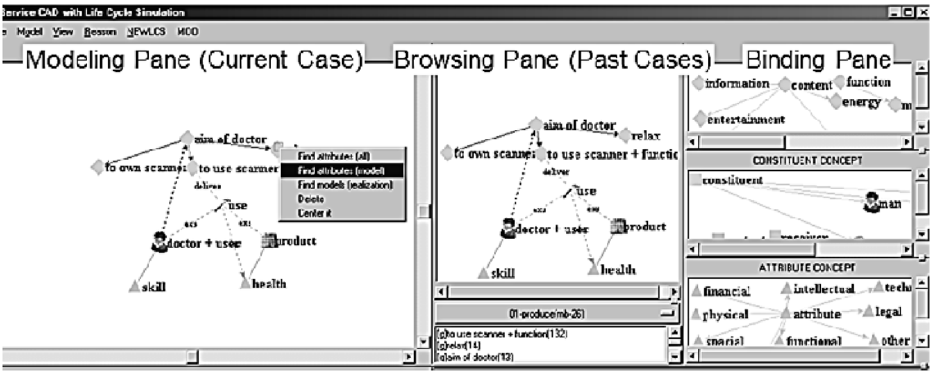


Fig. 4. The screen dump of the tool

Fig. 5 briefly shows an example of the support implemented on the tool. The example is captured at a business model at the use of a medical instrument. First, the business model is analyzed. Fig. 5 (a) shows a goal node "to use scanner", which is not related to parameter nodes and activity nodes (i.e., no relation (3) or relation (5) in Table 1). Thus, the node is regarded as an unrealized goal node (see Table 2). Second, other business models stored on the tool are suggested so that they complement the missing relations. Fig. 5 (b) shows the list of the suggested business models, which include the relation (3) and relation (5). Then, the designer selects one of the suggested business models. Third, possible bindings between the concept nodes in the business model and those in the selected business model are generated (i.e., transformation). In the example, among the suggested business models, the business model that includes an activity node "use" is selected (Fig. 5 (c)). Fig. 5 (c) shows that an element node "product" in the selected business model is added to the business model under development. Fig. 5 (d) shows that an element node "user" in the selected model is regarded as an element node "doctor" in the model under development. Furthermore, the goal node in the current case "to use scanner" and the goal node "function" in the selected model is connected. Finally, Fig. 5 (e) shows the result of the addition of the selected business model to the business model under development, where the concept node with underline belong to the business model under development.

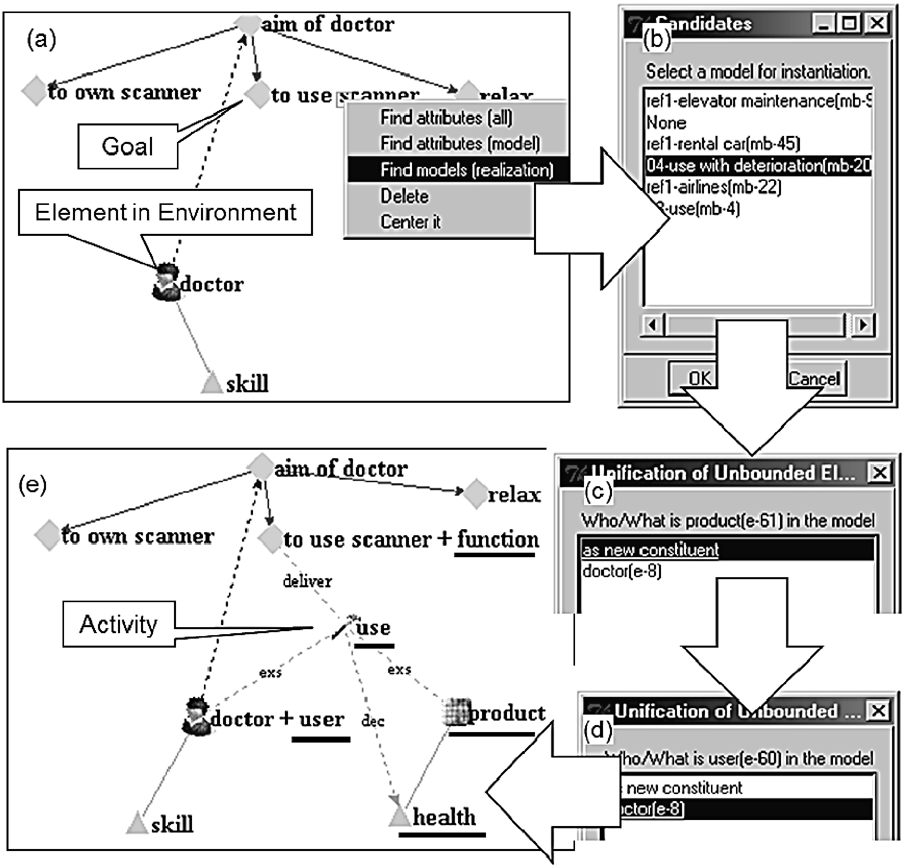


Fig. 5. The proposed support implemented in the tool

5 Summary

Design of services at the use stage of products is crucial for the manufacturing industry to increase value delivery to product users through the life cycle. The paper has proposed an approach to the formation of hypothesis regarding services and related service elements such as service providers and channels, which meets such given specifications as goals and quality criteria. The formation procedure, which consists of analysis, suggestion, transformation of a business model, has been designed so as to represent the reasoning performed by the designer of a manufacturers' business model by means of abduction, which hypothesize missing elements of a business model to be found in the realization domain in order to satisfy the elements defined in the specification domain. The paper has shown a tool to support these procedures.

For the representation of a business model suitable to the support has been proposed, which is based on the service modeling studied in the field of service engineering. As a result of the development of the support and its implementation, it was found that the representation was also useful to classify activities in a business model in relation to other concept nodes in the business model.

Acknowledgment. The research in this paper has been partly conducted at Delft University of Technology, Delft, The Netherlands. The authors acknowledge Prof. Dr. T. Tomiyama and Prof. Dr. J. C. Brezet for giving comments and advices about the study.

References

1. Tukker, A., Tischner, U.: New Business for Old Europe. Gleenleaf Publishing, Sheffield (2006)
2. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems — IPS2. CIRP Annals - Manufacturing Technology 59(2), 607–627 (2010)
3. Peirce, C.S.: In: Hartshorne, C., Weiss, P. (eds.) Collected Papers of Charles Sandars Pierce, pp. 1–6. Harvard University Press (1958)
4. Yoshikawa, H.: Design Philosophy: The State of the Art. Annals of the CIRP 38(2), 579–586 (1989)
5. Takeda, H., Sasaki, H., Nomaguchi, Y., Yoshioka, M., Shimomura, Y., Tomiyama, T.: Universal Abduction Studio — Proposal of a Design Support Environment for Creative Thinking in Design. In: Proceedings of 14th International Conference on Engineering Design, ICED 2003, Paper No. 1504 (2003)
6. Shimomura, Y., Watanabe, K., Akasaka, F., Kimita, K.: Fun Out of Japanese Service Engineering – the State of the Art. In: [8], pp. 15–20 (2011)
7. Pahl, G., Beitz, W.: Engineering Design: A Systematic Approach, 2nd edn. Springer, London (1996)
8. Jürgen, H., Herrmann, C. (eds.): Functional Thinking for Value Creation, the Proceedings of 3rd CIRP International Conference on Industrial Product Service Systems, May 5-6. Technische Universität Braunschweig, Braunschweig (2011)
9. Vladimirova, D., Evans, S., Martinez, V., Kingston, J.: Elements of Change in the Transformation towards Product Service Systems. In: [8], pp. 21–26 (2011)
10. Isaksson, O., Larsson, T.C., Johansson, P.: Towards a Framework for developing Product/Service Systems. In: [8], pp. 44–49 (2011)
11. Chen, J.L., Huang, S.C.: Eco-Innovative Design of Product Service Systems by using the Substance-Field Analysis Method. In: [8], pp. 63–68 (2011)
12. Sadek, T., Koester, M.: Analyzing the Practical Usability of the Heterogeneous Modeling Approach for Conceptual Product-Service System Development. In: [8], pp. 135–140 (2011)

13. Annamalai, G., Hussain, R., Cakkol, M., Roy, R., Evans, S., Tiwari, A.: An Ontology for Product-Service Systems. In: Xu, Y. (ed.) Decision Engineering Report Series, pp. 978–971. Cranfield University (2010) ISBN number 978-1-907413-08-7
14. Alonso-Rasgado, M.T., Thompson, G., Dannemark, O.J.: State of the art in service design and modelling. VIVACE Consortium Monograph (2004)
15. Shostack, G.L.: How to Design a Service. European Journal of Marketing 16(1), 49–63 (1981)
16. Hill, A.V., Collier, D.A., Froehle, C.M., Goodale, J.C., Metters, R.D., Verma, R.: Research opportunities in service process design. Journal of Operations Management 20, 189–202 (2002)
17. Iacobucci, D., Grisaffe, D., Duhachek, A., Marcati, A.: FAC-SEM: A Methodology for Modelling Factorial Structural Equations Models, Applied to Cross-Cultural and Cross-Industry Drivers of Customer Evaluations. Journals of Service Research 6(1), 3–23 (2003)
18. Tomiyama, T., Shimomura, Y., Watanabe, K.: A Note on Service Design Methodology. In: Proceedings of the 16th International Conference on Design Theory and Methodology, DETC2004-57393 (2004)
19. Sakao, T., Shimomura, Y.: Service Engineering: a Novel Engineering Discipline for Producers to Increase Value Combining Service and Product. J. Clean. Prod. 15, 590–604 (2007)
20. Arai, T., Shimomura, Y.: Service CAD System - Evaluation and Quantification. Annals of the CIRP 54(1), 463–466 (2005)
21. Komoto, H., Tomiyama, T.: Integration of a Service CAD and a Life Cycle Simulator. Annals of the CIRP 57(1), 9–12 (2008)
22. UNEP: Product-Service Systems and Sustainability: Opportunity for sustainable solutions (2002), http://www.unep.fr/pc/sustain/reports/pss/pss-imp-7.pdf
23. Morelli, N.: Developing new product service systems (PSS): methodologies and operational tools. J. Clean. Prod. 14(17), 1496–1501 (2006)
24. Umeda, Y., Ishii, M., Yoshioka, M., Shimomura, Y., Tomiyama, T.: Supporting conceptual design based on the function-behavior-state modeler. Artificial Intelligence for Engineering Design, Analysis and Manufacturing 10(4), 275–288 (1996)
25. Komoto, H., Tomiyama, T.: Systematic Generation of PSS Concepts Using a Service CAD Tool. In: Sakao, T., Lindahl, M. (eds.) Introduction of Product/Service-System Design, pp. 71–91. Springer, Berlin (2010)

Computer-Aided Service Design for the Development of Product-Service Systems – Motivation and Benefits

Katja Laurischkat

Department of Mechanical Engineering, Ruhr-Universität Bochum, Bochum, Germany
katja.laurischkat@rub.de

Abstract. Companies are forced to rethink their product-focused business strategies due to technological equivalence and a severe price competition. Product-Service Systems (PSS) allow for long-term customer loyalty and an increase in profit margins. The systematic development of PSS is essential in order to tap their full potential. However, the integration of heterogeneous components during the PSS-development still poses a major challenge. It necessitates the integration of heterogeneous information held by actors with very different professional backgrounds. Especially the systematic consolidation, archiving and reuse of heterogeneous service information during the PSS-concept development represent a considerable gap in research. Furthermore, the modeling of remote-supported and automated services during the domain-specific detailing of PSS has not been sufficiently researched yet. Hence, this paper presents a novel approach, referred to as Computer-aided Service Design (CASD), used to systematically integrate heterogeneous service information into a PSS's concept development and to model manual, but also remote-supported and automated services.

Keywords: Product-Service System, Computer-aided Service Design, Service.

1 Introduction

1.1 The Necessity of Product-Service Systems (PSS)

Product-centric business strategies have to be reconsidered by today's companies due to technological equivalence, decreasing profit margins and a severe price competition caused by the increasing international rivalry. This is attended by an increasing customer demand for greater company support and reliability during an entire product life cycle [1] [2]. Many companies answer to this request by offering services, mostly in the area of maintenance. But, due to short-term strategies, they often fail to turn this into an economic success [3] [4] [5].

Product-Service Systems (PSS) constitute a change in paradigm. Such lifecycle-oriented problem solutions ask for value-oriented business strategies instead of pure product- or service-offers. Thereby, PSS not only allow for a constant distinction of competitors and long-term customer loyalty, but for the increase in profit margins. Moreover, many authors connect PSS to the reduction of environmental impact [6] [7]

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 547–560.
DOI: 10.1007/978-3-642-30820-8_46

[8]. Although the conceptual composition of the term PSS indicates a system only consisting of products and services depending on the respective offer, a value proposition is put into action with the aid of physical artifacts and/or software and/or processes and services as well as by a network of different stakeholders. While the ratio of products, software and processes can vary relative to the value proposition that is to be put into practice, a certain amount of services is indispensable [9].

1.2 The Development of PSS

The systematic development of PSS has a substantial influence on their economic and ecological success [10]. On an abstract level, the development of PSS can be subdivided into two main phases: a PSS's concept development (phase 1) and its domain-specific detailing (phase 2). During an early stage of the PSS-development, referred to as PSS-concept development, the aim is to create an abstract idea of how a value proposition can be put into practice. Therefore, different components, like products, software and services are integrated, but without detailing each component. This phase can result in either one or several PSS-concepts. A PSS-concept or rather its components are developed separately during the domain-specific detailing of a PSS. An interdisciplinary team uses domain-specific development methods and tools during this phase. A superior requirement management continuously guarantees the consistent integration and detailing of all components. Thereby, it is ensured that (inter)dependencies between heterogeneous components are constantly considered during the entire PSS-development [11] [12].

1.3 Heterogeneity during the Development of PSS

The heterogeneity of PSS-components (e.g. products, services, software) leads to an extended complexity during the development of PSS because it necessitates the integration of most diverse information held by actors with very different professional backgrounds. Such complexity is increased by the heterogeneity of the service domain itself. Services vary not only strongly in themselves (e.g. maintenance, training, consulting, recycling, certification, etc.), but also with regard to the multiplicity of products, software or persons they are assigned to.

The selection of actors necessary to develop PSS is a major challenge. During a PSS's concept development, different professional knowledge is essential in order to create innovative, value-oriented PSS-concepts. However, the heterogeneity of services highly complicates the precise location of service know-how within a company. Depending on the respective service, actors from different divisions and hierarchical levels may possess the required service information. This influences the domain-specific detailing of services as well. For instance, the detailing of maintenance similarly requires the know-how of the design engineer's as well as the practical knowledge of the involved service technicians. Hence, very different professional expertise is needed, depending on the respective service. This applies to manual, remote-supported and automated services. These coherences are illustrated in figure 1.

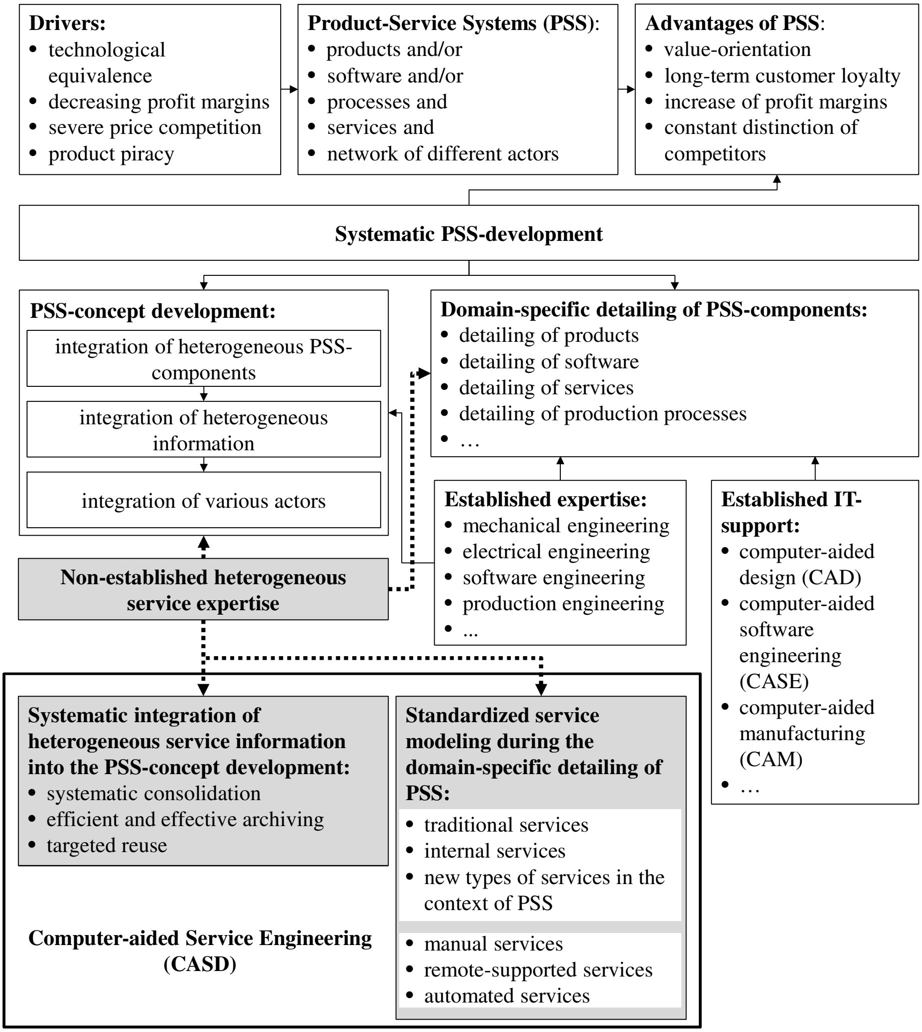


Fig. 1. Motivation for Computer-aided Service Engineering (CASD)

To put it concisely, the descriptions above are summarized as follows: The development of PSS requires the integration of heterogeneous information held by various actors. Services are an indispensable part of PSS (s. chapter 1.1). Hence, the systematic integration of service know-how into the PSS-concept development significantly contributes to the targeted development of value-oriented and innovative PSS. However, especially the systematic consolidation, archiving and reuse of heterogeneous service information during a PSS's concept development present themselves as a major gap in research. Furthermore, the standardized modeling of manual, remote-supported and automated services is required during a PSS's domain-specific detailing, but has not been sufficiently researched [9].

1.4 Computer-Aided Service Engineering (CASD) – A Novel Approach

This paper presents a novel approach, referred to as Computer-aided Service Design (CASD), which closes the aforementioned research gaps. CASD offers interactive user assistance during the entire development of a PSS, plausibility checks with regard to service contents as well as a reduction of development time and costs. Required service knowledge is automatically generated during a PSS's concept development based on a complex system of rules. Heterogeneous service information are systematically consolidated and archived with the aid of CASD. Furthermore, the standardized modeling of manual and for the first time also remote-supported and automated services is made allowance for during a PSS's domain-specific detailing. In addition, service times and costs are calculated automatically based on a specific service process design.

Consecutively, a description of CASD and its benefits is presented. Prior to this, the concept service is redefined, since it changes in the context of PSS. Thereby, the aim is to specify services as "design objects" which are generated and modeled with the aid of CASD.

2 Rethinking the Concept Service in the Context of PSS

PSS represent value-oriented business strategies and therefore no longer gear towards the selling of products. In the same way the role of products has changed in the context of PSS, the existing understanding of services has to be questioned as well. As part of a detailed analysis which considers both theory and case examples it has been investigated, whether the established definition of the concept service can be equally used in the context of PSS or whether a revised form is required. The results of this analysis are presented in chapter 2.2. Prior to this, the definition of the concept service, as it is currently known in literature, is introduced in chapter 2.1. Due to its complexity, the analysis itself is not further detailed in this paper, but can be looked up in [9].

2.1 Traditional and Internal Services

In service research, a standardized definition of the term service does not exist. Nonetheless, the majority of authors explain services with the aid of three dimensions or the three constitutive characteristics which result from these. With regard to the "capability dimension" a service is explained as the ability and willingness of a provider to render the service in question. Such ability is considered intangible. Therefore, the first constitutive characteristic used to define a service is "intangibility" [13].

With reference to the "process dimension" a service is characterized by its simultaneous consumption and production as well as by the integration of so called external factors. Examples for such factors are the customer's personnel, goods, rights or information. In this regard, the term "external" points out that a service's provider is never part of its customer's company. Hence, the second and third constitutive characteristics, referred to as "uno-actu-principle" and "integration of external factors", result from the process dimension [13].

The definition of the notion service which follows from the "result dimension" is the most discussed one. While some authors argue that a service results in tangible and intangible outputs, others persist that a service has intangible output only. In the following, a service's output is considered solely intangible. For example, the output of a machine's repair is the machine's restored operativeness. Tangible parts such as spare parts are considered to be technical resources during a service's provision rather than a tangible output. This means that the first constitutive characteristic can also be derived from the result dimension [13] [14]. Consequently, processes which comply with the previously explained three constitutive characteristics are subsequently called traditional services.

In opposition to traditional services where a provider and its customer are never part of one company, the receiver of an internal service is part of the company who offers and provides the service in question. Hence, an internal service is not demanded by an external customer, but by the provider's personnel themselves. Furthermore, an internal service is rendered only within the provider's company or rather its property. From this follows that internal services can be equally defined by the first and second constitutive characteristics but do not integrate external factors [15].

2.2 New Services in the Context of PSS

Three new types of services have been defined in the context of PSS in addition to traditional and internal services. They result from the previously mentioned analysis of the concept service. An analysis of the capability dimension and result dimension of traditional, internal and new services has proved that the previously established definition of such dimensions can be equally applied (see chapter 2.1). The constitutive characteristic "intangibility" similarly applies to traditional, internal and new services.

Hence, the defined new services differ from traditional and internal services in terms of their process dimension. While the uno-actu-principle applies to new services as well, the combination of the process-related characteristics "receiver of a service", "allocation of resources and responsibility" and "location of a service's provision" clearly points out the differences between traditional, internal services and new services. Table 1 compares traditional services (type 1.1 to type 1.4), internal services (type 2.1 to type 2.2) and new services (type 3 to 5 type) based on the previously stated characteristics. Each line represents one specific type of service.

Table 1. Traditional, internal and new services in the context of PSS [9]

Service Type	Receiver of a service's provision		Allocation of resources and responsibility during a service's provision				Location of a service's provision	
			responsibility		resources			
	P	C	P	C	P	C	P	C
Type 1	**Traditional services**							
1.1	no	yes	yes	no	yes	no	yes	no
1.2	no	yes	yes	no	yes	no	no	yes
1.3	no	yes	yes	no	yes	yes	yes	no
1.4	no	yes	yes	no	yes	yes	no	yes
Type 2	**Internal Services**							
2.1	yes	no	yes	no	yes	no	yes	no
2.2	no	yes	no	yes	no	yes	no	yes
	New Services							
Type 3	yes	no	yes	no	yes	no	no	yes
Type 4	yes	no	yes	no	yes	yes	no	yes
Type 5	no	yes	no	yes	yes	yes	no	yes

P=provider of a PSS, C=customer of a PSS.

Service type 3 does not integrate external factors. Hence, it cannot be considered to be a traditional service. The provider of service type 3 is at the same time its receiver. Yet, service type 3 is not rendered at a PSS-provider's location, but at its customer's property. As a result, service type 3 cannot be defined as an internal service.

Equally to service type 3, service type 4 is rendered at a PSS-customer's location, but, in opposition to type 3, external factors are integrated. But, although service type 4 integrates external factors, it cannot be labeled a traditional service, because the PSS-provider is at the time the receiver of the service.

The provider and receiver of service type 5 is the customer of a PSS. Type 5 is rendered at a PSS-customer's location. Moreover, the PSS-customer bears full responsibility for the service's successful provision. Yet, resources of the PSS-provider are integrated into the provision of type 5. Hence, service type 5 cannot be considered as a traditional or an internal service.

In the following, the definition of new services is exemplified. The respective examples are presented in table 2. Each new service is related to a particular business's strategies which is derived from the descriptions of [16]. Each of these strategies can occur in the context of PSS. Especially example 3 points out that although in the context of PSS the focus is no longer on the sale of products, customers still may request it.

Table 2. Examples of new services in the context of PSS

	example 1	**example 2**	**example 3**
business strategy	availability-oriented – "level 2"	result-oriented	availability-oriented – "level 1"
descrip-tion of the business strategy	PSS-provider offers technical availability of "level 2"; the customer only pays for the of-fered availability; the machine tool stays in the own-ership of the PSS-provider	PSS-provider is integrated into the production of the PSS-customer; PSS-customer only pays for the parts which have passed quality inspection and are produced in time	PSS-provider offers technical availability of "level 1"; PSS-customer pays for the machine's installation, implementing, condi-tion monitoring, repair and person-nel instruction; PSS-customer owns the machine tool; PSS-customer uses its own maintenance team for preventive maintenance, but is bounded by contract to rend-er it according to the provider's maintenance instruction; PSS-provider offers remote support for preventive maintenance, if required
service type	type 3	type 4	type 5
service	repair	operation of machine	preventive maintenance
receiver of the service	machine tool is owned by the PSS-provider	machine tool is owned by the PSS-provider	machine tool is owned by the PSS-customer
responsi-bility for service	PSS-provider bears full respon-sibility	operator of the PSS-provider bears full respon-sibility	PSS-customer bears full responsi-bility
allocation of service resources	technical resource, human resources and required in-formation are provided by the PSS-customer	operator is em-ployed by the PSS-provider, manufacturing execution system (MES) is provided by the PSS-customer and made available for the PSS-provider	technical and human resources are provided by the PSS-customer, maintenance instruction and tech-nical equipment for remote-support are provided by the PSS-provider
location of service provision	production of the PSS-customer	production of the PSS-customer	production of the PSS-customer

A revised form of the concept service is necessary and has been introduced in chapter 2 of this paper. Thereby, the "design object" service could be specified for its use within the scope of CASD. In the following, CASD and its use during the development of PSS are introduced.

3 Computer-Aided Service Design (CASD)

3.1 CASD – Research Motivation

A detailed analysis of the service and PSS literature has confirmed that the systematic integration of heterogeneous service information into the concept development of PSS has not been sufficiently researched yet [9] [17]. Existing approaches concentrate on the visualization of services and their influence on the receiver [18] [19] [20] [21] [22] [23] [24] [25]. Some authors particularly focus on the integrated modeling of products and services [21] [26] [27] [28]. However, none of them highlight how heterogeneous service knowledge held by actors with very different expertise can be systematically consolidated, archived and context-sensitively reused during an early stage of the PSS-development [9].

Furthermore, if the visualization of services is focused on, it only addresses the modeling of manual services. However, depending on the respective value proposition that is to be put into practice, the development of manual, but also remote-supported and automated services is equally required during the domain-specific detailing of a PSS [9].

This paper presents a novel approach which closes the aforementioned research gaps. A detailed description of the literature analysis can be looked up in [9]. The structure of CASD is outlined in chapter 3.2. Its use during the PSS-concept development and the domain-specific detailing is presented in chapters 3.3 and 3.4. Based on that, the realized software prototype is introduced in chapter 3.5.

3.2 CASD – Structure

The reuse of heterogeneous service expertise is of particular importance during the concept development of PSS, because it specifically enhances the development of innovative value-oriented PSS-concepts. CASD particularly supports actors from different hierarchical levels and divisions in reusing diverse service information, as CASD context-sensitively generates these (chapter 3.3).

It also offers the modeling of manual, remote-supported and automated services during the domain-specific detailing of PSS (chapter 3.4). Service costs, service time and required resources are automatically generated based on a specific service design. Each modeled service is archived, so that it can be reused and modified in a context-specific way.

In order to enhance the systematic consolidation of heterogeneous service expertise, which is the basis for the context-sensitive generation of diverse service information, a software assistant has been integrated into CASD. It particularly enhances the efficient archiving due to its interactive user assistance.

A so called "service overview" allows for the continuous tracking of service information which have been integrated into a particular PSS-concept. The previously described structure of CASD is illustrated in figure 2.

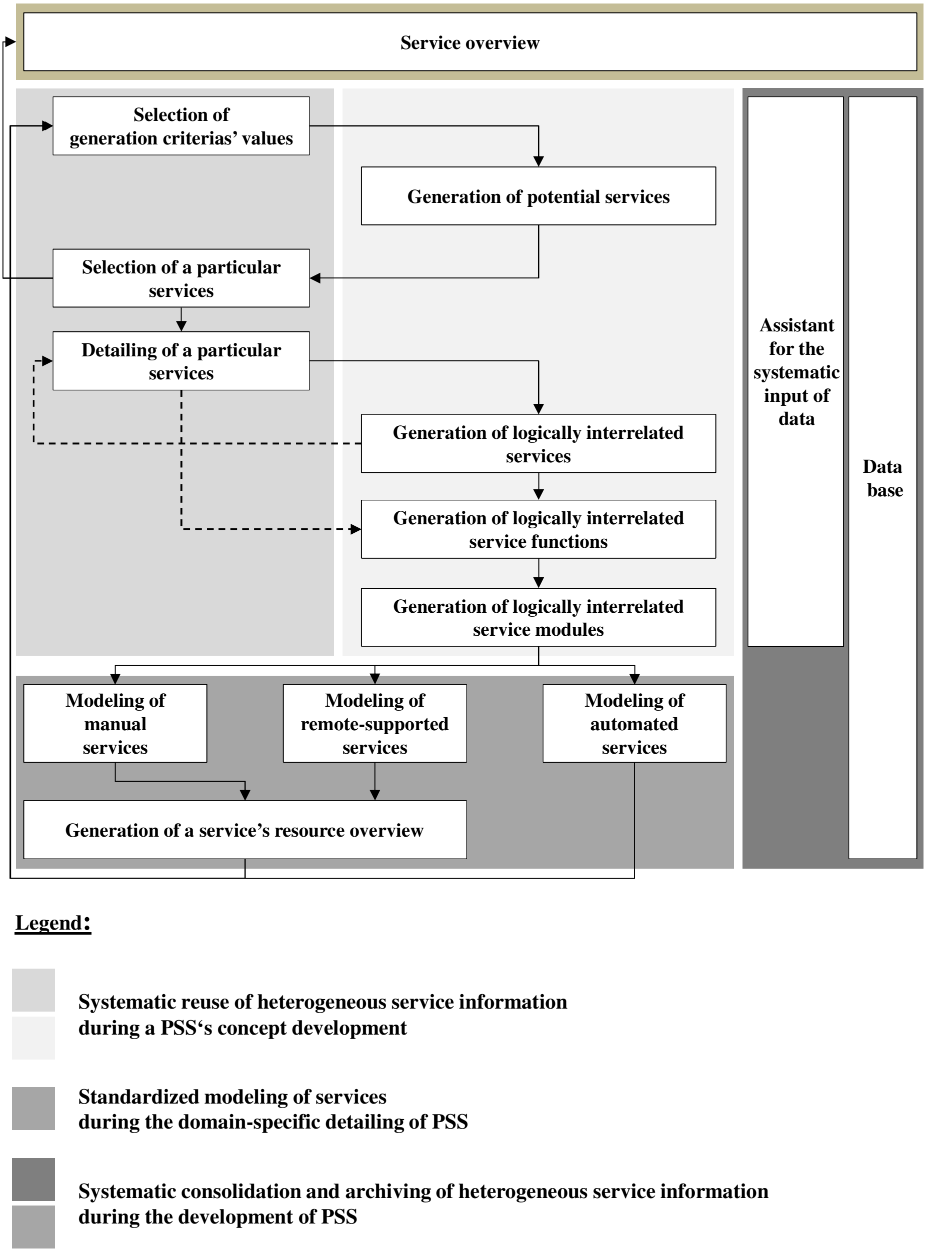


Fig. 2. Overview of Computer-aided Service Design (CASD)

3.3 CASD – Generating Heterogeneous Service Information during the PSS-Concept Development

The PSS-concept development aims at the value-oriented integration of various PSS-elements. Services are essential elements of every PSS-concept. Hence, CASD pursues the following goals:

- the automatic and context-sensitive generation of heterogeneous service information, based on information which is available at an early stage of the PSS-development
- a systematic consolidation and archiving of diverse service information held by actors with different professional backgrounds

The automatic generation is initiated by selecting the following so called generation criteria: the targeted value proposition (1), the life cycle phase in which the service in question is to be rendered (2), the product, process or person the required services relates to (3), the definition of the product's ownership (PSS-provider/PSS-customer) or the assignment of a person/process to the PSS-provider/PSS-customer (4) and the legal obligation of the required service (5).

Based on the selected generation criteria or rather their values, a list of potential services is automatically generated (6). Out of this list, the PSS-developer/team picks a specific service out of that list (7). Now, the selected service is further detailed by: choosing a specific service case out of a list of different case differentiations which are related to the chosen service (8), negating or approving of the remote support of the selected service (9), selecting the level of service automation (manual service, semi-automated or automated service) (10) and assigning the respective responsibility which clarifies whether the PSS-provider or PSS-customer is responsible for the accurate service provision (11).

The consistency of a PSS-concept is enhanced with the aid of CASD significantly. In this regard, CASD automatically generates services which are logically interrelated with the initially selected service (12). Thereby, it is ensured that all services which are dependent on each other are integrated into the respective PSS-concept. A simple example clarifies such interrelations: the repair of a machine tool requires the condition monitoring of the respective machine tool. Otherwise there is no trigger for the repair. In turn, the machine's repairs can be reduced by regular maintenance. Hence, regular maintenance, repair and condition monitoring are logically interrelated and have to be similarly integrated into the respective PSS-concept.

CASD advances the standardization of services during the PSS-concept development, as interrelated service functions are generated automatically. This means that the previously chosen service, which represents the main function, is now complemented with so called auxiliary functions, support functions and subfunctions (13). A main function determines a service's principal task (e.g. "repair machine"). An auxiliary function is used to further detail a particular service (e.g. "prepare workstation" or "perform functional check"). A support function represents a provider's remote support (e.g. "support repair" or "support functional check"). A subfunction is used to further detail a main function, an auxiliary function or a support function. In general, each function is formally described by a verb combined with a noun. Since each service function represents a specific part of a service, CASD automatically highlights which part is provided at a PSS-provider's location and which is rendered at a PSS-customer's property.

The automatic generation of service modules allows for the systematic domain-specific detailing of the chosen service. In this regard, the previously generated service functions are transformed into a main module, auxiliary modules, support modules and submodules (14). Such modules mainly differ from the aforementioned functions by their interfaces. In opposition to existing approaches, a service module's interface is described by the status of the noun used to formally describe a particular function. In this regard, a module's input is consistent with the status of the noun before a respective function's fulfillment (e.g. "not repaired machine tool"). A module's output accords with the noun's status after a certain function's fulfillment (e.g. "repaired machine tool"). The transformation from one status into another is represented by the verb used to formally describe a function to be fulfilled (e.g. "repair"). As a result, manual, remote-supported and automated service processes can be hidden within a module according to the principles of modularization referred to as "limited access" and "loose coupling". This allows for more flexibility during a PSS's domain-specific detailing, because modules or rather their contents can be changed individually without interfering with the contents of related modules. Furthermore, with regard to time-critical processes, different versions of such service processes can be hidden simultaneously within a single module.

A complex system of rules guarantees the plausibility of the automatically generated service information. For example, the selection of a product's ownership is restricted by the previously chosen value proposition, the distinction of cases is limited by the selected service and value proposition, the level of automation is narrowed down by the chosen remote support, the assignment of property is restricted by the chosen value proposition, auxiliary functions inherit the "responsibility for service provision" of the related main function, etc.

3.4 CASD – Modeling Services during the Domain-Specific Detailing of PSS

The standardized modeling of manual, remote-supported and automated services is aimed at during the domain-specific detailing. Thereby, CASD particularly contributes to the efficient and effective design of heterogeneous services.

A manual service is modeled with the aid of the following modeling elements: one or several process steps, connecting elements (and/or/xor) as well as one or several human, technical resources and information, which are directly assigned to a specific process step. In this regard, the value proposition chosen during the PSS-concept development automatically restricts whether a particular service resource is to be supplied by the PSS-provider or its customer. Moreover, specific personnel qualification and competence profiles are modeled. Thereby, the heterogeneity of service actors is specifically taken into account. The related product, process or person which has been chosen during the PSS-concept development can be detailed as well. That way, specific characteristics of the product/process/person in question, which may influence the service provision, can be systematically archived.

In the context of remote-supported services, the remote support as well as the actual service provision are modeled simultaneously. In principle, the initially introduced modeling elements are similarly used, but it is differentiated between the perspective of the customer and the point of view of the provider. As a result, additional costs for the required remote support are made transparent.

Automated services are modeled with the aid of the following modeling elements: critical values, critical rules and critical actions. A critical value defines a maximum permissible value of a certain state variable. Such a variable is used to define a particular machine's behavior. A critical rule describes the relation between a critical value and a critical action. It determines which action results from exceeding a certain critical value. A critical action defines the specific action which is to be carried out if a critical value has been exceeded. With the aid of the developed notation it is aimed at the systematic consolidation and archiving of know-how related to the automated condition monitoring of machines.

3.5 CASD – Software Prototype

The proposed software prototype has been programmed according to the model-view-controller design pattern. The view itself follows the standards for "design criteria for physical input devices" of DIN 9241-410. In order to develop a valid software prototype, all theoretical explanations have been formalized with the aid of entity-relationship models and UML-class diagrams. Figure 3 presents screenshots of the implemented prototype.

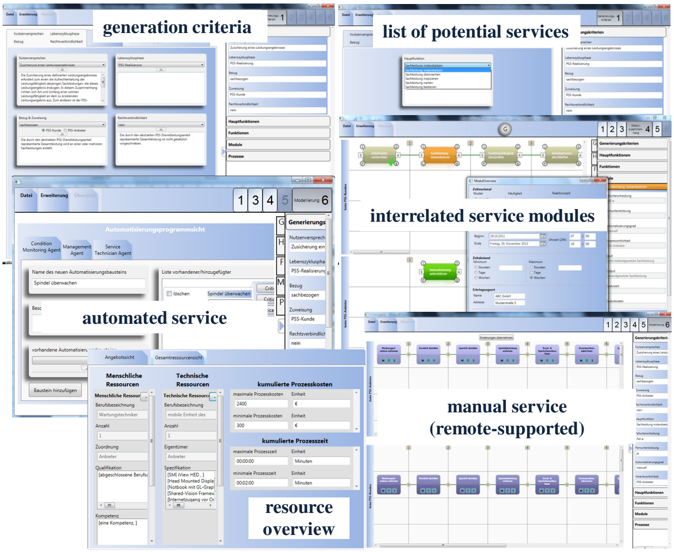


Fig. 3. Screenshots of the implemented software prototype (CASD)

4 Conclusion

This paper introduces Computer-aided Service Design (CASD) as an efficient and effective tool for the integration of heterogeneous service information during the development of Product-Service Systems. It has highlighted considerable benefits of CASD such as plausibility checks with regard to service contents, the automatic generation of diverse service information during the PSS-concept development, the standardized modeling of services and the automatic generation of service costs and time during the domain-specific detailing of PSS. Thereby, it has been possible to successfully close existing gaps in research. Moreover, a revised form of the concept service has been introduced in chapter 2 of this paper. Thereby the "design object" service has been specified within the scope of CASD.

References

1. Schreiner, P.: Gestaltung kundenorientierter Dienstleistungsprozesse. Deutscher Universitätsverlag, Wiesbaden (2005)
2. Busse, D.: Innovationsmanagement industrieller Dienstleistungen. Deutscher Universitätsverlag, Wiesbaden (2005)
3. Tan, A.R., McAloone, T.C.: Characteristics of strategies in product/service systems development. In: Proceedings of the 9th International Conference on Design, pp. 1435–1442 (2006)
4. Statistisches Bundesamt: Produktbegleitende Dienstleistungen, Wiesbaden (2002)
5. Becker, J.: Wertschöpfungsnetzwerke – Konzepte für das Netzwerkmanagement und Potenziale aktueller Informationstechnologien. Physica-Verlag, Heidelberg (2008)
6. Goedkoop, M., van Halen, C., Te Riele, H., Rommens, P.: Product-Service systems – Ecological and Economic Basis. Report for the Dutch ministries of Environment and Economic Affairs (1999)
7. Mont, O.: Product-Service Systems - Panacea or myth? Dissertation. LUND University, The International Institute for Industrial Environmental Economics (2004)
8. Baines, T.S., et al.: State-of-the-art in product-service systems. Journal of Engineering Manufacture 221(10), 1543–1552 (2007)
9. Laurischkat, K.: Product-Service Systems – IT-gestützte Generierung und Modellierung von PSS-Dienstleistungsanteilen. Dissertation. Ruhr-University Bochum (2012)
10. Tukker, A., Tischner, U.: Product-services as a research field: past present and future. Journal of Cleaner Production 14(17), 1552–1556 (2006)
11. Spath, D., Demuß, L.: Entwicklung hybrider Produkte. In: Bullinger, H.-J., Scheer, A.-W. (eds.) Service Engineering, pp. 463–502. Springer, Berlin (2006)
12. Schweitzer, E., Willenborg, J., Pier, M., Fuchs, C., Jenne, F.: Entwicklung investiver Produkt-Service Systeme. In: Aurich, J. (ed.) Produkt-Service Systeme, pp. 31–66
13. Corsten, H.: Dienstleistungsmanagement. Oldenbourg, München (2001)
14. Knoblich, H., Oppermann, R.: Dienstleistung – ein Produkttyp. In: Der Markt, pp. 13–22 (1996)
15. Georgi, D., Hadwich, K.: Management von Kundenbeziehungen. Gabler, Wiesbaden (2010)
16. Tukker, T., Tischner, U.: New business for old Europe. Greenleaf Publishing Limited, Sheffield (2006)

17. Alsonso-Rasgado, M.T., Thompson, G., Dannemark, O.J.: State of the Art in Service Design and Modelling. University of Manchester and Volvo Aero Corporation (2004)
18. Sakao, T., Shimomura, Y., Sundin, E., Comstock, M.: Modeling design objects in CAD system for Service/Product Engineering. Computer Aided Design 41, 197–213 (2009)
19. Hara, T., Arai, T., Shimomura, Y.: A CAD system for service innovation: integrated representation of function, service activity, and product behavior. Journal of Engineering Design 20(4), 367–388 (2009)
20. Bullinger, H.-J., Fähnrich, K.-P., Meiren, T.: Service Engineering – Methodical Development of New Service Products. International Journal of Production Economics 85(3), 275–287 (2003)
21. Schlicker, M., Blinn, N., Nüttgens, M.: Modellierung technischer Serviceprozesse im Kontext hybrider Wertschöpfung. In: Thomas, O., Loos, P., Nüttgens, M. (eds.) Hybride Wertschöpfung – Mobile Anwendungssysteme für effiziente Dienstleistungsprozesse im Technischen Kundendienst, pp. 144–175. Springer, Heidelberg (2010)
22. Scheer, A.-W., Grieble, O., Klein, R.: Modellbasiertes Dienstleistungsmanagement. In: Bullinger, H.-J., Scheer, A.-W. (eds.) Service Engineering – Entwicklung und Gestaltung Innovativer Dienstleistungen, pp. 19–51. Springer, Berlin (2006)
23. Corsten, H., Gössinger, R.: Rahmenkonzept zur integrativen Modellierung von Dienstleistungen. In: Corsten, H.: Ausgabe 58 von Schriften zum Produktionsmanagement.: Technische Universität Kaiserslautern, Lehrstuhl für Produktionswirtschaft, Kaiserslautern (2003)
24. Kunau, G., Loser, K.-U., Herrmann, T.: Im Spannungsfeld zwischen formalen und informellen Aspekten – Modellierung von Dienstleistungsprozessen mit SeeMe. In: Herrmann, T., Kleinbeck, U., Krcmar, H. (eds.) Konzepte für das Service Engineering, pp. 149–166. Physica-Verlag, Heidelberg (2005)
25. Gronau, N., et al.: Wissensorientierte Modellierung im Lebenszyklus von Dienstleistungen. In: Thomas, O., Nüttgens, M. (eds.) Dienstleistungsmodellierung – Interdisziplinäre Konzepte und Anwendungsszenarien, pp. 3–23. Physica-Verlag, Heidelberg (2010)
26. Becker, J., Beverungen, D., Knackstedt, R., Müller, O.: Konzeption einer Modellierungssprache zur softwarewerkzeugunterstützten Modellierung, Konfiguration und Bewertung hybrider Leistungsbündel. In: Thomas, O., Nüttgens, M. (eds.) Dienstleistungsmodellierung – Methoden, Werkzeuge und Branchenlösungen, pp. 53–69. Physica-Verlag, Heidelberg (2009)
27. Hara, T., Arai, T., Shimomura, Y., Sakao, T.: Service CAD system to integrate product and human activity for total value. CIRP Journal of Manufacturing Science and Technology 1, 262–271 (2009)
28. Sadek, T.: Ein modellorientierter Ansatz zur Konzeptentwicklung industrieller Produkt-Service Systeme. Dissertation, Ruhr-Universität Bochum (2009)

Energy Service Companies for Office Lighting: Characterization and Economic Potential

Joris Van Ostaeyen, Hans Vanhees, and Joost R. Duflou

Department of Mechanical Engineering, KU Leuven, Celestijnenlaan 300A, Leuven, Belgium
joris.vanostaeyen@cib.kuleuven.be

Abstract. Artificial lighting is responsible for between 20 to 45% of the total electricity demand in office buildings. The energy efficiency of lighting systems can be improved by replacing existing installations with the best available technology and by implementing lighting control systems. The deployment of these technical solutions should be based on a sound business model. Traditionally, lighting systems are sold as products, but a promising alternative is offered by Energy Service Companies (ESCOs), whereby energy efficiency projects are developed, installed and financed over a period of several years. This article argues that ESCO-offerings should be regarded as a special case of PSS, and provides a novel characterization method for ESCOs for office lighting, that allows to unambiguously describe existing ESCO types. The outline and results of a quantitative analysis of the economic potential of an ESCO for office lighting are presented and interpreted.

Keywords: ESCO, Cost, Simulation, PSS.

1 Introduction

Artificial lighting is responsible for between 20 to 45% of the total electricity demand in commercial buildings [1, 2]. A reduction of at least 50% is deemed feasible [1], and can be realized through the implementation of a diverse set of measures, including on the one hand the replacement of lighting systems (luminaires, lamps and ballasts) by the best available technology, and on the other hand the implementation of lighting control systems (e.g. application of daylight harvesting, occupancy or time control). In promoting these energy-efficiency improvements, there is a need for a viable business model. Traditionally, lighting systems and lighting control systems are sold as products, in a production-based economic model. The prevalence of this business model limits the uptake of the best available technology, especially for existing installations, since customers often have no knowledge about the potential improvements and lack access to the required capital. A promising alternative is offered by a performance-based rationale [3], whereby lighting systems and lighting control systems are sold under energy performance contracts [4]. A key role is foreseen for so called Energy Service Companies (ESCOs), companies typically engaged in developing, installing and financing performance-based projects, centered around the improvement of the energy efficiency of facilities [5]. In the case of office buildings, an ESCO will implement energy efficiency improvements (e.g. lighting renovation and

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 561–572.
DOI: 10.1007/978-3-642-30820-8_47

lighting control), assume (part of) the performance, energy price variation and financing risks during a certain fixed or variable contract period and will obtain revenue based on the actual energy savings realized during that period.

In the specialized literature, several definitions and classifications of ESCOs are provided [5-8]. They have drawn criticism for their lack of consistency and clarity in describing different ESCO types [9]. In essence, the term ‘ESCO’ refers to a type of business model, a business model being a ‘representation of a firm’s underlying core logic and strategic choices for creating and capturing value within a value network’ [10]. Business models can be characterized by specifying the different building blocks that constitute them. Examples are the popular business model canvas of Osterwalder [11], with nine building blocks, and the representation proposed in reference [12], whereby business models for investment goods are represented in a structure with four domains and twelve building blocks. But in order to highlight the core characteristics of a certain ESCO, a comprehensive description of all of these building blocks is not required. Based on a review of the available descriptions of ESCO models (e.g. in references [6], [7] and [8]), the following main characterizing features of an ESCO were determined:

- The *value offering* of the ESCO (i.e. which products and services it offers)
- The *revenue mechanism(s)* of the ESCO (i.e. according to which logic it generates revenues from its offering)
- The way *risks* are assigned between the involved stakeholders (the main stakeholders involving the ESCO, the end user, plus potentially an external financing organization and other intermediaries)

Since the value offering of an ESCO is essentially an integration of products and services, whereby the focus is on value-in-use and not so much on exchange value, it is evident that the value offering of an ESCO can be seen as a *special case of a Product-Service System (PSS)*, specifically applied within the energy sector. Therefore, the representation method and typology developed in reference [13] can be applied for the specific case of ESCOs.

This article proposes a novel way of characterizing ESCOs for office lighting, based on a description of the three main building blocks identified above. This is elaborated in Section 2. In Section 3, insight is provided on the economic potential of an ESCO business model for office lighting through an extensive Monte Carlo simulation of a lighting system's life cycle costs. The focus of this study is on lighting applications in Belgian offices. In Section 4, the main conclusions are stated.

2 ESCO Business Model Characterization

In this section, a new way for characterizing ESCO models for office lighting is provided, based on a description of the value offering (Subsection 2.1), revenue mechanism (Subsection 2.2) and the distribution of the main risks within the ESCO model (Subsection 2.3).

2.1 Value Offering of an ESCO for Office Lighting

ESCOs offer an integrated combination of products and services that delivers value in use, specifically in the energy sector. In the specific case of lighting systems for office buildings, the ESCO offering contains a specific set of *product and service components*. The possible components are represented in Figure 1. A further partitioning of these components is still possible, e.g. the lighting system can be divided into luminaires, lamps and ballasts.

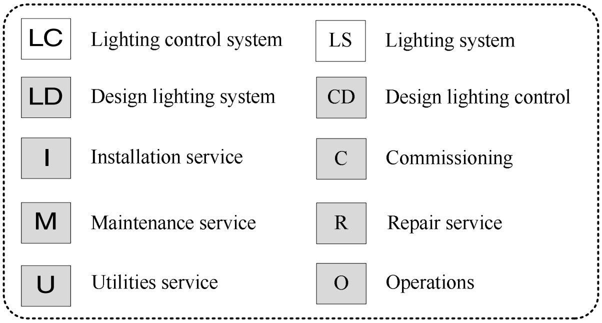


Fig. 1. Product and Service components that can be part of the offering of an ESCO for office lighting (products components: white, service components: gray)

Thus, the offering of an ESCO for office lighting will always be a combination of (some of) the product and service components defined above. In combining these products and services, some of them can be integrated in an 'integrated offering' (visually, this is represented by joining the rectangles). This means that they will always be sold together and have a common revenue generation mechanism. As such, the complete offering of an ESCO can have a combination of different revenue mechanism, one for each integrated combination of products and services. The possible types of revenue mechanisms are presented in the next subsection.

2.2 Revenue Mechanisms

Different *types of revenue mechanisms* can be discerned (cfr. [13]), based on the degree of performance orientation:

1. An *input-based (IB)* revenue mechanism means that revenue is transferred from the customer to the provider according to the inputs delivered to effectuate the function of a product or service. In case of a product, this means that the property rights of the products (e.g. lamps, luminaires, sensors, …) are transferred to the customer and revenue for these products is generated at the moment of property transfer. For a service, this means that revenue is generated per intervention, based on the resources necessary to deliver the service, such as labor hours or materials.

2. An *availability-based (AB)* revenue mechanism means that revenue is transferred from the customer to the provider based on the time period during which the product or service are available for the customer, independent of how much they are actually being consumed during that period. For a product this means for example a monthly rental or leasing fee and for a service this means a fixed monthly sum to be paid for which the provider promises to deliver the service to the customer whenever necessary.
3. A *usage-based (UB)* revenue mechanism means that revenue is generated only during the actual usage of the product or service. Usage can be expressed in time units (in the case of office lighting: the number of hours that there is a lighting demand).
4. A *performance-based (PB)* revenue mechanism means that revenue is generated based on the functional performance of the product or service. Functional performance can be related to the main customer demands that the product or service aims to fulfill. The main customer demands for a lighting system are twofold: it should *provide visual comfort* and the user should be able to *control the usage costs*. In between these demands and the product and service elements of Figure 1, the functions of these elements can be expressed on different levels of abstraction [13]. On the lowest level of abstraction, the functions are expressed in terms of parameters of a specific solution (e.g. 'Generate luminous flux', expressed in lumen). On a higher level of abstraction, the functions are expressed in terms of effect on the environment (e.g. 'Provide illuminance of a task area', expressed in lux), and on the highest level of abstraction the function is directly expressed in terms of the subjective demand that is to be fulfilled ('Provide visual comfort'). Thus, three subtypes of performance based revenue mechanisms can be discerned [11]:

   - Solution-oriented performance based *(PB-SO)* revenue mechanism
   - Effect-oriented performance based *(PB-EO)* revenue mechanism
   - Demand fulfillment-oriented performance based *(PB-DO)* revenue mechanism

The different types of revenue mechanisms for the specific case of office lighting are indicated in Figure 2, organized according to the two main customer demands. The reason why there is no demand-fulfillment oriented revenue model for the 'control costs' demand is that this would have to be expressed in terms of the subjective appreciation of costs, which is not a practical concept. All the other options are (theoretical) possibilities that indicate on which basis lighting (control) systems could be sold. From Figure 2 it becomes clear that, apart from the business models that are traditionally regarded as ESCO models (on the right hand side, related to the customer demand 'control costs'), different theoretical ESCO models also exist on the left hand side of the figure, related to the customer demand 'provide visual comfort'. Since the revenue models on the right hand side are more prevalent for existing ESCOs, in the remainder of this article they will be the main focus.

		VISUAL COMFORT	CONTROL COSTS
PERFORMANCE-BASED	DEMAND-FULFILLMENT ORIENTED	Per promised level of VISUAL COMFORT	×
	EFFECT-ORIENTED	Per LUX $[lm/m^2]$	Per € SAVED [€]
	SOLUTION-ORIENTED	Per LUMEN [lm]	Per kWh SAVED [kWh]
USAGE-BASED		Per LIGHTING HOUR [hr]	
AVAILABILITY-BASED		Per MONTH [month]	

Fig. 2. Types of revenue mechanisms for office lighting ESCO's, corresponding to the two main customer demands related to a lighting system (provide visual comfort and control costs)

2.3 Risk Allocation within the ESCO

The way the main risks are distributed is an essential characteristic of an ESCO model. There are three main risks involved:

- The *risk of variation of the energy price.* Since ESCO contracts are running over a period of several years, and the variation of the energy price over these years is uncertain, this risk will exist in every possible ESCO model. In case a PB-EO revenue mechanism is chosen, whereby the ESCO is paid a fixed percentage of the actual monetary savings in energy cost until the end of the contract period, the risk is shared between the customer and the ESCO. In case the PB-SO revenue mechanism is chosen, whereby the ESCO is paid a fixed sum per saved kWh of energy, this risk is completely allocated to the customer.
- The *performance risk.* This risk is related to the system's ability to achieve the stated savings. In most ESCO models, this risk is primarily assigned to the ESCO itself, since this gives the ESCO the right incentives to optimize the performance of the system delivered.
- The *credit risk.* This is the financial risk related to the possibility to recover invested funds. It depends on which party does the investments in the equipment. Credit risk depends on the salvage value of a system being offered that is being used as a lien for acquiring the necessary financing. In case the customer would terminate the activities in the building where the lighting (control) systems are being employed and would fail to commit to the contract agreements, it is difficult – if not impossible – to take the lighting components out of this building and put them into service elsewhere, since the labor costs for removing and re-installing the equipment are prohibitive. This is different for equipment that is more mobile (e.g. a mobile construction machine, such as a bulldozer or portable compressor, that can in most cases easily be transported and put into operation elsewhere). Therefore, the credit risk will be considerable in the case of office lighting (control) systems.

Apart from these risks, another important characteristic is the contract term in which the ESCO operates. It can be fixed or variable [7, 14]. In general, if the contract term is longer, the three relevant risks will be considered to be larger. For example, in what is known as a 'First-Out' ESCO model, whereby the ESCO invests in the energy saving technology and is paid the full energy savings benefits until an agreed sum is acquired [15], the contract term is shorter than in case the ESCO gets for example 60% of the real cost savings for a fixed contract period (this last model being known in literature as the 'Shared Savings' ESCO model [15]), and the three risks for the ESCO will be larger for the latter model.

2.4 Characterization of ESCO Models: 2 Examples

ESCO models can be characterized by the features discussed in the previous subsections. Since going through all the main ESCO types is not feasible within the scope of this paper, two ESCO types are described in detail, for the specific situation of office lighting: the *Shared Savings type* and the *Guaranteed Savings type*. The value offering and corresponding revenue models of both types are visualized in Figure 3.

This visualization can be interpreted as follows. For the Shared Savings type, the investment in materials (i.e. LC and LS) are performed by the ESCO and not arranged by the customer, as is the case in a Guaranteed Savings type. This is indicated on the left hand side of Figure 3: for the Shared Savings type the product components are integrated with the service components and all are sold according to a common performance-based revenue mechanism (i.e. an effect-oriented model (PB-EO), such as defined in Subsection 2.2 and Figure 2). For the Guaranteed Savings type only most of the service components are integrated in a solution-oriented revenue mechanism (price per kWh saved above a certain threshold). Ambiguity exists in the literature on ESCOs on whether the ESCO receives a fixed payment per saved kWh above the threshold or whether the ESCO receives the actual cost savings above the kWh threshold. In this article, the Guaranteed Savings type is restricted to the first interpretation.

The comparison in risks and contract terms between both models is given in Table 1. The main difference lies in the allocation of the credit risk. Since the contract period is longer for the Guaranteed Savings type, the performance risk for the ESCO is larger (stated as 'high', 'medium' or 'low'). According to the interpretation of Guaranteed Savings chosen in this article, the energy risk is completely for the customer's account and mainly for the ESCO in the Shared Savings model.

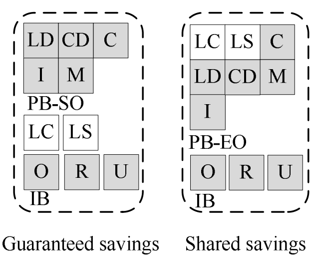
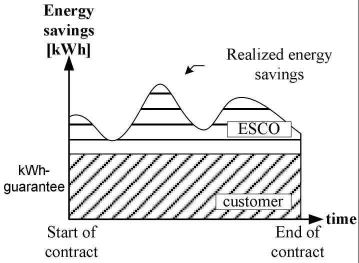
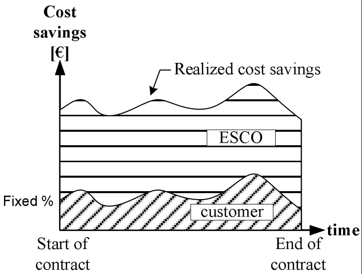


Fig. 3. Visualization of the value offerings and revenue models of a Guaranteed Savings and a Shared Savings ESCO type, whereby the abbreviations of Subsections 2.1 and 2.2 are used

Table 1. Comparison of a Guaranteed Savings and Shared Savings ESCO model

ESCO type	Visualization	Contract term	Risk allocation
Guaranteed Savings		Fixed (5-15 years)	Credit: ESCO Performance (for ESCO): high Energy price: customer
Shared Savings		Fixed (1-10 years)	Credit: customer Performance (for ESCO): medium Energy price: mainly ESCO

The other ESCO types that occur in practice can also be described by the characterization method introduced in this section, which allows for a comprehensive and unambiguous description of ESCOs. This contributes to a better understanding of the specific characteristics of ESCO types.

3 Quantitative Analysis of the Economic Potential of an ESCO for Office Lighting

The economic potential of an ESCO business model for office lighting has been analyzed, based on a comprehensive Life Cycle Cost simulation model. The basic research goal was to establish the conditions under which an ESCO could be profitable in replacing existing lighting systems by state-of-the-art luminaire, lamp and ballast technology and/or by implementing advanced lighting control strategies. Several base scenarios and improvement scenarios were identified, and the cost improvement potential has been quantified of certain improvement scenarios over a certain base case. Furthermore, a sensitivity analysis has been performed on the results, in order to define the key success factors for ESCO profitability. In Subsection 3.1, the outline of the method is described. Subsection 3.2 summarizes the results obtained within this study.

3.1 Method Description

The modeling approach used is a Monte Carlo simulation of the Life Cycle Cost (LCC), whereby the uncertainty and variability in the input parameters was modeled by using appropriate statistical distributions and thus obtaining the output distribution of the Life Cycle Cost. The general structure of the method is depicted in the flowchart of Figure 4. The model generates cellular offices (< 40 m²) and open plan offices (> 40 m²) with variable size and usage patterns. The design of the lighting system is based on the lumen method (e.g. described in [16]), whereby a luminaire layout is calculated from a required illuminance level of task areas according to the European standard EN12464, assuming a depreciation of the lighting system over its maintenance cycle (represented by a maintenance factor) and a lighting efficiency represented by a utilization factor, which is determined by the European standard EN13032. The maintenance factor and utilization factor assume information about the selected *luminaire-lamp-ballast (LLB) combination*. In this research a pool of 26 LLB combinations, representative for the lighting systems installed in European offices, and 6 best available technology (BAT) LLB combinations are adopted from a study on the Belgian office lighting market [17]. The design of the lighting control system is based on European standard EN15193, whereby the formulas in that standard are applied to

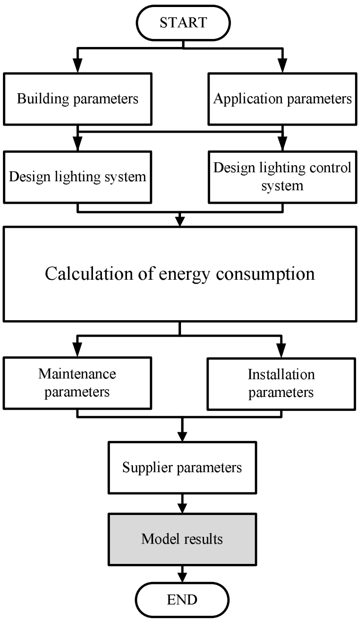


Fig. 4. General outline of the simulation model

estimate the savings from *dimming to a maintained illuminance* as a function of the maintenance factor, the savings from *occupancy control* and the savings from *daylight control*. The *maintenance parameters* represent periodic group lamp replacements and the *installation parameters* represent the installation times of the components of a lighting system. The *supplier parameters* contain labor costs and discount rates. All input parameters are modeled according to a uniform or PERT distribution and were determined by eliciting expert information from a range of stakeholders (e.g. an electrical installation company, a lighting control systems provider, a lighting technology specialist). The model output is the LCC of the lighting system, expressed as the Net Present Value of the aggregated installation, energy, maintenance and removal costs of luminaires, lamps, ballasts, cabling and lighting control system components over a period of 20 years.

3.2 Results and Discussion

Six analyses were performed, as indicated in Table 2.

Table 2. Description of the six analyses performed within this study

Analysis	Description	Goal
1	Base Case	Identification of LLB combination with significant high total LCC (base case scenario)
2	BAT	Identification of LLB combination with lowest total LCC (best available technology)
3	Sweep + dimming	Analysis of the potential of a new lighting system with automatic lighting control based on a sweep function and dimming to a constant maintained illuminance w.r.t. the base case scenario
4	Presence detection + dimming	Analysis of the potential of a new lighting system with automatic lighting control based on automatic presence detection and dimming to a constant maintained illuminance w.r.t. the base case scenario
5	Daylight + sweep + dimming	Analysis of the potential of a new lighting system with automatic daylight control, sweep function and dimming to constant illuminance w.r.t. the base case scenario
6	Daylight + presence + dimming	Analysis of the potential of a new lighting system with automatic daylight control, automatic presence control and dimming to constant illuminance w.r.t. the base case scenario

Some of the main findings are:

- *Determination of base case and best available technology (BAT) scenario.* The base case and best available technology scenarios were determined by calculating the Normalized Power Density (NPD) of a lighting system for the different LLB combinations of reference [17]. The NPD is a measure of the efficiency to illuminate a specific task area [18]. This analysis defined 5 out of 26 LLB combinations as energy inefficient, i.e. they represent on average a higher NPD, expressed in

W/m².100 lux. One LLB combination was defined as the best available technology, with a low NPD and a ballast type that allows for the implementation of a lighting control system.

- *The potential of replacing base case scenarios with BAT.* The potential was determined to replace the lighting systems in a building in one of the 5 base case scenarios with the BAT scenario of Analysis 2, with manual control. The key finding is that the potential is there for open plan offices (potential of on average between 0 and 15 €/m², taking into account a discount rate of 10%) and that the savings in energy and maintenance costs for cellular offices are smaller than the higher investment required. The key success factor determining the profitability of an ESCO model is the room index, which is defined as the ratio of the horizontal and the vertical area of the room. In Figure 5, the sensitivity of the net cost savings of investing in the best available technology in €/m² is shown in function of the room index. As can be seen, for a room index higher than 1.4, the investments in BAT becomes profitable.

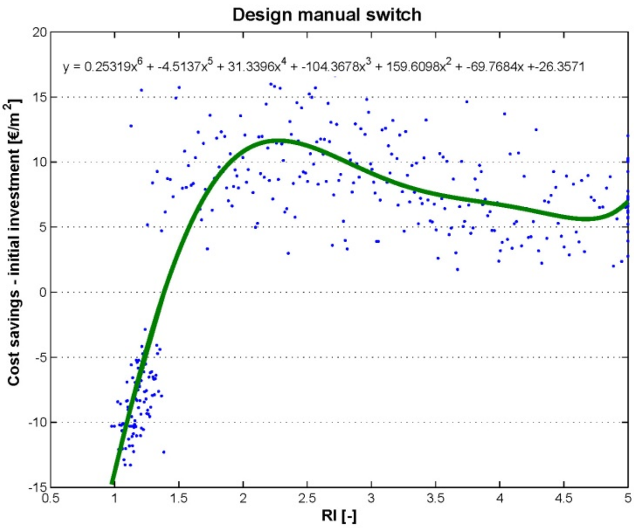


Fig. 5. Sensitivity analysis of the net cost savings of changing the base case scenario with the best available technology in function of the room index

- *The potential of automatic lighting control.* The potential was determined for analyses 3 to 6. An upgrade of a base case scenario to a new lighting system with automatic daylight and presence control and dimming to constant illuminance is the most profitable investment in open plan offices with a potential ranging from 5 to 20 €/m² over the lifecycle of the lighting system or a discounted payback period ranging from 10 to 17 years depending on the base case scenario. The investment in cellular offices is not profitable due to the geometry of the offices (i.e. the room index). A sensitivity analysis determined the most important factors for the profitability of an ESCO model that would apply scenario 6 in open plan offices: the room index, the type of luminaire (more specifically its downward light output ratio DLOR [16], which has a major impact on the utilization factor) and to a lesser extent the discount rate and the energy price. This indicates that the performance risk is dominant and that it mainly depends on the choice of the base case. Therefore, an ESCO should carefully consider which buildings it chooses for implementation of an energy saving project. Out of the existing building stock of Belgian offices described in reference [17], it was determined that an investment in energy-efficient lighting systems can be profitable in 10.8% of the Belgian offices. Offices with a room index above 1.4 have a potential of 5-20 €/m² over the lifecycle of the lighting system and a discounted payback period of 10-17 years.

4 Conclusions, Limitations and Future Research

This article argues that ESCOs can be considered as the application of the PSS concept in the energy industry. A novel method for characterizing ESCO models, based on a representation method and typology of PSS has been proposed. This allows for a comprehensive and unambiguous representation of the essential characteristics of a certain ESCO type.

Apart from this qualitative description, the outlines of a quantitative study have been proposed wherein the potential of an ESCO for office lighting was determined for the Belgian office market. The analysis of the potential of the investment in energy efficient lighting systems with several lighting control options pointed out that an ESCO should focus on upgrading the lighting systems of open plan offices by installing new energy efficient lighting systems with automated daylight and presence control and dimming to a constant illuminance. It also highlighted that the ESCO should choose with great care the type of lighting systems that are to be replaced, since these parameters are dominant in determining the profitability of the investments.

The main limitation of this study is its high reliance on the description of the base case scenarios of reference [17]. Recommendations for future study are to validate the results of this study with other data concerning the current situation in European offices. This could lead to a new pool of representative luminaires used in offices that can be used as input for the model. Furthermore, the profitability of the different ESCO types (such as the Shared Savings and Guaranteed Savings type) could also be compared more in detail, whereas the profitability potential of an ESCO as presented here is stated independently of the specific type of ESCO applied.

References

1. Dubois, M.-C., Blomsterberg, A.: Energy saving potential and strategies for electric lighting in future North European, low energy office buildings: A literature review. Energy and Buildings 43(10), 2572–2582 (2011)
2. Commercial Building Energy Consumption Survey, United States Department of Energy, Washington, DC (1999)
3. Stahel, W.R.: The Performance Economy. Palgrave Macmillan (2010)

4. Steinberger, J.K., van Niel, J., Bourg, J.: Profiting from negawatts: Reducing absolute consumption and emissions through a performance-based energy economy. Energy Policy 37(1), 361–370 (2009)
5. Vine, E.: An international survey of the energy service company (ESCO) industry. Energy Policy 33(5), 691–704 (2005)
6. Bertoldi, P., Rezessy, S., Vine, E.: Energy service companies in European countries: Current status and a strategy to foster their development. Energy Policy 34(14), 1818–1832 (2006)
7. Hansen, S.J., Langlois, P., Bertoldi, P.: ESCOs Around the World: Lessons Learned in 49 Countries. Fairmont Press (2009)
8. Studebaker, J.M.: Esco: Energy Services Company Handbook. PennWell Corporation (2001)
9. Duplessis, B., et al.: An empirical typology of energy services based on a well-developed market: France. Energy Policy 45, 268–276 (2012)
10. Shafer, S.M., Smith, H.J., Linder, J.C.: The power of business models. Business Horizons 48(3), 199–207 (2005)
11. Osterwalder, A.: Business model generation: a handbook for visionaries, game changers, and challengers (2010)
12. Van Ostaeyen, J., Neels, B., Duflou, J.R.: Design of a Product-Service Systems Business Model: Strategic Analysis and Option Generation in Functional Thinking for Value Creation, pp. 147–152. Springer, Heidelberg (2011)
13. Van Ostaeyen, J., Van Horenbeek, A., Pintelon, L., Duflou, J.R.: A refined typology of Product-Service Systems based on Functional Hierarchy Modeling. Journal of Cleaner Production (2013)
14. Shippee, G.E.: The future for energy service companies: changes and trends. The Electricity Journal 9(6), 80–84 (1996)
15. Limaye, D., Limaye, E.: Scaling up energy efficiency: the case for a Super ESCO. Energy Efficiency 4(2), 133–144 (2011)
16. Rea, M.S.: The Iesna Lighting Handbook: Reference & Application: Illuminating Engineering Society of North America (2000)
17. Van Tichelen, P., et al.: Final Report Lot 8: Office lighting, in Preparatory Studies for Ecodesign Requirements of EuPsVITO (2007)
18. Hanselaer, P., et al.: Power density targets for efficient lighting of interior task areas. Lighting Research and Technology 39(2), 171–184 (2007)

Modeling of Flexibility within Dynamic IPS² Business Models – A Conceptual System Dynamics Case Study

Horst Meier[1], Marion Steven[2], Mario Boßlau[1], and Solmaz Alevifard[2]

[1] Institute Product and Service Engineering, Chair of Production Systems,
Ruhr-University Bochum
{meier,bosslau}@lps.ruhr-uni-bochum.de
[2] Faculty of Management and Economics, Chair of Production Economics,
Ruhr-University Bochum
{marion.steven,solmaz.alevifard}@ruhr-uni-bochum.de

Abstract. In order to remain competitive, IPS² providers have to react flexibly to changes which are caused by environmental dynamics and the long duration of the business relationship. To ensure this, the provider can provision flexibility either by short-term or long-term actions which differently affect the IPS² profitability. Accordingly, the paper at hand focuses on two research questions: 1) How can the provider estimate the economic effects of short-term and long-term flexibility measures? 2) How do these measures influence the dynamics of IPS² business models? To answer these questions, the authors use the approach of System Dynamics (SD) and illustrate the economic effects of integrating flexibility in the IPS² business model. A conceptual case study of a German solution provider is presented to exemplarily show how decision support is provided by SD.

Keywords: IPS² flexibility, decision support, IPS² business model.

1 Introduction

An IPS² (Industrial Product-Service System) results from a systematic configuration of integratively developed [1-2] and reciprocally substitutable product and service modules [1]. It is a holistic and customer-specific problem solution without the necessity to transfer the ownership of the product [3]. In competition, IPS² represent a sustainable success factor in a market environment where achieving competitive advantages just through products is becoming a constant challenge for most of the companies [4].

IPS² are usually delivered within long-term business relationships in which uncertainty has to be considered [5]. In this article, risk and uncertainty are used as synonyms. They refer to the possibility that deviations from the business relationship's objectives can occur [6-7]. Further, risks arise due to insufficient information about future events within the relevant system boundary [8]. The *dynamics* of IPS² business relationships make it difficult to anticipate future, environmental events [5] and the

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 573–584.
DOI: 10.1007/978-3-642-30820-8_48

future behavior of the counterpart [6]. The *long duration* of the relationship enhances the degree of difficulty in anticipating the future regarding both environmental and behavioral perspectives. It increases the probability of changes and requires rescheduling efforts. Flexibility is considered as an appropriate way to deal with uncertainty and to keep the IPS² performance at a high level [5].

In addition, managers have to understand how to deal with uncertainty and how to ensure profitability in these dynamic IPS² business relationships, especially with respect to the economic effects of provisioning flexibility. In order to react flexibly to changes, the provider has to keep resources available without really being sure whether these will be used actually. Flexibility can be provisioned by either short-term or long-term measures which differently affect the economical advantageousness of an IPS². According to that, two research questions are to be answered:

1. How can the provider estimate the economic effects of short-term and long-term flexibility measures?
2. How do these measures influence the dynamics of IPS² business models?

In the literature, there are various approaches which deal with business dynamics and associated uncertainties (see sections 2 and 3). Despite that, specific characteristics of IPS² are not taken into account by these approaches. To fill this research gap, a conceptual case study of a hypothetic solution provider's business model is introduced. Finally, several simulation runs of selected scenarios are accomplished for strategic decision support. The authors use the method of SD to illustrate complex feedback structures which have to be considered for strategic decision making.

2 Industrial Product-Service Systems

2.1 IPS² Business Model

The heterogeneous understanding of the business model concept results in a relatively unstructured discussion in the engineering and economic literature [9]. An IPS² business model has to vary according to the dynamics of an IPS², e.g. as caused by a change of the customer's requirement and hence, the underlying product-service combination. Teece (2010) defines a business model in a more static approach as "the design or architecture of the value creation, delivery and capture mechanism employed. The essence of a business model is that it crystallizes customers' needs and ability to pay, defines the manner by which the business enterprise responds to and delivers value to customers, entices customers to pay for value, and converts those payments to profit through the proper design and operation of the various elements of the value chain" [10]. In the context of dynamic IPS² it has to be considered that an IPS² is always an individual solution for a customer which is tailored for a specific situation. Thus, in the majority of cases, an IPS² is unique. Taking into account these IPS²-specific aspects, this definition can be expanded by adding the fact that every customer-provider relationship is characterized by one specific business model [9], while other value-adding partners can also be involved (e.g. suppliers) [11].

2.2 IPS² Life Cycle

The provision of customer value over the entire life cycle is a central aspect of IPS². Accordingly, they must adapt dynamically to changing customer requirements. Dealing with uncertainty, in terms of high complexity and dynamics, is thus one of the key challenges while provisioning flexibility. The IPS² life cycle is divided into five phases. In the planning phase, the customer requirements have to be identified and correspondingly the contract has to be designed. In the development phase, the provider specifies the solution in close collaboration with the customer. The implementation phase includes the allocation of the physical artifacts of the IPS² and the provision of service capacities in order to operate the IPS² within the operation phase subsequently. Finally, in the closure phase, the contractual business relationship ends [12-13].

2.3 Integration of Flexibility

In order to deal with uncertainty, an IPS² has to be flexible [5], [7]. Flexibility potentials are to be taken into account at the beginning of the business relationship, i.e. in the planning and the development phase. IPS² flexibility is separated into internal and external flexibility [14]. The external flexibility is subdivided into primary and secondary flexibility. It is broken down according to the relationship development and contractual agreements. The *primary* flexibility refers to the provider's abilities and capabilities to fulfill the customer's requirements at the planning phase. Examples for this category are the provision of financing or of personnel if the customer does not have these resources available. Thus, the primary flexibility is necessary to build the business relationship. The *secondary* flexibility refers to options that can be used in further steps of the relationship if requirements change. There are two possibilities for reaching agreements relating to the options.

An *ex ante* contractual agreement, i.e. at the planning and development phase, simplifies the calculation from the provider's point of view. In this context, the long-term engagement of new staff can be seen as an example. In the case of an *ex post* agreement, a lack of staff eventually causes production stops, which result in performance losses and increased redesign costs, respectively [14]. Consequently, the cost and revenue effects of provisioning flexibility depend on the time of the agreement, too.

The *internal* flexibility concerns the provider's abilities and capabilities to react flexibly to the customer requirements in a concrete IPS² relationship as well as in all IPS² relationships the provider is involved in. The external and the internal flexibility overlap if a certain IPS² is considered. Thus, the provider's investments in flexibility potentials for a certain IPS² can positively impact the overall, internal flexibility. There are three factors [15] which determine the internal flexibility, i.e. human resources, structural resources and relational resources. *Human resources* (HR) include, for example, know-how, competencies, qualification etc. In addition, HR include personalized knowledge of employees. *Structural resources* (SR) refer to issues such as the quantity of employees (especially service personnel), technical equipment, transportation fleet, communication structures etc. [16-17]. Finally, the provider needs *relational resources* (RR). For example, solid relationships with investors and with cooperation partners or suppliers [16] are necessary, in order to ensure the provider's competitiveness in the long-term [15], [18].

3 Case Study

In this section, a conceptual case study from the field of micro production is introduced in order to demonstrate in section 4 the economic effects of provisioning flexibility within the IPS² business model. This case study serves two major objectives. First, is to evaluate the profitability of this business model with short-term and long-term flexibility measures. Second, is to analyze by means of SD the influence of the mentioned flexibility measures on the chosen IPS² business model.

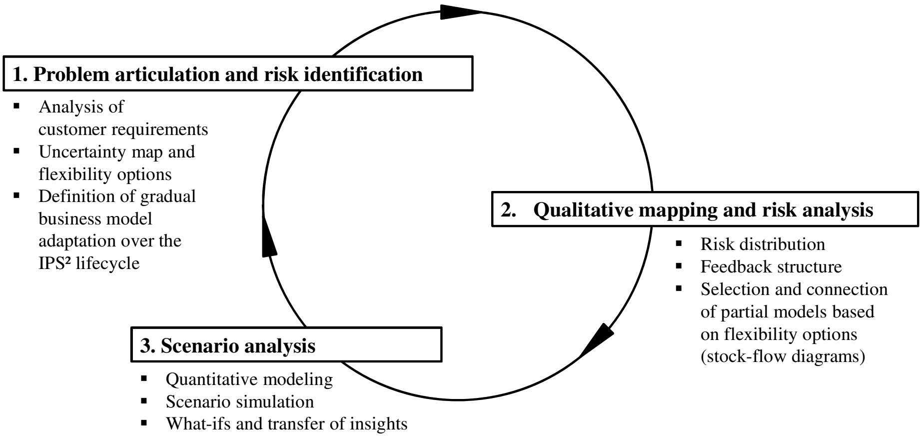


Fig. 1. Iterative process for case study analysis

In order to achieve these objectives, three steps are necessary which form an iterative process. After problem articulation and risk identification (step 1, see Figure 1), the relevant partial models are selected considering the risk distribution (step 2, see Figure 2). Based on case-specific key data, a series of simulation runs is performed (step 3, see Figure 3) by means of the SD approach to support the management's decision process in finding an adequate strategy for the sustainable implementation of a customer-specific business model and the corresponding flexibility options.

SD is a method to enhance learning and understanding of complex socio-technical systems, especially in a complex business environment [19], and is thus a suitable tool for analyzing IPS² and their business models [13]. It is based on simple graphical notations to model systems: causal loop diagrams and stock and flow diagrams. Sterman, Morecroft and Warren give a detailed introduction and critical analysis to the use of SD with special focus on business dynamics, strategic modeling and management dynamics [19-21]. On this basis, Meier introduces an integrated business model design and engineering approach for IPS² business models using SD [22].

The respective company is a solution provider (SP) in the field of micro milling machines and has currently more than 20 running IPS² contracts in Germany. Thus, SP is a well-established provider focusing on long-term customer relationships and an integrated development of product and service offers. An interview with the customer (C), a German manufacturer of watches in the medium-price segment, revealed that C requires a specific micro milling machine to produce high-quality watch movements for chronographs in the high-price segment. Up to now, C has externally purchased standard watch movements to produce watches for the medium-price segment. Thus, a differentiation from competitors has only been possible through design aspects. From now on, the top management of C additionally aims at expanding the product portfolio by high-quality watches. Hence, it must be assured that core competencies for this new segment can be provided in a long-term perspective.

4 Performance Modeling and Evaluation

4.1 Problem Articulation and Risk Identification

In order to further specify the customer-specific solution, a second interview was conducted in which SP and C interacted intensively for analyzing the current requirements.

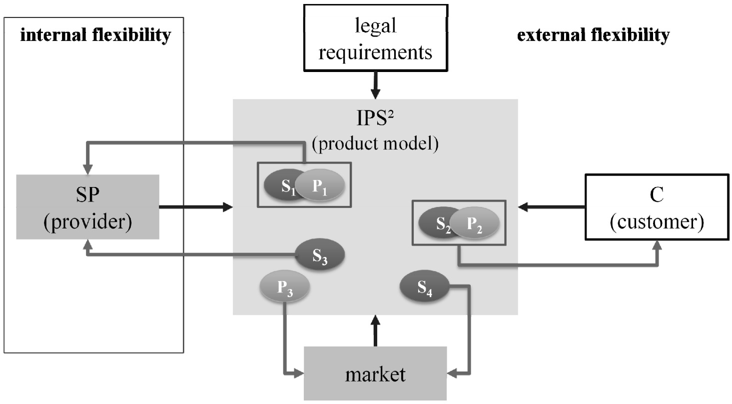


Fig. 2. Uncertainty map

The business partners used the uncertainty map (see Figure 2) to identify and describe relevant uncertainties and risks which determine the IPS² performance [23-25]. The uncertainty map helps to structure the problem situation. It includes four sources of uncertainty [7], i.e. the customer's firm, the market, the provider's firm and legal requirements. The arrows pointing inward indicate the influence of each source whereas the arrows pointing outward illustrate each business partner's performance tasks. The tasks are distributed based on competence analyses and on available resources. The modules that are linked to the market are to be delivered by the provider's cooperation partners. This attribution has not to be addressed in customer interaction. The explanation is only for the sake of completeness.

As shown in Figure 2, the uncertainty map focuses on the simplified IPS² product model [26]. The respective IPS² includes two hybrid modules (surrounded module couples), two pure service modules and one pure product module.

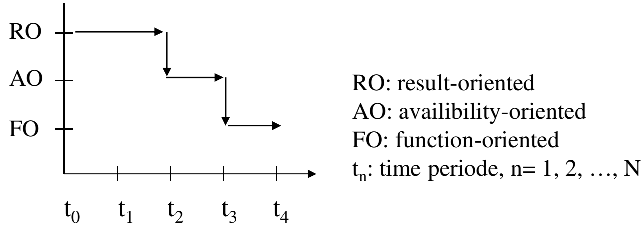


Fig. 3. Gradual business model adaptation

Base Scenario. Uncertainties resulting from C's firm include know-how deficits in dealing with the micro milling machine, lack of finances and of personnel. Therefore, SP recommends a gradual business model adaptation that begins with a result-oriented value proposition (see Figure 3, $t_0 – t_2$) in order to prepare C to develop core competencies over time. Hence, SP bears to a certain extent the market risks of the customer due to the result-oriented revenue generation. Once C has gathered know-how and core-competencies in the movement production process, a change to the availability-oriented revenue model occurs (see Figure 3, $t_2 – t_3$) as contractually agreed upon. In this collaboration-intense business model, SP does not have to bear the market risks anymore, but the coordination necessities within the business relationship are higher due to the high degree of interaction between both partners [9], e.g. SP is responsible for services to ensure availability and C runs the production process. Furthermore, C's market situation is characterized by volatile demand. Due to the high demand for the high-quality watches, the SP's personnel capacities are running close to full capacity. Finally, there are not any uncertainties regarding legal requirements. Based on the uncertainties mentioned, flexibility options are contractually agreed upon (see Figure 4). Internal flexibility options are in the focus of this investigation (see Figure 4, printed in bold).

Flexibility Options. In order to establish the business relationship, SP offers the options 1-3 which are components of a result-oriented value proposition. For being flexible in case of increased demand, optional automation by the use of robots is agreed contractually. From SP's perspective, internal flexibility is required to satisfy the demand for micro milling machines. To build internal flexibility, two options are possible (see Figure 4):

1. SP can hire temporary workers (T), train them and provide them to C for a certain price (hiring and training costs), even after t_3 (scenario I).
2. The second option is a long-term capacity enlargement (overlapping of external and internal flexibility). According to that, SP hires employees for the long-run and can use them for other IPS², too, when C's need for personnel decreases (scenario II).

After t_3, a transition to a function-oriented value proposition would be possible (see Figure 3, $t_3 – t_4$). In the interests of clarity and rationality, this business model, which is commonly used in practice and thus a minor research aspect for IPS² [9], is not part of the developed SD model.

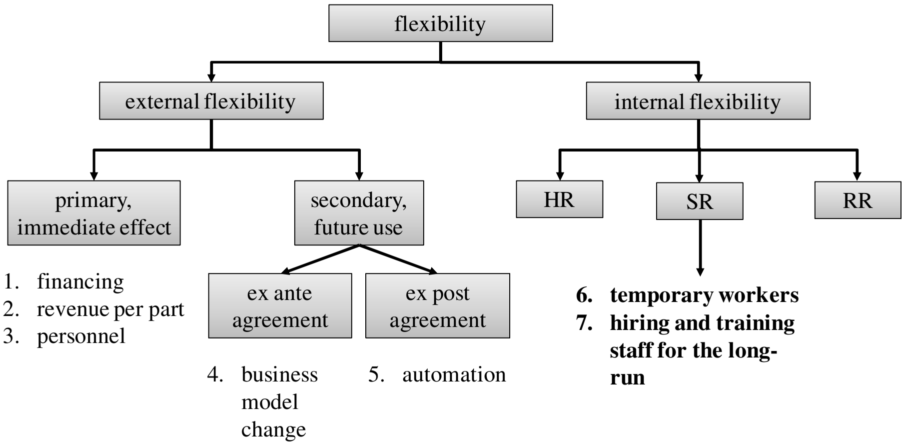


Fig. 4. Case-specific flexibility options

4.2 Qualitative Mapping and Risk Analysis

In this section, the dynamic behavior in the case being considered is examined within two scenarios by means of SD which result from the two flexibility options mentioned above. A key aspect within these workforce-driven options is the development of core competencies and knowledge over time.

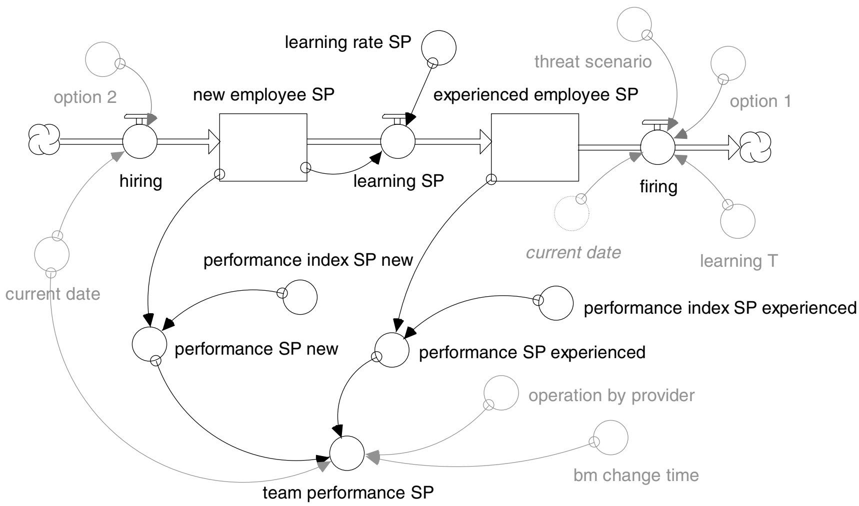


Fig. 4. Stock-flow diagram of an aging chain

This workforce aging chain [19-20] represents a workforce where employees gain experience over a certain period of time. The main symbols of the respective stock and flow diagram within the iThink SD software are shown in Figure 5 (black symbols within diagramming notation). Stocks are accumulations and characterize the state of a system and generate the necessary information for decision support. They are represented by a rectangle. Inflows are represented by a pipe pointing into the stock. Outflows are represented by a pipe pointing out of the stock. Flow rates are represented by a valve on a double line and are necessary to control the flows. Clouds represent the sources and sinks for the flows and thus the model boundary [19], [27].

New and experienced employees within the aging chain model (see Figure 5) have a different performance depending on their know-how level. Team performance is simply the sum of each category working at its own performance. These basic constructions are fundamental for modeling the organizational partial models for the workforce of SP, C and T.

In order to perform a scenario analysis, quantitative modeling is necessary. Therefore, feedback processes between the identified risks, planned flexibility options and other factors affected have to be described by various stock-flow diagrams structured in IPS²-specific partial models (value architecture, result- and availability-based revenue streams, cost structure and organization).

Figure 6 depicts the most important aspects of this investigation within a simplified version of the partial model *value architecture* (production of movement plates for C's high-quality watches). The *completion rate* of the production process is dependent on the *overall team FTE* (full time equivalent) and the *effort per order*. In addition, there is a differentiation of the output in *accepted units* for final assembly and *rejected units*, which are dependent from the *error rate* closely linked to the variable *relative work pressure*.

4.3 Scenario Analysis by means of Quantitative Modeling

In the *base scenario* (see section 4.1) the IPS² business model is gradually adapted over the lifecycle as contractually agreed upon without any problems. The partial model *value architecture* (see Figure 6) is connected to two further partial models: revenue generation and cost structure.

Within the partial model for revenue generation, the gradual business model adaptation is also considered by two different revenue constructions (result-based and availability-based). The result-based part is based on *accepted units*. The availability-based part is based on OEE (Overall Equipment Effectiveness) which is calculated by multiplying the quality, performance and availability index. The used model structure can be found in [13], [22]. Figure 7 shows the resulting *cumulative net operating result* (black solid line) over time of the business relationship for the base scenario.

In a *threat scenario*, SP faces the problem of workforce shortage due to an unexpected increasing quit rate of SP's employees. As a result, there is a decline in the cumulative net operating results due to losses in year 2 (phase $t_1 - t_2$).

Figure 7 shows the respective curve characteristics (gray solid line). Hence, flexibility is necessary which can be realized by means of the above mentioned two options. Within these two options, the gradual business model adaptation has also been agreed on by analogy to the base scenario.

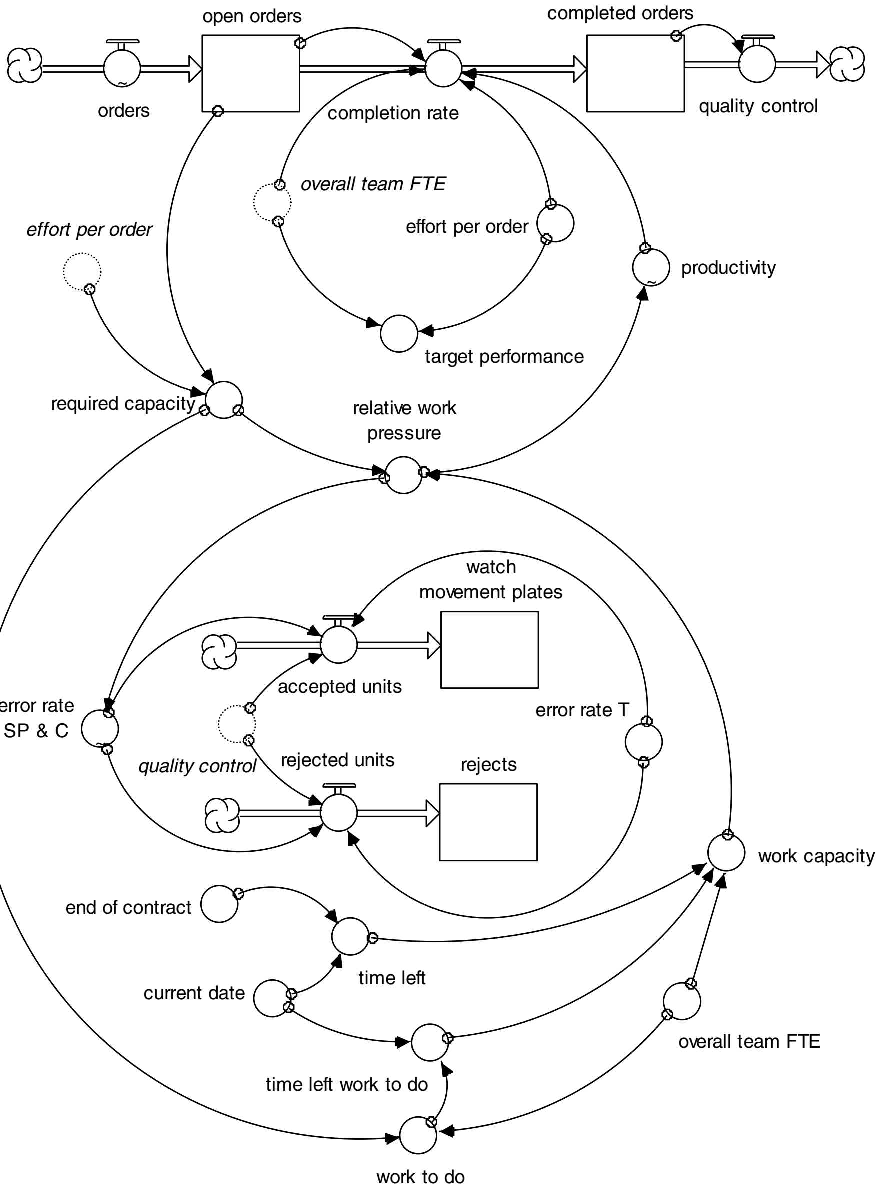


Fig. 6. Partial model value architecture (simplified)

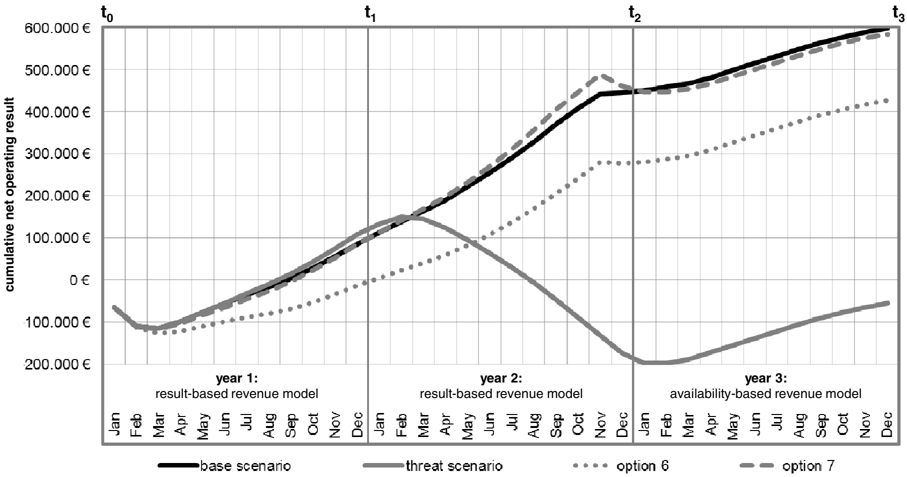


Fig. 7. Cumulative net operating result based on scenarios and flexibility options

Aiming at flexible employment contracts, SP has the possibility to decide for *option 6*, i.e. the use of T. Thereby, the quality management realizes in t_1 a relatively high reject rate (*quality control*). A detailed cause analysis reveals that the high work pressure involves carelessness and de-motivation. Within the model, the *relative work pressure* increases which results in a correspondingly higher *error rate T*. Hence, the amount of *accepted units* is reduced as well. On the one hand, this results in a decline of result-based revenue. On the other hand, there is an increase of costs caused by a higher reject rate. The gray dotted line in Figure 7 illustrates the course of the resulting *cumulative net operating profit*. Within the scope of *option 7*, SP can decide for a strategic capacity enlargement in order to be flexible in the long-run. On the one hand, this causes hiring and training costs which decrease the rate of return in short-run. On the other hand, this measure produces also an increase in the net operating result (see Figure 7, gray dashed line) in the long-run due to a higher *productivity* and an increasing quality rate. As a result, option 7 is the better strategy in dealing with the threat scenario.

5 Summary and Further Research

For an IPS² provider it is extremely important to estimate the economic effects of provisioning flexibility which is needed to deal with uncertainty and to ensure profitability in complex and dynamic IPS² business relationships. Since the provider has different possibilities for building flexibility, i.e. through short-term and long-term measures, decision support is necessary to evaluate the economic effects of these measures. In order to ensure this evaluation, complexity reduction as well as the consideration of IPS²-specific decision parameters is indispensable to support decision making within complex IPS² business relationships. Therefore, methods such as SD have to be consistently applied in order to examine all relevant interdependencies and feedback structures within the respective IPS² business model.

Accordingly, the authors present a modeling and simulation approach which comprises important feedback structures of the value architecture of a solution provider's business model. The presented procedure of qualitative mapping clearly shows that the consistent use of SD simplifies this dynamic complexity. By defining flexibility options which imply various scenarios, quantitative modeling is introduced. On this basis, the resulting revenue streams and the cost structure are derived in order to establish various scenario simulations focusing on the cumulative net operating result as an indicator for the success of the respective business model scenario.

Nevertheless, it is still unclear, how to convince a customer of the advantages of a specific business model configuration. Consequently, further research has to pay attention to using the presented approach for communicating the different effects resulting from flexibility measures in order to raise the customer's awareness for investments in flexibility at an early stage. The visualization of the consequences of choosing a flexibility option offers opportunities to assure the costumer in investments. This can help if the customer tends to choose external, ex post flexibility. In this case, the objective of the communication is to convince the customer of ex ante flexibility and cost sharing.

Acknowledgements. We express our sincere thanks to the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) for financing this study within the Collaborative Research Center Transregio 29 (CRC/TR 29) on Industrial Product-Service Systems – dynamic interdependencies between products and services in the production area.

References

1. Meier, H., Uhlmann, E., Kortmann, D.: Hybride Leistungsbündel: Nutzenorientiertes Produktverständnis durch interferierende Sach- und Dienstleistungen. wt Werkstattstechnik Online 95(7/8), 528–532 (2005)
2. Mont, O.K.: Clarifying the Concept of Product-Service System. Journal of Cleaner Production 10, 237–245 (2002)
3. Roy, R.: Sustainable Product-service Systems. Future 32(3/4), 289–299 (2000)
4. Belz, C., Schuh, G., Gross, A.S., Reinecke, S.: Erfolgreiche Leistungssysteme in der Industrie. In: Belz, C., Schuh, G., Gross, A.S., Reinecke, S. (eds.) Industrie als Dienstleister. St. Gallen, Thesis (1997)
5. Richter, A., Sadek, T., Steven, M., Welp, E.G.: Use-oriented business models and flexibility in Industrial Product-Service Systems. In: Roy, R., Shehab, E. (eds.) Proceedings of the 1st CIRP IPS^2 Conference, pp. 186–192. Cranfield University Press, Cranfield (2009)
6. Das, T.K., Teng, B.-S.: Trust, Control, and Risk in Strategic Alliances: An Integrated Framework. Organization Studies 22(2), 251–283 (2001)
7. Datta, P.P., Christopher, M.G.: Information sharing and coordination mechanism for managing uncertainty in supply chains: a simulation study. International Journal of Production Research 49(3(1)), 765–803 (2011)
8. Walker, W.E., et al.: Defining uncertainty: a conceptual basis for uncertainty management in model based decision support. Integrated Assessment 4(1), 5–17 (2003)

9. Rese, M., Meier, H., Gesing, J., Boßlau, M.: An Ontology of Business Models for Industrial Product-Service Systems. In: Proceedings of the 4th CIRP International Conference on Industrial Product Service Systems, Tokyo, Japan (2012) (yet to be published)
10. Teece, D.J.: Business models, business strategy and innovation. Long Range Planning 43(2-3), 172–194 (2010)
11. Meier, H., Uhlmann, E., Völker, O., Geisert, C., Stelzer, C.: Reference Architecture for dynamical organization of IPS^2 service supply chains in the delivery phase. In: 2nd Intl. Conference on IPS^2, Linköping (2010)
12. Meier, H., Uhlmann, E.: Hybride Leistungsbündel – ein neues Produktverständnis. In: Meier, H., Uhlmann, E. (eds.) Integrierte Industrielle Sach- und Dienstleistungen, pp. 1–21. Springer, Heidelberg (2012)
13. Meier, H., Boßlau, M.: Dynamic Business Models for Industrial Product-Service Systems. In: Proceedings of the 30th International Conference of the System Dynamics Society, 13th PhD Colloquium, Plenary Session, St. Gallen, Switzerland (2012)
14. Steven, M., Alevifard, S., Keine genannt Schulte, J.: Economic Relevance of IPS^2 Flexibility. In: Hesselbach, J., Herrmann, C. (eds.) Functional Thinking for Value Creation, pp. 261–265. Springer, Heidelberg (2011)
15. Alwert, K., Heisig, P., Mertins, K.: Wissensbilanzen – Intellektuelles Kapital erfolgreich nutzen und entwickeln. In: Mertins, K., Alwert, K., Heisig, P. (eds.) Wissensbilanzen – Intellektuelles Kapital Erfolgreich Nutzen und Entwickeln. Springer, Heidelberg (2005)
16. Narasimhan, R., Das, A.: An empirical examination of sourcing's role in developing manufacturing flexibilities. Int. J. Prod. Res. 38(4), 875–893 (2000)
17. Sethi, A.K., Sethi, S.P.: Flexibility in Manufacturing – A Survey. The International Journal of Flexible Manufacturing Systems 2(4), 289–328 (1990)
18. Kayis, B., Kara, S.: The supplier and the customer contribution to manufacturing flexibility – Australian manufacturing industry's perspective. Journal of Manufacturing Technology Management 16(7), 733–752 (2005)
19. Sterman, J.D.: Business Dynamics: Systems thinking and modeling for a complex world. McGraw (2000)
20. Morecroft, J.: Strategic Modelling and Business Dynamics. Wiley (2007)
21. Warren, K.: Strategic Management Dynamics. Wiley (2008)
22. Meier, H., Boßlau, M.: Design and Engineering of Dynamic Business Models for Industrial Product-Service Systems. In: Proceedings of the 4th CIRP International Conference on Industrial Product Service Systems, Tokyo, Japan (2012) (yet to be published)
23. Schermann, M.: Risk Service Engineering. Gabler, Wiesbaden (2011)
24. Rieke, T.: Prozessorientiertes Risikomanagement: Ein informationsmodellorientierter Ansatz. Inauguraldissertation, Wirtschaftswissenschaftliche Fakultät, Westfälische Wilhelms-Universität, Münster (2007)
25. Seibold, H.: IT-Risikomanagement. Oldenburg, München (2006)
26. Meier, H., Völker, O.: Aufbau- und Ablauforganisationzur Erbringung hybrider Leistungsbündel. In: Meier, H., Uhlmann, E. (eds.) Integrierte Industrielle Sach- und Dienstleistungen, pp. 137–161. Springer, Heidelberg (2012)
27. Pidd, M.: Tools for Thinking. Modelling in Management Science. Wiley (2003)

The Real Nature of Industrial Product Service Systems

Mario Rese, Julian Everhartz, Kira Maiwald, and Gina Mende

Marketing Department, Ruhr-University Bochum, Universitätsstraße 150, Bochum, Germany
{mario.rese,julian.everhartz,kira.maiwald,gina.mende}@rub.de

Abstract. Literature reveals several characteristics that differentiate Industrial Product Service Systems (IPS²) from rather simple stand-alone products and (value added) services. Taking a closer look on these, the authors argue that the collaboration within provision and use phases of IPS² is the most significant characteristic to distinguish IPS² from other offerings. The empirical part of the paper supports this assumption. It is shown that the collaboration between supplier and customer during the later stages of the IPS² life cycle in terms of co-creation of value actually constitutes the real nature of IPS².

Keywords: Industrial Product Service Systems, Characterization, Collaboration and Value Co-Creation.

1 Introduction

Traditional manufacturing firms are increasingly shifting from selling stand-alone product or service offerings toward selling bundles of integrated product and service components. These highly customized solutions can also be characterized as Industrial Product Service Systems (IPS²).

Literature reveals that several aspects differentiate IPS² offerings from rather simple stand-alone products and (value added) services. These are i) the combination and integration of product and service components, ii) the suppliers' customer orientation, iii) the suppliers' flexibility to adopt to changing customer demands, iv) the collaborative planning and development of these components, and v) the co-creation of value during the life cycle or rather the collaborative provision and use of these components. The research question arises whether these aspects are equally important to distinguish IPS² from stand-alone offerings or furthermore from common product-service combinations.

In order to analyze IPS² characteristics compared to usual product and service offerings we conducted a survey with 127 participants. All participants have been involved in buying decisions concerning manufacturing technology and automation solutions. In a first step the participants had to be divided into two groups: IPS² customers and Non-IPS² customers. For this it was necessary to find out in which specific characteristics both groups differ from each other. Based on the various definitions of IPS² and on supplemental literature review specific characteristics of IPS² were elaborated.

The paper at hand is organized as follows: First, we provide an overview of the commonly used characteristics to define IPS². Afterwards, we illustrate our empirical

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 585–596.
DOI: 10.1007/978-3-642-30820-8_49

research methods and discuss the results. Within the last section we point out the implication of our research and present further research questions.

2 Defining Industrial Product Service Systems

In order to characterize IPS² an underlying definition is needed. Therefore, different definitions found in literature are presented and compared in the following.

As Meier, Uhlmann and Kortmann (2005) stated, ‘‘an Industrial Product-Service System is characterized by the integrated and mutually determined planning, development, provision and use of product and service shares including its immanent software components in Business-to-Business applications and represents a knowledge-intensive socio-technical system’’ [1 p.529]. Following this definition Meier, Roy and Seliger (2010) listed several aspects of IPS² in detail. According to their understanding, an “IPS² is an integrated product and service offering that delivers values in industrial applications – IPS² is a new product understanding consisting of integrated product and service shares – IPS² comprises the integrated and mutually determined planning, development, provision and use – IPS² includes the dynamic adoption of changing customer demands and provider abilities – a partial substitution of product and service shares over the lifecycle is possible – This integrated understanding leads to new, customer-adjusted solutions – and IPS² enable innovative function-, availability- or result-oriented business models.” [2 p.608]

In other words, IPS² can be defined as bundles of several product and service components. These bundles can also be denoted as high-value integrated solutions designed to address a specific customer’s business or operational needs, like Davies (2004) as well as Davies et al. (2006) elaborate [3-4]. Bonney and Williams (2009) differentiate these types of offerings from traditional stand-alone product and service offerings as they note: “unlike individual products or traditional product/price bundles, solutions are idiosyncratic offerings that integrate a range of supplier capabilities and assets to address fundamental, often latent buyer needs.” [5 p.1032] More detailed Sharma et al. (2002) characterize a solution by listing its criteria. In their view “a real solution … is a fundamentally different approach that creates additional value for customers and suppliers by meeting five criteria: It is *co-created* by a customer and a supplier; It *integrates* products with services to meet essential customer needs; Suppliers accept some of the *risk*, often through performance-based and/or risk-based contracts; Relationships between suppliers and customers are unusually *intimate*, far beyond a traditional buy-sell relationship; Solutions, therefore, are tailored to each customer.” [6 p.3]

Further, Ulaga and Reinartz (2011) refer to such solutions as hybrid offerings [7]. In their recent article they adopt the conceptualization of Shankar et al. (2007) particularly with regard to hybrid offerings in business markets that combine industrial goods and services. According to this, a hybrid offering is a combination of “one or more goods and one or more services, creating more customer benefits than if the good and service were available separately.” [8 p.2] The same authors provide a much simpler definition in a managerial article: “hybrid solutions are products and services combined into innovative offerings”. [9 p.95]

However, these definitions – despite that different terminologies are used to describe the offering – share several commonalities. On this basis, we describe an IPS² by five characteristics:

- Combination and integration of product and service components,
- Customer orientation,
- Flexibility of contracts,
- Collaborative planning and development, and
- Collaborative provision and use.

In the following we will have a closer look on these characteristics.

3 Characterizing Industrial Product Service Systems

3.1 Combination and Integration of Product and Service Components

In Business-to-Business markets many suppliers offer services on top to the core product as a strategy to tailor their offerings better to each customer's unique requirements [3]. Services can be implemented at any stage of the long-lasting business relationship between customer and supplier. Services before the use phase are for example all consultancy services, like planning, developing or financing. During the use phase services regarding the maintenance of operated systems are most common. After the use phase the supplier can offer services like dismantling or disposal [3]. As these examples show, there are different forms and types of services. On the one hand, a service can be a quite simplistic repair and overhaul contract. On the other hand, the supplier can also actively participate in the customers' production processes, e.g. carrying out certain steps of the production.

In contrast to these service offerings, which are added to the core product, IPS² are integrated solutions of product and service components that combine industrial goods and services in a way so that the combination of these special offers creates more benefit for the customer than if the good and service would be offered separately [8]. Therefore, the pure combination of product and service components is not sufficient for a unique characteristic of IPS², because specific customer orientated bundles of products and services are widely-used strategies in the Business-to-Business markets and services differ in the degree of the collaboration.

Asking practitioners about the degree of the combination and integration of product and service components, they would probably indicate the degree as high although they only purchase simple stand-alone offerings or rather product-related services.

3.2 Customer Orientation

Customer orientation is defined as the degree to which a supplier and its employees practice the marketing concept by trying to help their customers and being aware of the customer's specific needs [10-11].

From the IPS² definitions mentioned, it becomes apparent that customer orientation plays a key role in every stage of the IPS² life cycle and the occurring business relationship between customer and supplier. As already mentioned, IPS² are characterized by the integration of the customer in the planning, development, provision and use phase [1]. This close business relationship between both parties leads to an on-going dynamic adoption when the customer's demands are changing [2].

However, the importance of customer orientation is well-known within all Business-to-Business industries. It is based on the empirical evidence that customer orientation has a positive effect on the whole company's performance. Also stand-alone product and service offerings provided within the framework of traditional transactional business models are mostly highly customized. In fact in Business-to-Business markets there are hardly any companies that do not act customer orientated. In turn, the concept of customer orientation does not seem to be suitable to define the uniqueness of IPS².

3.3 Flexibility of Contracts

Flexibility of contracts is not a new concept in practice as well. Flexible contracts already exist also for stand-alone product and service offerings, because companies are aware of the environmental uncertainty [12], like external factors, which are not under the control of the contracting units and thus may change in an unpredictable way [13]. With flexible contracts both parties try to ensure themselves when unexpected situations occur. These unexpected situations are dependent on market related factors [14], for example changes in law or changes regarding suppliers' or customers' requirements, which influence the market as a whole. All these changes cannot be foreseen and for both contracting parties it is necessary to build up contracts that leave room for certain changes.

The flexibility of contracts for IPS² is based on the assumption that several aspects of the final offering might not be clearly determined during the contracting period, like the extent of delivery and the final configuration and relation between service and product components. In addition to that, most often even customers cannot explicitly determine their needs by themselves [15].

While for stand-alone products or services flexibility is usually desired in the development and construction phases of projects, IPS² contracts also need flexibility during the use phase. Nevertheless, the flexibility of contracts cannot be a unique characteristic that separates traditional transactional offerings from relational IPS² offerings, because the use of flexible contracts is common not only for IPS².

3.4 Collaborative Planning and Development

The aspect of collaborative planning and development between the supplier and the customer of products or services or product-service-bundles is not a rather new phenomenon. Many researchers from various fields investigate and analyse the necessity to involve the customer within the planning and development phase of products and services [16-19].

There are several factors that determine the degree to which a collaborative planning and development is necessary in a business relationship. First to mention is the individuality and specialization of an offering. The higher the amount of specific customer requirements and needs regarding an offering the higher is the necessity for a collaborative planning and development. In contrast, rather standardized offerings are in most cases solely developed by the supplier. Second, the importance of the offering within the customer's production process determines the necessity of collaborative planning and development efforts. If the offering plays a crucial role within the customers' production process, a collaborative planning and development is much more likely than in case of rather meaningless offerings.

If these two aspects that determine the amount of collaborative planning and development are applied to different kinds of offerings, it becomes obvious that it is not a characteristic that separates IPS² offerings from traditional product or service offerings. Indeed, IPS² are in most cases rather highly individual and specific and often play a crucial role within the customers' production processes. As Baines et al. (2007) point out, "a successful PSS needs to be designed at the systemic level from the client perspective and requires early involvement with the customer and changes in the organizational structures of the provider." [20 p.1549] Nevertheless, this collaborative planning and development can also take place in case of offering standard products and/or services. Therefore, a division of standard products/services and IPS² by the degree of collaborative planning and development is not appropriate.

3.5 Collaborative Provision and Use – The Co-creation of Value

The collaboration between the supplier and the customer during provision and use phases of an offering is a quite new phenomenon. This new type of relationship is emerging since new relational and collaborative business models came up [21]. First of all it is important to clarify what the term "collaborative provision and use" really means. Literature does not provide a clear definition of this co-creation aspect. The collaboration within provision and use phase between the supplier and the customer means a collaborative conducting of certain production processes [22]. In this sense, the role of customers is to "co-create value through the integration of firm-provided resources with other private and public resources". [23 p.148]

More and more suppliers tend not to sell their products, but carry out a certain production process within the properties of their customers. In most cases the customer can benefit from this new type of business collaboration as the initial investments are relatively low. Neither the purchase of facilities nor the hiring or qualification of personal is in the customers' responsibility. Therefore, the customer organization can concentrate on its core business, whereas the supplier conducts the underlying processes. Also the suppliers can benefit from such a business model. They do not sell their facility at one point of time, but can generate continuous incoming cash flows by getting paid on a regular base. Additionally, IPS² suppliers benefit from this business model as it is ensured that customers do not acquire specific knowledge regarding the production process and therefore somehow depend on the suppliers in conducting the production processes.

This collaboration in the use phase is an aspect that is unique for IPS² and to the best of our knowledge not applied in regular product business. At this point it becomes strikingly obvious what really characterizes IPS². As we have shown above, all commonly used characteristics and attributes are also applicable to usual product business. We are only talking of IPS² if the supplier offering contains business models in which he collaborates with the customer in the provision and use phase. Hence, the terminology 'service' has a slightly different meaning in the context of IPS². It not only encompasses all the intangible activities of the supplier like repair, maintenance, overhaul and so forth but also comprises collaborative business models.

4 Method

4.1 Survey Description

Our survey consisted of 127 participants who were visiting a huge international trade fair for manufacturing technology and automation. The trade fair displays the entire scope of state-of-the-art manufacturing technologies for the metalworking industry – from machine tools and precision tools, to automation technology, to complete systems. The participants were randomly selected and asked whether they had a certain role in their companies' buying processes. If they confirmed, each participant was given a four-page questionnaire. If they were not involved in their organizations' buying processes they were excluded from participation. In the first part of the questionnaire participants were asked about the five characteristics of business relationships, mentioned above. The scale items to measure IPS² characteristics are included in the appendix. Participants were asked to indicate their agreement regarding the five attributes on a seven-point Likert scale ranging from 1 (I strongly disagree) to 7 (I strongly agree). The participants were mainly male (94.4%) and had an average tenure of 18 years (standard deviation: 11.387).

4.2 Results and Discussion

Based on the five characteristics of IPS² participants had to be divided into two groups; one group of IPS² customers and the other group of Non-IPS² customers.

The first attempt was to subjectively decide whether participants are IPS² customers or not by considering all five characteristics simultaneously. These decisions were made by three experts on IPS² who are researching in this area. Afterwards their final categorizations were compared so that inter-rater reliability is assumed. Unfortunately, the final categorizations were not the same at all. Thus, this method was not appropriate.

The second attempt was to divide the participants by having a closer look to the mean values of all characteristics, which are presented in table 1. In doing so, it was assumed that IPS² customers would rate the degree of all characteristics above the overall average including the standard deviation. Since the mean values range from 3.74 to 4.65 adding the standard deviation, there were no participants who met these requirement concerning all characteristics. Thus, no IPS² customer group unfolds.

Table 1. Mean values of total survey

	Combination and integration of product and service components	Customer orientation	Flexibility of contracts	Collaborative planning and development	Collaborative provision and use
mean value	4.49	4.65	3.74	4.52	4.57
number of participants	125	127	123	126	127
standard deviation	1.418	1.570	1.492	1.701	1.530

Table 2. Mean values of IPS² and Non-IPS² customers

	IPS² customers vs. Non-IPS² customers	Number of participants	Mean value	Standard deviation	Standard error of mean values
Combination and integration of product and service components	IPS² customers	41	5.05	1.117	.174
	Non-IPS² customers	84	4.21	1.473	.161
Customer orientation	IPS² customers	43	5.26	1.364	.208
	Non-IPS² customers	84	4.35	1.587	.173
Flexibility of contracts	IPS² customers	41	4.22	1.525	.238
	Non-IPS² customers	82	3.50	1.425	.157
Collaborative planning and development	IPS² customers	42	5.88	1.017	.157
	Non-IPS² customers	84	3.83	1.559	.170
Collaborative provision and use	IPS² customers	43	6.26	.441	.067
	Non-IPS² customers	84	3.71	1.115	.122

The theoretical findings presented in chapter three, provide a solution for this dilemma. Finally, participants were divided into IPS² and Non-IPS² customers by using only one of the five characteristics; the collaboration within provision and use phase. From the authors perspective this is the most significant distinguishing characteristic between IPS² offerings and stand-alone product and service offerings. The group of IPS² customers indicated that the provision and use of the supplier's offering takes place in a strong collaboration. Participants within this group rated this characteristic higher than the mean value plus standard deviation (≥ 6). Non-IPS² customers indicated that there is only little collaboration in the provision and use phase (< 6). Using this method groups end up with a size of 43 participants within the IPS² customers group and 84 participants within the Non-IPS² customers group.

Based on this classification the mean values of all IPS² characteristics could be compared. Here it became apparent that for every characteristic the mean values in the group of IPS² customers were higher than in the Non-IPS² customers group. Further, the highest differences between the two groups were found regarding the characteristic "collaborative provision and use". These results are shown in table 2.

The differences in mean values that are shown in table 2 are significant. T-tests as well as variance analyses both show that the two groups differ significantly from each other in every of the five characteristics (see Appendix).

5 Summary and Conclusions

As we have shown, quantitative empirical research in the context of IPS² has a fundamental structural problem. If a comparison between IPS² and standard product and service offerings shall be conducted, it is necessary to identify characteristics that really distinguish these two forms of offerings from each other. Our paper proposes a first approach to deal with this issue.

As already stated, the commonly used definitions of IPS² identify five core characteristics regarding this type of offerings. These are namely the combination and integration of product and service components, a high customer orientation, the flexibility of contracts, a collaborative planning and development phase and a collaborative provision and use phase. Our literature review reveals that four of these five aspects (the combination and integration of product and service components, a high customer orientation, the flexibility of contracts and a collaborative planning and development phase) are also appearing within the context of standard stand-alone product and service business. Therefore, the collaboration between the customer and the supplier within the provision and use phase is the only aspect that really distinguishes these types of offerings from each other. We used this insight resulting of an extensive literature review and applied it on our empirical data, obtained from visitors of a huge trade fair on industrial manufacturing and automation. This way we were able to differentiate survey participants in two groups, the IPS² group and the non-IPS² group.

From a scientific perspective our research has several important implications. First, a way to distinguish IPS² offerings from standard product or service business is proposed. This is an important step and contributes to research in this area as more and more companies position themselves in the field of IPS² offerings although they are selling standard products and services in a traditional way. With the characteristic of collaboration between the supplier and the customer during the provision and use phase a way to identify "real" IPS² suppliers is given. Based on this researchers is given the opportunity to analyze many differing aspects between common product and service offerings and IPS².

Additionally, our empirical data show that the other characteristics that define an IPS² are meaningful. We found significant differences between the group of IPS² customers and the group of Non-IPS² customers regarding customer orientation, flexibility of contracts, the combination of products and services and a collaboration during planning and development phase.

Acknowledgments. We extend our sincere thanks to the German Research Foundation DFG for funding this research project and to all who contributed to preparing this paper.

References

1. Meier, H., Uhlmann, E., Kortmann, D.: Hybride Leistungsbündel –Nutzenorientiertes Produktverständnis durch interferierende Sach- und Dienstleistungen. wt Werkstattstechnik Online, 528–532 (2005)
2. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems – IPS^2. CIRP Annals - Manufacturing Technology 59, 607–627 (2010)
3. Davies, A.: Moving base into high-value integrated solutions: a value stream approach. Industrial and Corporate Change 13, 727–756 (2004)
4. Davies, A., Brady, T., Hobday, M.: Charting a Path Toward Integrated Solutions. MIT Sloan Management Review 47, 39–48 (2006)
5. Bonney, F.L., Williams, B.C.: From products to solutions: the role of salesperson opportunity recognition. European Journal of Marketing 43, 1032–1052 (2009)
6. Sharma, D., Lucier, C., Molloy, R.: From Solutions to Symbiosis: Blending with Your Customers. Strategy+Business 27, 1–11 (2002)
7. Ulaga, W., Reinartz, W.J.: Hybrid Offerings: How Manufacturing Firms Combine Goods and Services Successfully. Journal of Marketing 75, 5–23 (2011)
8. Shankar, V., Berry, L.L., Dotzel, T.: Creating and Managing Hybrid Innovations. Presentation at AMA Winter Educators' Conference, San Diego, CA, February 16-19 (2007)
9. Shankar, V., Berry, L.L., Dotzel, T.: A Practical Guide to Combining Products and Services. Harvard Business Review 87, 94–99 (2009)
10. Saxe, R., Weitz, B.A.: The SOCO scale: a measure of the customer orientation of salespeople. Journal of Marketing Research 19, 343–351 (1982)
11. Dubinsky, A.J., Staples, W.A.: Are Industrial Salespeople Buyer Oriented? Journal of Purchasing and Industrial Management 1, 12–19 (1981)
12. Olsson, N.O.E.: Management of Flexibility in Projects. International Journal of Project Management 24, 66–74 (2006)
13. Fumas, V.S., Whinston, A.B.: Flexible Contracting Theory and Case Examples. European Journal of Operational Research 3, 368–378 (1979)

14. Kleindorfer, P.R., Wu, D.J.: Integrating Long- and Short-Term Contracting via Business-to-Business Exchanges for Capital-Intensive Industries. Industrial Marketing Management 27, 373–384 (1998)
15. Tuli, K.R., Kohli, A.K., Bharadwaj, S.G.: Rethinking Customer Solutions: From Product Bundles to Relational Processes. Journal of Marketing 71, 1–17 (2007)
16. Schreier, M., Fuchs, C., Dahl, D.W.: The Innovation Effect of User Design: Exploring Consumers' Innovation Perceptions of Firms Selling Products Designed by Users. Journal of Marketing 76, 18–32 (2012)
17. Grönroos, C.: Value co-creation in service logic: A critical analysis. Marketing Theory 11, 279–301 (2011)
18. Ballantyne, D., Varey, R.J.: The service-dominant logic and the future of marketing. Journal of the Academy of Marketing Science 36, 11–14 (2008)
19. Chesbrough, H.W.: The Era of Open Innovation. MIT Sloan Management Review 44, 35–41 (2003)
20. Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M., Wilson, H.: State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers - Part B – Engineering Manufacture 221, 1543–1552 (2007)
21. Oliva, R., Kallenberg, R.: Managing the transition from products to services. International Journal of Service Industry Management 14, 160–172 (2003)
22. Rese, M., Gesing, J.: Selling Solutions Needs an Understanding of Dynamic Business Models – Towards a Systematic Framework. In: Proceedings of the 19th International Colloquium in Relationship Marketing, Rochester, NY (2011)
23. Vargo, S.L., Maglio, P.P., Archpru Akaka, M.: On value and value co-creation: A service systems and service logic perspective. European Management Journal 26, 145–152 (2008)

Appendix

Scale Items to measure IPS² characteristics, all questions are measured on a seven-point Likert scale anchored by "strongly disagree" (1) and "strongly agree" (7):

Combination and integration of product and service components: The offering consisted of combined and integrated product and service components.

Customer orientation: The supplier considered our individual needs within the preparation of the offering.

Flexibility of contracts: Contracted elements can be adjusted during the business relationship flexible.

Collaborative planning and development: As customer we were highly involved in the planning and development of the offering.

Collaborative provision and use: The offering's implementation and usage is conducted in strong cooperation and high interaction with the supplier.

Results of T-tests:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Signifikanz	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Combination and integration of product and service components	Equal variances assumed	3,326	,071	3,203	123	,002	,834	,261	,319	1,350
	Equal variances not assumed			3,518	101,502	,001	,834	,237	,364	1,305
Customer orientation	Equal variances assumed	2,809	,096	3,204	125	,002	,911	,284	,348	1,473
	Equal variances not assumed			3,364	96,811	,001	,911	,271	,373	1,448
Flexibility of contracts	Equal variances assumed	,254	,615	2,579	121	,011	,720	,279	,167	1,272
	Equal variances not assumed			2,521	75,453	,014	,720	,285	,151	1,288
Collaborative planning and development	Equal variances assumed	22,270	,000	7,723	124	,000	2,048	,265	1,523	2,572
	Equal variances not assumed			8,848	115,303	,000	2,048	,231	1,589	2,506
Collaborative provision and use	Equal variances assumed	52,061	,000	14,362	125	,000	2,542	,177	2,191	2,892
	Equal variances not assumed			18,282	119,486	,000	2,542	,139	2,266	2,817

Results of variance analyses:

Tests of Between-Subjects Effects

		Type III Sum of Squares	df	Mean Square	F	Sig.
Combination and integration of product and service components	Corrected model	19,187	1	19,187	10,259	,002
	Error	230,045	123	1,870		
	Corrected total	249,232	124			
Customer orientation	Corrected model	23,582	1	23,582	10,265	,002
	Error	287,174	125	2,297		
	Corrected total	310,756	126			
Flexibility of contracts	Corrected model	18,797	1	18,797	12,909	,000
	Error	176,183	121	1,456		
	Corrected total	194,980	122			
Collaborative planning and development	Corrected model	117,397	1	117,397	59,643	,000
	Error	244,071	124	1,968		
	Corrected total	361,468	125			
Collaborative provision and use	Corrected model	183,710	1	183,710	206,270	,000
	Error	111,329	125	,891		
	Corrected total	295,039	126			

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mittel der Quadrate	F	Sig.
Corrected Model	Combination and integration of product and service components	19,987[a]	1	19,987	10,420	,002
	Customer orientation	23,993[b]	1	23,993	10,420	,002
	Flexibility of contracts	18,354[c]	1	18,354	8,909	,003
	Collaborative planning and development	118,584[d]	1	118,584	59,380	,000
	Collaborative provision and use	178,545	1	178,545	197,363	,000
Intercept	Combination and integration of product and service components	2278,168	1	2278,168	1187,769	,000
	Customer orientation	2441,513	1	2441,513	1060,338	,000
	Flexibility of contracts	1621,759	1	1621,759	787,176	,000
	Collaborative planning and development	2501,130	1	2501,130	1252,421	,000
	Collaborative provision and use	2624,495	1	2624,495	2901,112	,000
SOL	Combination and integration of product and service components	19,987	1	19,987	10,420	,002
	Customer orientation	23,993	1	23,993	10,420	,002
	Flexibility of contracts	18,354	1	18,354	8,909	,003
	Collaborative planning and development	118,584	1	118,584	59,380	,000
	Collaborative provision and use	178,545	1	178,545	197,363	,000
Error	Combination and integration of product and service components	228,245	119	1,918		
	Customer orientation	274,007	119	2,303		
	Flexibility of contracts	245,167	119	2,060		
	Collaborative planning and development	237,647	119	1,997		
	Collaborative provision and use	107,654	119	,905		
Total	Combination and integration of product and service components	2685,000	121			
	Customer orientation	2899,000	121			
	Flexibility of contracts	1982,000	121			
	Collaborative planning and development	2793,000	121			
	Collaborative provision and use	2759,000	121			
Corrected Total	Combination and integration of product and service components	248,231	120			
	Customer orientation	298,000	120			
	Flexibility of contracts	263,521	120			
	Collaborative planning and development	356,231	120			
	Collaborative provision and use	286,198	120			

a. R Squared = ,081 (Adjusted R Squared = ,073)

b. R Squared = ,070 (Adjusted R Squared = ,062)

c. R Squared = ,333 (Adjusted R Squared = ,327)

d. R Squared = ,624 (Adjusted R Squared = ,621)

Calculation of Maintenance Costs on Poor Data Basis and Implementation in Industrial Practice

Gisela Lanza, Nicole Stricker, and Dominic Appel

Institute of Production Science, Karlsruhe Institute of Technology, Karlsruhe, Germany
{Gisela.Lanza,Nicole.Stricker,Dominic.Appel}@kit.edu

Abstract. Life-cycle cost statements become increasingly important for OEMs to stay competitive in today's global environment. However, OEMs have to create this information from a poor data basis. Generating reliable statistical LCC statements despite the poor data is the methodical challenge. Consequently, it's crucial to set up an instrument that prepares the data for analysis and simplifies future data collection. Therefore, a database was set up for Licon mt GmbH & Co. KG and the Weibull solution method was adapted by using a weighted pseudo inverse matrix. Both, the database and the adapted method are presented.

Keywords: Life Cycle Cost, Reliability, Data Analyses.

1 Introduction

According to the cooperating company Licon mt GmbH & Co. KG, OEMs face a growing competition and cost pressure due to increasing globalization on the market. [1] Therefore, product quality needs to be a differentiator. In order to visualize the advantages of high quality products Life Cycle Cost (LCC) statements are used. [2]

They demonstrate what studies of [3-7] revealed: purchase prices are 20% of the actual costs that derive from a product lifecycle. Considering the whole product lifecycle, high quality products can thus be cheaper than minor quality products due to less maintenance activities. Therefore, maintenance costs play a key role when concerning LCC.

Not only OEMs but also machine tool operators face an increasing global competition. Therefore, they need to reduce their production costs and improve their productivity which in turn results from a reduction of machine downtimes. Thus, machine reliability gains in importance over the whole machine's lifecycle.

The customer's request for reliable machines leads to special industrial product service systems. These systems consist of an integrated bundle of a product and its service, generating a higher value for the customer [8]. Within the machine and plant industry, special warranties represent those industrial product service systems (IPS²). Machines are sold in combination with a distinguished warranty which guarantees a level of availability, specifically the number of possible machine working hours. This increases the machine's value for the customer. These availability warranties are basic requirements for investment decisions, today. [9, 10]

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 597–608.
DOI: 10.1007/978-3-642-30820-8_50

In this context reliability improvement warranties (RIW) are in focus. Given a RIW, the machine manufacturer is obliged to provide a certain level of reliability. [8, 11-15] A related concept is represented by the Life-Cycle-Cost-Warranty (LCCW) that guarantees an upper limit of maintenance costs for selected LCC-components.

The reliability of machine components highly affects maintenance costs, which make up for a major share of Life Cycle Costs and therefore also build an essential part of LCC statements. [3, 16-20] So, when creating warranties both service costs for machine failures and the number of machine failures within the warranty period are crucial information highly influencing the warranty.

Data on these costs and lifetimes are generated via statistical models using field data which on the one hand have the advantage of being related to the practical use of the machine tool but on the other hand are a rather poor database. Due to few comparable machines which usually have a high reliability, failure data is mostly very sparse and suspended. [21]

As will be shown in section 2.2 the quality of data has a major impact on the generated statements. Therefore, presenting an approach for simplifying correct data collection and analyzing the existing poor data by taking into account minor data quality is the aim of this paper.

The paper is organized as follows: Chapter 2 gives an overview of the state of the art of and reliability analysis as well as possible censoring and failures of data. Chapter 3 presents the methodology of future data collection using a specific database and the new approach for exceeding analysis of the existing poor data. Chapter 4 gives the resulting conclusions and chapter 5 contains the summary.

2 Literature Review

2.1 Reliability Analyses

The aim of reliability analyses is to determine the failure behaviour of a machine's component. In this context reliability is defined according to [22-24]: reliability is the probability that a product does not fail under given environmental conditions during a defined period of time.

Considering a machine's reliability leads to substantiated prognosos on expected machine downtimes which have a high impact on future maintenance costs. Several analyzing and forecasting methods are used to generate reliability statements. The reliability of a component depends on the operating and load conditions under which it is processed. These factors influence the failure probability of a component. For example: the longer a component has been used, the more loads it has endured, the higher its failure probability. Therefore, statistical methods are used to describe the failure probability which directly leads to conclusions of its reliability.

For stochastic modelling of the failure probability different functions are suggested [12, 22, 25]. By far the most commonly used one among them is the two-parameter Weibull distribution [26, 22, 23, 27, 28]. The object of the Weibull analysis is to determine the distribution parameters (β, η) based on the failure data records and suspended data (see chapter 2.2). This data basis can be derived from life testing, maintenance and service reports or replacement part sales [see 29-31].

The suspended data records are taken into account of the analysis by using the Johnson method [32]. When applying the Johnson method a rank is assigned to each failure record according to its observed working hours without failures. In this assignment, the suspended data records are considered and affect the assigned ranks. Afterwards the Rank Regression is applied to fit the ranked data to the linearized Weibull curve [27]. This regression utilizes the least squares method. This is the most widely used procedure for the determination of the Weibull failure probability distribution function.

Other methods simply use the Mean Time Between Failures (MTBF) instead of a fully parameterized probability function. As the MTBF is an average value it contains less information than a fully parameterized probability function. However, it is much easier to calculate and understand which is the reason for its common use in industry. The calculation of the MTBF as the average value of the observed working hours often leads to misleading conclusions. Therefore, this method should not be used.

2.2 Quality of Data

Whatever analyzing method is used the given data is crucial for the results. Usually the given data is subject to certain failures or suspensions. The suspensions can be divided into right and left censored data. If the machine started working before the observation period begun, it is not known for how long the machine worked until its first observed failure. This is described by the term right censored data. Left censored data arise if the observation period ends while a machine is still working. So, only the machine's working hours until the end of the observation period are known but not the whole period of time until it failed. Only if at least two failures occur within the observation period unsuspended data records can be derived.

Besides, the suspension data can be faulty. If the data is not tracked automatically at each failure, some failure data records can be missed easily. This significantly prolongs the recorded working hours of the machine between two tracked failures before and after the missed one. Those failures and suspensions have strong effects on the accuracy of analysis which will be shown in section 3.4. Therefore, a systematic data acquisition is needed. By now most of the data records are generated manually when applying service to machines in the field which bears a high risk of data failures or losses. Achieving higher quality of data is one motivation for the development of an appropriate database, which then leads to an improvement in monitoring and forecasting reliability. With reliability being an essential factor for creating warranties as discussed earlier, handling low qualitative data is particularly important in the context of IPS².

3 Methodology

3.1 Database

The developed and implemented database is described in this section. Its structure and interface can be seen in Figure 1. The purpose of this database is both data collection and data analysis. Concerning data collection using this database supports simplified data acquisition by offering a systematic structure which includes a column for each relevant data information needed for analysis. Thus it is obvious which data to collect.

For each machine data is recorded whenever service work is done or a service part is ordered. The service technician records data for all columns in the database. Besides the relevant information needed for reliability analysis also service costs are recorded. As maintenance costs are calculated by service costs for machine failures and the number of machine failures, this database helps collecting information for better estimation of future maintenance costs. With rising complexity in innovative business models like IPS² additional planning effort is required. [33] This is respectively true for better planning of maintenance costs, which make up for an essential share of Life Cycle Costs and are therefore very important in the context of IPS².

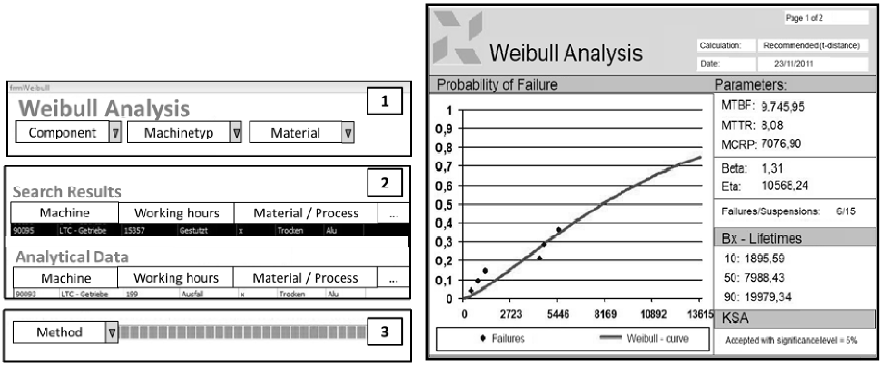


Fig. 1. User Interface of the developed database (left), upper section of the result window of data analysis (right)

Data Analysis is done by using the interface in Figure 1. This interface is organized in three sections (see numbers in Figure 1). For each analysis the corresponding acquired data is used. Therefore, section 1 provides different dropdown menus to specify the needed data, e.g. machine types, materials and so on.

Section 2 enables a final selection of the data records used for analysis. All data records matching the criteria specified in section 1 are shown in the black area of section 2. In some cases the user might wish to exclude some of these data records from analysis. A reason for this can be the implausibility of some data records which might indicate errors in the specific record. The finally selected data records are shown in the white data area of section 2 (“Analytical Data”). Section 3 consists of a status bar and a selection field. The user can determine here which calculation method to use for analysis, e.g. consideration of a confidence interval. The status bar indicates the remaining time needed for calculation.

The analysis yields to a result window which is also composed of three sections. The upper section is shown in Figure 1 on the right side. This section of the result window shows the calculated Weibull distribution on the left and all obtained statistical rating numbers on the right. The result of the Kolmogorov-Smirnov-Test (here KSA) for confidence level of 95% is also given at the bottom of the window’s right side. The middle section of the result window is given in Figure 2.

Used Data									
ID	*Machine number*	*Assembly group*	*Station*	*Position /axis*	*BS-counter*	*Failure/ Suspended*	*Wet/ dry*	*Material*	*Repair time*
7028	12345	Motor	3	X	11000	Failure	Wet	Aluminium	

Fig. 2. Middle section of the result window of data analysis

It visualizes the data records used for analysis. So it shows the finally selected data. These data records are uniquely numbered. Figure 3 gives the lower section of the result window.

Data from the service reports:								
ID	*Station*	*Spindle position / axis*	*Designation*	*Assembly group*	*Article ID dismounted*	*Article ID mounted*	*Crash*	*Category of failure*
7028	3	X		Motor	123456-0	123456-0	Yes	

Fig. 3. Lower section of the result window of data analysis

This section gives the service reports of the used data records and additional information, if available. Given the graphical and clear presentation of the results, this tool proves to be very useful for industrial purposes. So the developed database is easy to use although it includes heavy calculations. The next section will give a brief overview of the different calculation methods used within the tool.

3.2 Weaknesses in the Latest Common Analysis

As described in section 2.1 the usual procedure for the determination of the failure probability distribution function is to first consider the suspended data using the Johnson-method, second linearizing the Weibull function and then fitting a line to the given data which then represents the found Weibull distribution. The linearization is done by logarithmically scaling the axis according to formula 1.

$$\begin{gathered} F(t) = 1 - e^{-(\frac{t}{\eta})^{\beta}} \\ -\ln(1 - F(t)) = (\frac{t}{\eta})^{\beta} \\ \ln(-\ln(1 - F(t))) = \beta * \ln(t) - \beta * \ln(\eta) \\ \downarrow \\ y = m * x + c \end{gathered} \tag{1}$$

According to formula 1 the Weibull distribution function can be transformed into the regular linear function with slope m and intercept c by using the logarithm. Therefore, x and y are calculated as shown in formula 2.

$$\begin{aligned} y &= \ln(-\ln(1 - F(t))) \\ x &= \ln(t) \end{aligned} \tag{2}$$

When fitting a line to the Weibull function after linearizing it, certain problems arise. When linearizing the Weibull function, all failures are incorporated equally for the calculation of the regression line but the early failures have a greater impact on the least squares method due to the logarithm (see formula 1). Consider two failure data records at $t_1=100h$ and $t_2=10.000h$. The true underlying Weibull distribution function shall be:

$$F(t) = 1 - e^{-(\frac{t}{5174})^{0,63}} \tag{3}$$

Given this function, the true values for t_1 and t_2 are $F(t_1)=0,08$ and $F(t_2)=0,78$. The corresponding values obtained by the Johnson-method are $F_J(t_1)=0,1$ and $F_J(t_2)=0,8$. So the difference for both values is $\Delta F(t)= F_J(t)-F(t)=0,02$.

Regarding the same calculation for the linearized case the following results arise:

For t_1=100h: x_1=4,605;y_1=-2,250 y_{J1}=-2,484;$\Delta y_1=y_{J1}-y_1$=0,234
For t_2=10.000h: x_2=9,210;y_2=0,476 y_{J2}=0,415;$\Delta y_2=y_{J2}-y_2$=0,061

So, when linearizing the function before applying the least squares method, early failures have a greater impact than later failures do. In order to overcome this weakness in the presented procedure, different methods are proposed in the next section.

3.3 Exceeding Analysis Methods

The here presented approaches have been developed in close cooperation with Licon mt GmbH & Co. KG, a supplier of machining centers and production systems. The developed methods have one common property: they consider and overcome the weakness presented in section 3.2. They either fit the data to a Weibull distribution function before linearizing the function or they compensate the arising consequences.

In this paper two approaches are presented: The numerical minimization of the sums of error squares which fits the data to the Weibull distribution before the linearization and the algebraic minimization of the sums of error squares which takes the problems into account that are arising from the linearization. Both methods apply the Johnson method to the failure data in order to generate $F_J(t)$.

When using the numerical minimization of the sum of error squares, Weibull distributions with different parameter combinations (β, η) are build. For each parameter combination the sum of error squares between the Weibull distribution and the underlying data is evaluated. Since two parameters need to be adjusted, this calculation has two loops, one for β and one for η. The parameter combination with the smallest sum of error squares is chosen.

When applying the algebraic minimization of the sums of error squares, a system of linear equations arises. Each failure data record leads to one linear equation. The equation system can then be expressed in a matrix notation. As the resulting matrix is not invertible and not in quadratic form, its inverse cannot be created.

Since more than two equations face two variables, this equation system cannot be fulfilled for linear independence of the equations. In order to find the solution that best meets the criteria of minimizing the sum of error squares, the Moore–Penrose pseudo inverse [34] is used. This concept is exceeded by using the weighted pseudo inverse [35] to offset the linearization problems (see section 3.2). Therefore, three assumptions have to be made:

1. All recorded failures in the data records are statistically independent.
2. The expected value of the difference between the recorded failure data and the actual Weibull distribution is zero.
3. The variance of the difference between the recorded failure data and the actual Weibull distribution has a constant value.

Given these assumptions, the weighted pseudo inverse can be used to identify the Weibull distribution that best fits the recorded failure data.

The here presented numerical and algebraic methods as well as the commonly used procedure using the Rank-Regression will be compared in the next section.

3.4 Comparison of the Analyses

When comparing the presented methods, different data conditions have to be considered. As mentioned in chapter 1, the database given for analysis can be very poor. Therefore, the methods are compared regarding data of different quality levels: complete data and data with 20% losses. The corresponding database is generated by simulating Weibull distributions with different parameter combinations.

Four parameters can be altered: β, η, the number of relevant machines and the observed period of time. Those four parameters were selected because they vary in given industrial data. The parameter η however, is not further varied, since it determines only the position but not the shape of the Weibull distribution.

Failure data records are now generated corresponding to the specified parameters (β, the number of concerned machines and the observed period of time). Weibull distributions are determined according to the parameters, and data records are drawn from them randomly. Therefore, uniformly distributed numbers out of the range 0 to 1 are drawn. The dissolution of the Weibull distribution function then results in corresponding failure times *t*.

$$t = \eta \left[\ln \left(\frac{1}{1 - F(t)} \right) \right]^{\frac{1}{\beta}} = \eta \left[\ln \left(\frac{1}{1 - random()} \right) \right]^{\frac{1}{\beta}} \tag{4}$$

For each machine random numbers are drawn until the sum of the individual failure times *t* is greater than the specified observation period. Then the last failure data record will be deleted. The difference between the sum of failure times and the observation period represents a suspension. This is done for the specified number of machines and leads to a complete database. The databases with losses are generated by randomly deleting 20% of the given data records. The resulting data basis is analyzed by using the presented three methods. The results are shown below. In the given results two characteristic values were examined: the difference in MTBF values and the standard deviation. Each simulation run generates a data basis. When analyzing this data basis the different methods lead to different Weibull parameters and thus expect different underlying Weibull distributions. Based on the determined parameters the expected MTBF ($MTBF_{sim}$) for the expected underlying Weibull distribution is calculated. For each simulation run with the same input parameters, the resulting MTBF is calculated. Then the arithmetic mean of these MTBFs ($MTBF_{am}$) is calculated. As the true underlying Weibull distribution is known from the input parameters β and η of the simulation, the true MTBF ($MTBF_{true}$) can be calculated as well. The difference of $MTBF_{am}$ and $MTBF_{true}$ is a measure of the quality of the analysis.

Besides, the standard deviation of the different $MTBF_{sim}$ values for simulation runs is regarded. This gives an impression about the robustness of the different methods. The results for the different data basis are shown below.

Complete Data. Figure 4 shows the results for all three methods when analyzing a complete data basis.

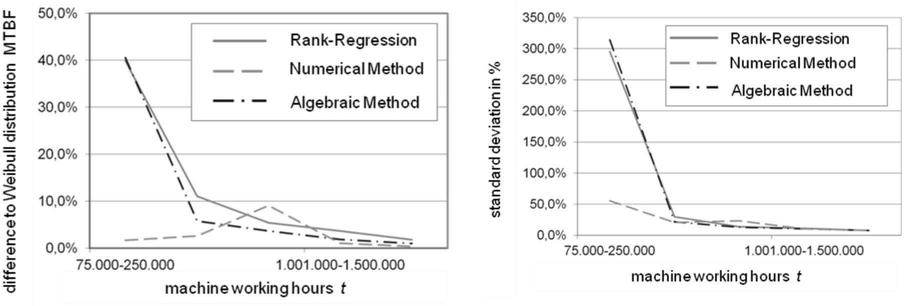


Fig. 4. Difference to Weibull distribution MTBF for complete data (left) and standard deviation of $MTBF_{sim}$ for complete data (right)

Figure 4 clearly shows that all calculation methods converge towards the true underlying Weibull distribution for high machine working hours which means, for a long observation period. It also demonstrates that the commonly used Rank-Regression method cannot compete at any time with the best practices. Considering the scattering of the calculated $MTBF_{sim}$ it leads to a similar result. If the standard deviation of the $MTBF_{sim}$ is plotted against the machine hours (see Figure 4), the numerical method shows an even greater dominance. So for complete data the numerical method is the most robust one.

Data with 20% Losses. 20% of data losses seem to be realistic. The lifecycle of machines is much longer than the warranty period of its manufacturer lasts. After the warranty expires, most customers handle maintenance activities on their own.

So afterwards, only a small percentage of failure data records are reported to the machine manufacturer. Besides, some data records get lost due to human reporting errors. As can be seen in Figure 5, all the curves shifted significantly upwards in comparison to the complete data basis. The numerical method is no longer clearly superior to the algebraic one.

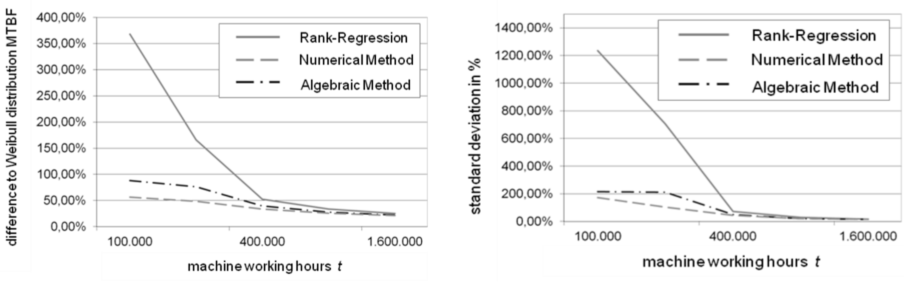


Fig. 5. Difference to Weibull distribution MTBF for data with 20% losses (left) and Standard deviation of $MTBF_{sim}$ for complete data (right)

Figure 5 shows the strong dominance of the new calculation methods (numerical and algebraic ones). Although all calculation methods converge towards the same difference level for long observation periods again, the Rank-Regression method is clearly exceeded for all machine working hours. The algebraic and the numerical method are clearly superior as they adopt much better $MTBF_{am}$ values, even for short observation periods.

The standard deviation shows a similar behavior (see Figure 5). All methods show a weaker performance as with the complete data basis. But considering the logarithmic scaling of the axis, the presented numerical and algebraic methods are clearly superior to the Rank-Regression.

4 Conclusions

As shown in section 2.2, a poor data basis always has a negative effect on the result achieved by analysis. This negative effect is obviously given for all analyzing methods. The better the quality of the data basis is the better are the achieved results. Therefore, the given data should be as complete as possible. Improving the quality of the data basis is supported by the database presented in section 3.1. It allows a systematic collection of data. By the predetermined information fields, the data quantity to be recorded is also reduced to the relevant data parts.

In industrial practice, the available data basis is generally poor. In order to get the best possible information out of the available data, it is crucial to use appropriate methods of analysis. According to section 3.2 the commonly used Rank-Regression method is inferior. Both presented methods the numerical and the algebraic minimization of the sums of error squares are to be preferred to the case of incomplete data.

5 Summary

The paper presents an approach for simplifying correct data collection by using an appropriate database. The presented database is offering a simple overview of the needed data. It consists of a systematic structure which includes columns for relevant data information needed for analysis. With regard to maintenance costs all relevant data for prediction, i.e. service costs for machine failures and the historical machine lifetimes, are collected. However, the purpose of this database is not only data collection but also an integrated data analysis with a simple user-friendly interface. Besides the database the paper presented and compared different analyzing methods. The performance of these methods was regarded for different data qualities by the use of simulations. The proposed methods showed to be superior in the case of poor data.

So, those new methods generate more trustworthy predictions of the machine's reliability and maintenance costs and thus enable the manufacturer to calculate prices for the IPS² bundle of machine and warranty more precisely. As [15] states the unavailability of useful data for prediction is a problem in the flied of IPS². Therefore, this paper will support the diffusion process of IPS² in the machine and plant industry.

The close cooperation with Licon mt GmbH & Co. KG in developing the analyzing methods and building the database led to a direct feedback from industry. The database with its analyzing methods is set up to the needs of our cooperating partner. It now is an implemented part in the industrial practice of Licon mt GmbH & Co. KG.

Acknowledgments. We extend our sincere thanks to the German Federal Ministry of Economics and Technology (BMWi) and to the Deutsche Forschungsgemeinschaft (German Research Foundation) for the promotion of the research project "Scalable life-cycle performance prediction methods for machine and plant industry" ("Skalierbare Life-Cycle-Performance-Prognoseverfahren für den Maschinen- und Anlagenbau").

References

1. Lauven, L., Wiedenmann, S., Geldermann, J.: Lebenszykluskosten als Entscheidungshilfe beim Erwerb von Werkzeugmaschinen. Research Paper Nr. 10; Schwerpunkt Unternehmensführung, Wirtschaftswissenschaftliche Fakultät, Georg-August-Universität Göttingen (2010)
2. Boge, C.: LCC/TCO aus Sicht eines Werkzeugmaschinenherstellers. In: Schweiger, S. (ed.) Lebenszykluskosten Optimieren: Paradigmenwechsel für Anbieter und Nutzer von Investitionsgütern, pp. S117–S133. Gabler (2009)
3. Dervisopoulos, M., et al.: Chancen und Risiken von Life Cycle Costing im Maschinen- und Anlagenbau. Industrie Management (2006); Blischke, W.R., Murthy, D.N.P.: Warranty Cost Analysis. Marcel Decker, New York (1994)
4. Huth, J.: Lebenszykluskosten wichtig für den Kauf von Großmaschinen. Tiefbau 6/2005, Schrobenhausen (2005)
5. Krawitz, G.: Beschaffungsstrategien unter Berücksichtigung von Life Cycle Costing. VDI Nachrichten Konferenz Life Cycle Costing, Augsburg (2004)
6. Westkämper, E., von der Osten-Sacken, D.: Lebenslaufgerechte Anlagen ausgestalten – Life Cycle Costing ermöglicht innovative Produkte. Industrieanzeiger 20 (1997)
7. Ziegler, G., Albrecht, V.: Total Cost of Ownership bei DaimlerChrysler. VDMA-Informationstag Lebenszykluskosten, Frankfurt (2006)

8. Meier, H., Völker, O., Funke, B.: Industrial Product-Service Systems (IPS^2) - Paradigm shift by mutually determined products and services. The International Journal of Advanced Manufacturing Technology 52, S1175–S1191 (2010)
9. Fleischer, J., Nesges, D.: Identifying Availability Contribution of Lifecycle-Adapted Services. In: Brissaud, D., et al. (eds.) Innovation in Life Cycle Engineering and Sustainable Development. Springer (2006)
10. Lanza, G., Behmann, B.: Advanced steps to optimize the serviceability. In: Frick, J. (ed.) Advances in Production Management Systems (APMS). Value Networks: Innovation, Technologies and Management, Stavanger, Norwegen. Springer, Herausgeber/ Veranstalter, Heidelberg, New York (2011)
11. Blischke, W.R., Murthy, D.N.P.: Warranty Cost Analysis. Marcel Decker, New York (1994)
12. Blischke, W.R., Murthy, D.N.P.: Reliability – Modelling, Prediction, and Optimization. Wiley, New York (2000)
13. Erkoyuncu, J., Roy, R., Shehab, E., Cheruvu, K.: Understanding service uncertainties in industrial product–service system cost estimation. The International Journal of Advanced Manufacturing Technology 52, S1223–S1238 (2011)
14. Gandara, A., Rich, M.D.: Reliability Improvement Warranties for Military Procurement. A Project Air Force report prepared for the United States Air Force, R-2264-AF (1977)
15. Murthy, D.N.P., Blischke, W.R.: Warranty Management and Product Manufacture. Springer, London (2006)
16. Donati, D.: The Life Cycle Cost Paradigm Shift in Maintenance. In: 2007 International Applied Reliability Symposium. ARS Europe, Frankfurt (2007)
17. Fleischer, J., Weismann, U.: Interorganisationelles Anlagencontrolling – Eine Vorgehensweise zur Ableitung fallbezogener Kennzahlen und deren Überwachung im Lebenszyklus. wt Werkstattstechnik Online 96 (2006)
18. Lanza, G., Werner, P., Niggeschmidt, S.: Life Cycle Performance als wesentliches Qualitätsmerkmal von Investitionsgütern. 11. FQS-Forschungstagung 2009, Frankfurt/Main, Deutschland, Herausgeber/Veranstalter FQS Forschungsgemeinschaft Qualität e.V., Band FQS-Band 80 - 09 Erfolgsfaktor Qualität - 20 Jahre FQS, pp. S134–S144 (2009)
19. Niemann, J., Stierle, T., Westkämper, E.: Kooperative Fertigungsstrukturen im Umfeld des Werkzeugmaschinenbaus – Ergebnisse einer empirischen Studie. wt Werkstattstechnik Online, Düsseldorf (2004)
20. Niemann, J., Westkämper, E.: Investitionskosten versus Betriebskosten. Wt Werkstattstechnik Online, Düsseldorf (2004)
21. Lanza, G., Werner, P., Behmann, B.: Prognosis of machine tool warranty costs considering arising risks through weak data sets and unknown load profiles. In: ESREL - European Safety and Reliability Conference. Verlag CRC Press - Taylor & Francis Group, Herausgeber/Veranstalter European Safety and Reliability Association, Rhodos, Griechenland, London (2010)
22. Bertsche, B., Lechner, G.: Zuverlässigkeit im Fahrzeug- und Maschinenbau. Ermittlung von Bauteil- und System-Zuverlässigkeiten. Springer, Berlin (2004)
23. Birolini, A.: Reliability Engineering, Theory and Practice. 5. Auflage. Springer, Berlin (2007)
24. Department of Defense (Hrsg.): Military Standard 785: Reliability Program for Systems and Equipment – Development and Production, Washington, USA (1980)
25. Birolini, A.: Qualität und Zuverlässigkeit technischer Systeme. 3. Auflage. Springer, Berlin (1991)

26. Abernethy, R.B.: The new Weibull Handbook – Reliability and Statistical Analysis for Predicting Life, Safety, Survivability, Risk, Cost and Warranty Claims, North Palm Beach (2000)
27. Deutsches Institut für Normung (Hrsg.): DIN IEC 61649, Weibull-Analyse – Anpassungstests und Vertrauensbereiche von Weibull verteilten Daten. Beuth-Verlag, Berlin (2004)
28. Ramirez, R.B.: Application of Reliability Demonstration Testing to the Product Development Life Cycle. In: International Applied Reliability Symposium, ARS Europe, Frankfurt (2007)
29. Fleischer, J., Niggeschmidt, S., Wawerla, M.: Optimizing the Life-Cycle-Performance of Machine Tools by Reliability and Availability Estimation. In: 14th CIRP Conference on Life Cycle Engineering, Tokyo, Japan (2007)
30. Fleischer, J., Wawerla, M.: Risk Management of Warranty Contracts in Machine Building Industry. In: 2007 International Applied Reliability Symposium, Frankfurt, S. T2–S4 (2007)
31. Fleischer, J., Wawerla, M., Niggeschmidt, S.: Machine Life Cycle Cost Estimation via Monte-Carlo-Simulation. In: 14th CIRP Conference on Life Cycle Engineering, Tokyo, Japan (2007)
32. Deutsches Institut für Normung (Hrsg.): DIN EN 61649: Weibull Analyse. Beuth-Verlag, Berlin (2008); Blischke, W.R., Murthy, D.N.P.: Reliability – Modelling, Prediction, and Optimization. Wiley, New York (2000)
33. Uhlmann, E., Gabriel, C., Raue, N., Stelzer, C.: Influences of the IPS2 Business Model on the Development of a Micro Milling Spindle. In: 3rd CIRP IPS2 Conference (2011)
34. Zurmühl, R., Falk, S.: Matrizen und ihre Anwendungen. 6. Auflage. Springer, Berlin (1997)
35. Brammer, K., Siffling, G.: Kalman-Bucy-Filter – Deterministische Beobachtung und statistische Filterung: 3. Auflage. Oldenburg, München (1989)

Lifecycle Oriented Flexibility Assessment of Customized Solutions in Capital Goods Industry: A State of the Art

Johannes Keine genannt Schulte[1], Sebastian Waltemode[2], Marion Steven[1], and Jan C. Aurich[2]

[1] Faculty of Management and Economics, Ruhr-Universität Bochum, 44780 Bochum, Germany
[2] Institute for Manufacturing Technology and Production Systems, University of Kaiserslautern, P.O. Box 3049, Kaiserslautern, 67653, Germany
johannes.keinegenanntschulte@rub.de, waltemode@cpk.uni-kl.de

Abstract. The beginning of a Product-Service System´s lifecycle is surrounded by a high degree of uncertainty regarding customers' todays and prospective requirements. Thus, the ability to adapt a Product-Service System to changing customer requirements by providing flexibility becomes an important quality and success criterion along the entire lifecycle. This paper analyzes existing approaches of economic and engineering theory dealing with the assessment of flexibility in the industrial environment. A State of the Art is provided including literature reviews on both the economic assessment, based on NPV and ROA, and the engineering assessment, based on a detailed flexibility analysis that originates from manufacturing systems. The article continues with implications, followed by a recommendation and appoints tasks for further research.

Keywords: Product-Service Systems, Flexibility, Assessment.

1 Introduction

Customers of capital goods no longer demand pure technical products, but customized solutions, consisting of a product enhanced by different services along its life cycle that are generally understood as Product-Service Systems (PSS) in the industrial B2B-area [1-2]. Therefore, capital goods manufacturers enter into long-term business to business relationships with their customers. In particular, at the beginning of these relationships a high degree of uncertainty regarding customers' todays and prospective requirements exists [3].

Thus, the ability to adapt PSS to changing customer requirements becomes an important quality and success criterion along the entire lifecycle. While flexibility of manufacturing systems has been subject of research for many years [4-6], flexibility of service structures and processes is rarely considered. In order to assess and improve flexibility of PSS a flexibility concept is required that contains PSS-specific types of flexibility as well as adequate assessing methods. Against this background, this paper aims at analyzing existing approaches of flexibility assessment that mostly originate from an economic perspective. It also focuses on manufacturing systems

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 609–620.
DOI: 10.1007/978-3-642-30820-8_51

regarding their suitability for PSS. At first, a conceptual understanding of PSS flexibility is given. Subsequently, requirements regarding a suitable assessment method for PSS flexibility are derived. Finally, these requirements are confronted with existing assessment approaches for assessing flexibility from economic and manufacturing perspective. Therefrom, implications for further research on assessing flexibility of PSS are derived.

2 Flexibility of Product-Service Systems

2.1 Definition

The scientific literature provides a variety of definitions of flexibility in the context of manufacturing systems [4-6]. Due to the fact that most of these definitions are formulated rather generally and refer to systems, they can be used as a basis for developing a flexibility definition for PSS. Besides of manufacturing aspects, it is of particular importance to include flexibility of service structures and processes of a PSS. In this area there is still a lack of definitions and concepts in the literature.

In the following, flexibility of PSS is understood as the ability to adapt to changing customer requirements without significant effort of time and cost. Additionally, an adequate consideration of arising risks is necessary. Thereby, adaptions of the product, of services and external production factors as well as their interplay have to be taken into account. Therefore, a wide range of possible system conditions constitutes a key prerequisite. Moreover, flexibility of PSS is understood as a relative property that depends not only on a PSS but also on the external requirements respectively changing circumstances.

2.2 New Scope of Consideration

In order to assess flexibility, first the scope of consideration has to be defined. PSS can be viewed from a static and a dynamic perspective [7]. From a static, system theoretical point of view, PSS can be differentiated into three subsystems [8, see Figure 1]. Those contain different elements that include the production factors for delivering PSS. The subsystem "product" represents a technical product that is divided by means of a function structure. The subsystem "customer" includes all external production factors the customer contributes to the PSS-realization (e.g. production site, user). The subsystem "service network" comprises the organizational and operational structures that are necessary to produce different services. When having a system theoretical view on PSS, flexibility is considered as system inherent.

In general, the lifecycle of PSS can either be viewed from provider's or from customer's perspective [1-2]. In the following, a PSS within customer environment is considered as scope of investigation for flexibility assessment. It starts with an investment phase that can be differentiated into decision making and purchasing. This is followed by a long usage phase of the product that is supported by different services. Finally, the disposal of the product takes place [9-10]. Neither the integrated processes of planning and developing a PSS nor the manufacturing processes are subject of the flexibility assessment. Thus, a suitable flexibility concept for PSS has to cover both system flexibility and the flexibility of the delivery processes from customer's point of view.

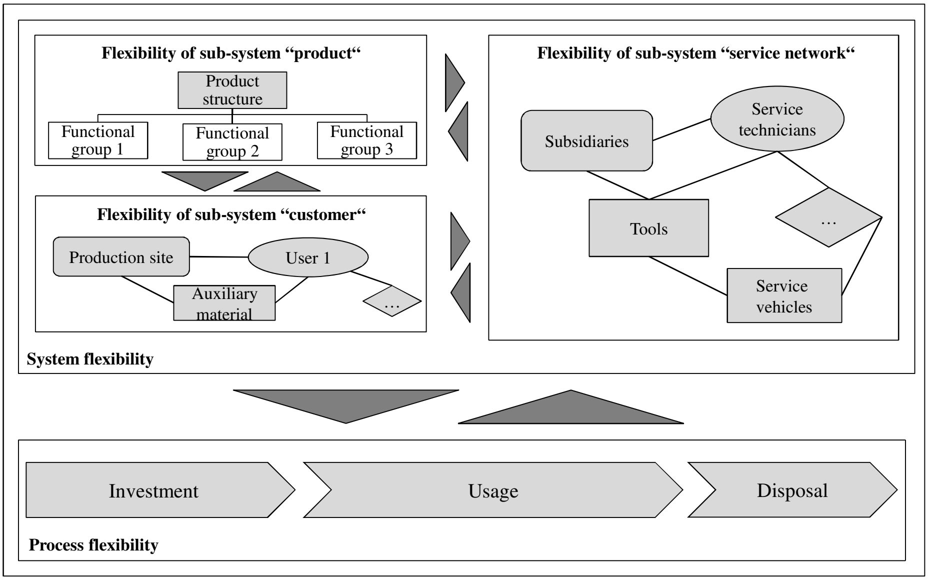


Fig. 1. New scope of flexibility evaluation (following [7])

2.3 Types of Flexibility for Product-Service Systems

In the scientific literature there is agreement that flexibility is a multidimensional phenomenon and determined by numerous influence factors [11]. This can also be transferred to PSS. In order to assess flexibility, different types of flexibility have to be defined that operationalize system and process flexibility of PSS. System flexibility consists of the flexibility of the aforementioned sub-systems. System flexibility is an intrinsic property respectively potential that sets the architecture for process flexibility of PSS. Process flexibility comprehends the ability of adapting process sequences and deployed internal and external production factors within delivery of PSS. Those processes result from the interaction between the sub-systems of a PSS.
In the following, system-oriented types of flexibility are proposed that serve for assessing flexibility of PSS and are mainly based on [4-6]:

Sub-system "product"

- **Product flexibility:** ability of a product to carry out different production tasks economically and with acceptable quality. This also includes the ability for convertibility.
- **Volume flexibility:** ability of a product to produce different production lots economically and with acceptable quality.

- **Operation flexibility:** ability of a product to operate in different production environments (e.g. mobile working machinery) as well as to produce different product variants.
- **Expansion flexibility:** ability of a product to be expanded without noteworthy cost and time (e.g. by additional product modules).

Sub-system "customer"

- **Customer flexibility:** ability of external production factors (customer's personnel, auxiliary material etc.) to adapt to changing circumstances.

Sub-system "service network"

- **Service flexibility:** ability of a service network to perform different types of services economically and with acceptable quality.
- **Volume flexibility:** ability of a service network to perform different numbers of services economically and with acceptable quality.
- **Operation flexibility:** ability to deliver services in different (production) environments as well to deliver different service variants.
- **Expansion flexibility:** ability of a service network to be expanded easily (e.g. additional service technicians).

Process flexibility of PSS can be specified into flexibility of production processes and flexibility of service processes:

- **Production process flexibility:** ability to achieve production goals in different process sequences. Depends on the flexibility of the product and the machine user.
- **Service process flexibility:** ability to generate a customer benefit with different process sequences. Depends on the flexibility of service network as well as on the flexibility of external factors (e.g. customer's personnel).

3 State of the Art in Flexibility Assessment: Review

Flexibility of PSS is analyzed from different points of view. At first, contextual requirements are worked out. In the second place, the assessment process of flexibility is based on an economic perspective. In the third place, flexibility is analyzed from a technical, engineering perspective.

3.1 Identification of Requirements

Regarding the characteristics of PSS in the industrial area (B2B), the following requirements to assess a PSS´s value were identified as working definitions:

- Level of assessment

The level of assessment is subdivided into two hierarchical categories: The PSS´s level considers the generic system and process level. In other words, the generic result can be metered. The second hierarchical level is understood as level of elements. It contains the subsystem and subprocess level and provides a more detailed description of flexibility of product and service parts, as well as the influence of the external factor. This level is far more detailed and gives insight in form of subsystems or subprocesses that are necessary to achieve the generic result.

- Dimensions of assessment

The dimensions of assessment include the categories of cost, time, adaptability and risk. These dimensions help to ensure a PSS´s functionality and productivity and therewith its overall performance. Therefore, they are important factors for an economically significant assessment of PSS in the industrial area and necessary to support technical decisions by economic values.

- Time of assessment

As far as PSS are considered, their attention is devoted to a long-term orientation and therewith to a lifecycle centered point of view. The long-term influence of decisions made in this context reverts to the underlying processes that are in charge of running the PSS successfully. Going on to an assessment that is conducted during the whole lifecycle and several times, effects of changes over time become obvious. This enables decision makers to adapt decisions formerly made to maintain the effectiveness of the underlying PSS and to react properly to changes in customer requirements or market needs.

But why is the assessment of flexibility important for PSS and how it can be done? In today´s economic environment the importance of long-term success is more and more under pressure by rising competition mostly from BRIC-countries. Anyway, the rising competition is accompanied by an increased appreciation of lifecycle costs by decision makers mostly from Eastern countries [12]. Even if some decision makers still rely on acquisition costs, their portion is decreasing because decision makers from emerging countries overcome this traditional, short-term thinking and switch to a lifecycle orientation [12].

In the following, the state of the art in evaluating flexibility of PSS is provided.

3.2 Assessment of Product-Service Systems as Investment Projects

PSS in the industrial area can be characterized as investment projects, because of the need for investments under uncertainty at the beginning of their development [13]. Hence, the approaches to be introduced in 3.2.1 originate from an investment point of view.

3.2.1 Literature Review Regarding Flexibility Assessment of Product-Service Systems

In reference [14] it is argued that use of the Real Options Analysis (ROA) can be a useful tool to determine a situation specific and appropriate degree of provided and inherent flexibility of a PSS. The whole purpose is to offer and understand flexibility as an option to improve the measurability of flexibility´s economic value in monetary terms [3]. Richter, Sadek and Steven [3] dealt with the concept of modularization [15] and observed that modularization may be a helpful tool to increase flexibility. They concluded that the approach of Baldwin and Clark [15] - when used for PSS in the industrial area - is of limited use, because of assuming additivity in value of modules. In contrast, PSS used in an industrial environment are characterized by interdependent parts of products and services that influence each other. This is due to the concerted development process regarding products and services [3].

Rese, Karger and Strotmann [16] tried to implement flexibility by determining the net present value, followed by a decision tree that is based on real options for prospective changes. In order to choose the best possible decision, the different option values are determined by using a recursive approach. By using a combination of NPV and ROA in the way of [16], a possible solution with and without flexibility is provided.

Karger et al. [17] valued flexibility according to the requirements of industrial PSS. On the one hand, the authors conducted the customer´s willingness to pay for additional flexibility and interpreted the result as value of the underlying option. On the other hand, the net value of the provided flexibility is conducted by including the provider´s costs for offering this flexibility and assessed by using the NPV approach. It is concluded that the supplier´s choice how to implement flexibility depends on the resulting value with regard to its amount in monetary terms.

Table 1. Literature review regarding assessment of flexibility of PSS

	Assessment level				Assessment dimension				Assessment type			Assessment approach	
	Product-Service System	Subsystem product	Subsystem service network	Subsystem external factor	Costs	Time	Adaptability	Risk	Ex ante	Lifecycle	Ex post	NPV	ROA
Abele et al. (2006)	○	●	○	○	◑	◑	◑	◑	◑	○	○	◑	◑
Steven et al. (2008)	●	○	○	○	○	○	○	◑	○	○	○	◑	◑
Rese/Karger/Strotmann (2009)	●	○	○	○	◑	◑	◑	○	○	◑	○	◑	◑
Karger et al. (2010)	●	○	○	○	◑	◑	◑	◑	◑	●	○	◑	◑
Richter/Sadek/Steven (2010)	●	○	○	○	◑	○	◑	◑	◑	◑	○	○	◑

completely fullfilled ● partially fullfilled ◑ not fulfilled ○

Abele et al. [18] created a concept to use the ROA on product centered manufacturing systems in order to insert flexibility including its contribution to create value. As the authors dealt with practical problems regarding different manufacturing systems, their proposal of using the Black-Scholes formula [19] is to be discussed briefly. The approach seems to be attractive for the focal scope as the authors focused on different kinds of manufacturing systems and tried to assess some kinds of flexibility.

Especially, the use of the Black-Scholes formula limits the focal analysis to only one kind of uncertainty. Furthermore, the Black-Scholes assumptions of a known market price in combination with a European option are quite unrealistic [20] for real assets in the B2B-area.

In the industrial environment of PSS, an option may also be an American option. This means that the option can be drawn at any time before maturity. Hence, the use of the Black-Scholes-Formula is insufficient with regard to the requirements of PSS and a multitude of different kinds of uncertainty. Furthermore, practitioners claim that a complexity reduction, as it is done by financial options using the Black-Scholes formula, may be risky because of the nonobservance of a multitude of variables that influence the underlying option(s) [21-22].

Table 1 unfolds that there is still a great potential for research regarding the measurability of flexibility by using Real Options in context of PSS. These articles are mainly based on the topic of industrial PSS but do not implement a formalized Real Options analysis capable to quantify a chosen flexibility option.

In the following, approaches for valuing Real Options are presented. Those are realistic but focus on valuing investment decisions with Real Options in general. Nonetheless, using these approaches seems to be an adequate way to enhance the measurability of flexibility for PSS in the B2B-area.

3.2.2 Evolution towards the Applicability on Product-Service Systems

The aforementioned approaches tried to implement flexibility into the context of PSS in the industrial B2B-area. These approaches can be understood as effective but still remain rudimentary in assessing real options and their value contribution.

As a first step to extend the adequacy of assessing the value of flexibility, the evaluation process of Copeland and Antikarov [20] is discussed. They argued, that the best comparable for the object of investigation is an adequate approximation of itself. The traditional approach of NPV is used on the investment project and constitutes the starting point for the further analysis. The NPV approach can normally be used as a static or dynamic version. Copeland and Antikarov use a Monte-Carlo simulation to determine an adequate approximation of prospective present values in different points of time. The assumption of a random walk of changes in the underlying present values supports the use of Monte-Carlo simulation in the evaluation approach. Due to this assumption, it is possible to consider a variety of uncertainties. This is an advantage compared to the Black-Scholes formula that is only capable to consider one kind of uncertainty.

But, the problem of an increase in complexity, because of a variety of different kinds of uncertainty is to narrow down. The complexity reduction is solved by combining different kinds of uncertainty - by using a Monte-Carlo simulation - and treating them like one. Therefore, the estimation of volatility is a key element to receive a satisfying result. This procedure may lead to falsification if the underlying uncertainties cannot be combined due to e.g. interdependencies. Even if statistical difficulties occur, an accompanying event tree can be constructed. It displays surrounding forms of uncertainty and the evolution of the present value in distinctive points of time in a binominal lattice. Until now, options to deal with underlying uncertainty are neither considered nor assessed.

By implementing specific kinds of flexibility, the event tree is transformed into a decision tree including a converted risk scheme and additional costs because of the provision of additional flexibility. For the first time, a difference between the values with and without flexibility results. Until now, the value of incorporated options is not evaluated separately. The approach concludes with valuing the different revenues from step to step of the decision tree and therewith the added Real Options.

3.2.3 Boundaries for the Applicability

As this approach seems to be feasible, some critics are noticeable. The problem is, that every time a decision tree is built up, assumptions have to be made, e.g. about future values of options etc., that are based primarily on uncertain and asymmetric information [21]. Haathela [23] constitutes that the approach of Copeland and Antikarov [20] leads to a bias in the estimated volatility and is therefore to be adapted according to the underlying focus of a particular analysis. Furthermore, the approach of Copeland and Antikarov [20] is not built up to value Real Options in (industrial) PSS. The special characteristic of an integrated development of product and service parts is difficult to measure. The value contribution of a technical part is measurable quite easily because of the existence of appropriate data. It becomes much more complicated to measure the value contribution of services like training courses or a technician's personnel skill. But the main problem to be solved in future research is to determine the value that evolves from the collaboration of provider and customer.

The similarities to the approaches analyzed in 3.2.1 are pointed out in the following:

An exclusive and separated usage of the approaches mentioned above, limits the focal scope to chosen, localized applications. Changes over time are not considered adequately. In case of using only a static NPV approach without considering flexibility options, the consequence will be a permanent underestimation of the project´s real value [16]. The resulting bias may lead to incorrect managerial decisions. Using ROA separately is extremely difficult to solve due to a significant rise in complexity and effort in computing option values. The approach of Copeland and Antikarov [20] including critics of Haathela [23] can be understood as a feasible starting point for the valuation of flexibility of (industrial) PSS.

3.3 Flexibility Assessment of Product-Service Systems Based on Approaches from a Manufacturing Perspective

3.3.1 Literature Review Regarding Flexibility of Manufacturing Systems

Flexibility assessments in manufacturing environments refer either to technical or to socio-technical systems. This includes approaches on different system levels (plant level, production line level, and machine level). In this context, numerous assessment approaches were developed. In the following section selected approaches for flexibility assessment on machine level are analyzed and evaluated against the defined requirements of PSS (see chapter 3.1).

Most approaches for assessing flexibility refer to manufacturing systems respectively machine level. Mandelbaum and Brill [24] developed a mathematical description of flexibility that is based on theory of probability. They defined measures in order to quantify the notion of how well a machine or group of machines can absorb changed requirements. They recommended measuring the efficiency of the manufacturing equipment in performing its tasks to evaluate manufacturing flexibility. Chang et al. [25] described flexibility of manufacturing systems as a function of range of operations, time, and cost. They propose different equations that are based on entropy approach, which was extended from information theory, and the Data Envelopment Analysis (DEA) for the measurement of manufacturing flexibility [25].

Table 2. Classification of selected approaches for flexibility assessment

	Assessment level				Assessment dimension				Assessment type		
	Product-Service System	Subsystem product	Subsystem service network	Subsystem external factor	Costs	Time	Adaptability	Risk	Ex ante	Lifecycle	Ex post
Mandelbaum et al. (1989)	○	●	○	○	○	◑	●	●	●	○	○
Chang et al. (2001)	○	●	○	○	●	○	◑	◑	●	●	○
Reinhart et al. (2007)	○	●	○	○	◑	◑	●	○	◑	●	●
Baykasoglu et al. (2008)	○	●	○	○	●	●	●	●	●	○	○
Lanza et al. (2010)	○	●	○	○	●	○	◑	◑	●	●	○

completely fullfilled ● partially fullfilled ◑ not fulfilled ○

Reinhart et al. [26] understand flexibility as a potential of a manufacturing system that is determined in the early phases of its design. Thereby, they considered volume and variant flexibility. In order to measure and assess flexibility of manufacturing systems they developed indicators for each flexibility type. These indicators are supposed to be monitored within so called flexibility corridors [26-27]. Baykasoglu et al. [28] the theory of permanents is applied to measure the flexibility of manufacturing systems. They developed a flexibility diagraph that comprehends different states that a system is able to work in and its possibility to move from one state to another. Flexibility is determined by assessing the efficiency of the current state as well as the efficiency of moving from one state to another. Moreover, flexibility depends on the probability of operating in one state as well as the probability of changing states [28]. Lanza et al. [29] propose an assessment approach for flexible quantities (volume) and product variants in production. It aims at forecasting production costs by a simulation algorithm that allows a comparison between different production scenarios.

Table 2 shows a scheme for classifying the approaches for flexibility assessment against the requirements derived from the characteristics of PSS. It serves as summarizing overview of the discussed approaches of flexibility assessment in manufacturing environments.

3.3.2 Implications to Flexibility Assessment of Product-Service Systems

Research on flexibility of manufacturing systems goes back to the early 1980s. Thus, numerous flexibility types and assessment methodologies were developed and discussed in this area. With regard to PSS it can be captured that these approaches are transferable to the sub-system "product" of a PSS. However, there is still a lack of approaches for flexibility assessment of service networks and the influences of external factors. Moreover, the interdependencies between product and services that occur within PSS delivery process are not covered by the existing approaches. In order to fill this gap, investigating the existing approaches regarding their expandability to assess flexibility of service network and external factor seems promising. Therefore, approaches have to be appropriate to measure and assess the flexibility types for PSS defined in chapter 2.3.

There is wide agreement in the scientific literature that flexibility of manufacturing systems can be assessed regarding the dimensions cost, time, and amount of possibilities for adaption. These dimensions are also included in the aforementioned flexibility definition for PSS. Among the analyzed approaches only [28] considers these three dimensions equally. Most of the approaches focus only on one dimension and consider the others indirectly. With regards to PSS the system-oriented flexibility types should be measured by indicators concerning possibilities for adaption. The process-oriented types of flexibility should be measured by indicators in terms of effort of cost and time needed for adaptions. For visualizing and monitoring these indicators, the flexibility corridor according to [26] is applicable. It has to be noted that system flexibility of PSS constitutes a key influence factor on process flexibility. These interdependencies between flexibility types exist and have to be revealed and included in the flexibility assessment of PSS.

Most of the analyzed approaches are based on ex ante assessments that use different scenarios and simulation algorithms to forecast flexibility. This is caused by the fact that flexibility is viewed as an inherent property of a system that is determined before its usage. But these simulation-based approaches seem problematic when transferring them to service processes. In particular, customer contributions in service processes are highly individual and therefore difficult to predict and hard to simulate [30]. Rather, a lifecycle oriented approach is necessary that allows a measurement of flexibility indicators at defined measuring times during delivery of PSS. At this point it can be concluded that new indicators have to be developed that are able to operationalize all flexibility types for PSS. In particular, indicators for measuring and assessing the flexibility types of service networks, customer influences on PSS flexibility as well as the interdependencies between products and services are required.

4 Summary and Further Research

This article focused on both the economic and the engineering point of view. From the economic perspective, the assessment of flexibility was analyzed by using approaches of investment theory. The technical assessment was conducted by focusing on a detailed description of flexibility types and appropriate indicators on a subsystem level. The authors conclude that a comprehensive flexibility assessment is required. It is recommended to assess a PSS´s value by using a combination of NPV and ROA that is to be combined with an indicator based approach in order to link strategic and operative needs by monitoring and control flexibility and its monetary impact along its lifecycle. Due to the special properties of PSS, the existing approaches cannot be transferred easily. For example, the influences of customers on process flexibility of PSS (production process flexibility, service process flexibility) have to be considered by using adequate indicators. From the technical perspective, an adapted definition of data gathering is needed for computing problem specific indicators as a task for further research. In the economic assessment of flexibility, the focus of future research lies on an adequate adaptation of the introduced approaches in order to implement specific characteristics and problems of industrial PSS.

Acknowledgments. This research is financially supported by the German Science Foundation (DFG) through SFB/TR 29 on Industrial Product-Service Systems[1] and also co-funded by the German state Rhineland-Palatinate and the European Funds for Regional Development (EFRE)[2] as part of the ongoing InnoProm-project "Productivity and Quality of Services".

References

1. Meier, H., Uhlmann, E., Kortmann, D.: Hybride Leistungsbündel – Nutzenorientiertes Produktverständnis durch interferierende Sach- und Dienstleistungen. wt Werkstattstechnik Online 95, 528–532 (2005)
2. Aurich, J.C., Fuchs, C., Wagenknecht, C.: Life Cycle Oriented design of Technical Product-Service Systems. J. Cleaner Prod. 7, 1480–1494 (2006)
3. Richter, A., Sadek, T., Steven, M.: Flexibility in industrial product-service systems and use-oriented business models. CIRP J. Manuf. Sci. Techn. 3, 128–134 (2010)
4. Browne, J., Dubois, D., Rathmill, K., Sethi, S.P., Stecke, K.E.: Classification of flexible manufacturing systems. FMS Magazine 2, 114–117 (1984)
5. Gupta, Y.P., Goyal, S.: Flexibility of manufacturing systems: Concepts and measures. Eur. J. Oper. Res. 2, 119–135 (1989)
6. Sethi, A.K., Sethi, S.P.: Flexibility in Manufacturing: A Survey. Int. J. Flex. Manuf. Sys. 2, 289–328 (1990)
7. Fuchs, C.: Life Cycle Management investiver Produkt-Service Systeme – Konzept zur lebenszyklusorientierten Gestaltung und Realisierung. Dissertation, Kaiserslautern (2007)
8. Aurich, J.C., Waltemode, S.: Qualität technischer Produkt-Service Systeme. wt Werkstattstechnik Online 102, 508–512 (2012)
9. Zehbold, C.: Lebenszykluskostenrechnung. Gabler, Wiesbaden (1996)

10. Brissaud, D., Tichkiewitch, S.: Product Models for Life-Cycle. Ann. CIRP 1, 105–108 (2001)
11. Wahab, M.I.M., Desheng, W., Lee, C.-G.: A generic approach to measuring the machine flexibility of manufacturing systems. European J. Operations Research 1, 137–149 (2008)
12. Keine gen. Schulte, J., Eckelsbach, H., Steven, M., Alevifard, S.: Hybride Leistungsbündel - Auf steinigem Weg in die Praxis. wt Werkstattstechnik Online 102, 485-492 (2012)
13. Richter, A., Steven, M.: Controlling-Aspekte industrieller Produkt-Service Systeme. wt Werkstattstechnik Online 99, 558–563 (2009)
14. Steven, M., Welp, E.G., Richter, A., Sadek, T.: Verfügbarkeitsorientierte Geschäftsmodelle und Flexibilität industrieller Produkt-Service Systeme. wt Werkstattstechnik Online 98, 587–592 (2008)
15. Baldwin, C.Y., Clark, K.B.: Design Rules: The Power of Modularity. MIT Press, Cambridge (2000)
16. Rese, M., Karger, M., Strotmann, W.-C.: The dynamics of Industrial Product Service Systems (IPS2) - using the Net Present Value Approach and Real Options Approach to improve life cycle management. CIRP J. Manuf. Sci. Tech. 1, 279–286 (2009)
17. Karger, M., Richter, A., Sadek, T., Strotmann, W.C.: Flexibility of Industrial Product Service Systems - An Assessment Based on Concept Modelling. Arbeitsberichte des Lehrstuhls für Produktionswirtschaft, Nr.8, Ruhr-Universität Bochum, Bochum, Germany (2010)
18. Abele, E., Liebeck, T., Wörn, A.: Measuring Flexibility in Investment Decisions for Manufacturing Systems. Ann. CIRP 55, 433–436 (2006)
19. Black, F., Scholes, M.: The Pricing of Options and Corporate Liabilities. J. Polit. Econ. 81, 637–654 (1973)
20. Copeland, T., Antikarov, V.: Real Options. A Practitioner's Guide. Texere, New York (2001)
21. Copeland, T., Tufano, P.: A Real-World Way to Manage Real Options. Harvard Bus. Rev. 82, 90–99 (2004)
22. Rigby, D.: Management Tools and Techniques: A Survey. Calif. Manage. Rev. 43, 139–159 (2001)
23. Haathela, T.: Displaced Diffusion Binomial Tree for Real Option Valuation (November 2010), `http://dx.doi.org/10.2139/ssrn.1932408`
24. Mandelbaum, M., Brill, P.H.: On Measures of Flexibility in Manufacturing Systems. Int. J. Prod. Res. 5, 747–756 (1989)
25. Chang, A.-Y., Whitehouse, D.J., Chang, S.-L., Hsieh, Y.-C.: An approach to the measurement of single-machine flexibility. Int. J. Prod. Res. 8, 1589–1601 (2001)
26. Reinhart, G., Dürrschmidt, S., Hirschberg, A., Selke, C.: Reaktionsfähigkeit für Unternehmen. Eine Antwort auf turbulente Märkte. ZWF 94, 21–24 (1999)
27. Dürrschmidt, S.: Planung und Betrieb wandlungsfähiger Logistiksysteme in der variantenreichen Serienproduktion. Dissertation, München (2001)
28. Baykasoglu, A., Özbakir, L.: Analysing the effect of flexibility on manufacturing systems performance. J. Manuf. Tech. Manage. 2, 172–193 (2008)
29. Lanza, G., Peter, K., Rühl, J., Peters, S.: Assessment of flexible quantities and product variants in production. CIRP J. Manuf. Sci. Tech. 3, 279–284 (2010)
30. Erkoyuncu, J.A., Roy, R., Shehab, E., Cheruvu, K.: Understanding service uncertainties in industrial product–service system cost estimation. Int. J. Adv. Manuf. Tech. 52, 1223–1238 (2011)

Preparing University Graduates for Product-Service Work Environments

Uta Wilkens[1], Thomas Süße[1], Ksenia Mänz[1], Bianca Schiffer[1], and Gregor Fabian[2]

[1] Ruhr-University Bochum, Institute of Work Science, Chair for Human Resources and Work, Ruhr-University, Bochum, Germany
[2] HIS-Hochschul-Informations-System GmbH, Hannover, Germany

Abstract. This paper asks how the system of higher education can support graduates in engineering studies to cope with the specific demands of product-service work systems. The analysis includes two aspects of higher education: The implementation of study programs or modules and the competencies required of university graduates in product-service work systems. An evaluation of study programs and modules of the 300 top universities shows a considerable worldwide implementation and a special emphasis given to the subject in Northern European countries. A graduate survey with 474 questionnaires conducted among German engineers in 2012 shows the increasing demands on employees' competencies in terms of methodical competencies, social competencies, area-specific knowledge, professional skills, and self-competencies. This leads to recommendations of how to develop these competencies by means of future study programs.

Keywords: higher education, university teaching, curricula development, competencies, Product-Service Systems, Industrial Product-Service Systems.

1 Introduction

There is increasing awareness in scientific writing of the economic impact of Product-Service Systems (PSS) during the last few years [1, 2, 3]. Such systems arise as a result of strategies "shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands" [4]. As an even more specific recent development, there is a trend towards Industrial Product-Service Systems (IPS^2), where production and services determine each other in a way that leads to "mutual planning, development, provision and use" [5]. The key characteristic of IPS^2 compared to PSS is that they are typical for a Business to Business area, whereas PSS are characteristic for both Business to Consumer and Business to Business areas [6]. PSS, and their special form IPS^2, are considered key drivers for the sustainable growth and competitiveness of companies in the engineering sector [1, 2, 7]. Continuous growth depends on certain parameters, including technological, managerial and institutional prerequisites [8]. One of these parameters is

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 621–633.
DOI: 10.1007/978-3-642-30820-8_52

the education system, related to the question of how graduate teaching in higher education can foster their development. There is currently no systematically acquired knowledge in this field, even though the competencies of the workforce have been stated as key factors for the long-term success of Product-Service Solutions in a highly competitive global market [9].

A critical analysis with respect to higher education teaching in product-service work environments is promising due to the specific challenges for the actors who have to deal with the complexity of these work systems. Heterogeneous fields of expertise need to be integrated and the customer-driven flexibility of the business model increases the coordination requirements of such work systems [10]. This leads to our research question: How can and does the higher education system prepare graduates in the engineering sector to cope with the challenges of PSS and IPS^2 work systems?

The preparation of higher education teaching for PSS and their special form IPS^2 can be analyzed from at least two perspectives. The development of specific programs – especially in graduate studies – is one key impact of the university system. The second aspect is the broader field of competence development that goes beyond the explicit content of a study program and addresses graduates' ability to adapt to and absorb future developments in their field of employment. There has been increasing awareness of teaching outcomes in terms of competencies, especially since the Bologna reform of university teaching in Europe. Competence development in higher education matured as a separate research domain called competence-based education [11-12]. It is closely linked with considerations on didactics and new forms of teaching, such as research- or problem-based teaching. We consider both study programs and competencies as conceptual anchors of our analysis that will be further outlined in the next section.

With reference to the conceptual background, we will introduce our findings in the third paragraph, including a worldwide map on PSS- or IPS^2-related university teaching and a specification of the competencies required especially for such work environments. The empirical findings lead to a recommendation of how to further improve the preparation of graduates in university teaching for new work systems characterized by the integration of products and services.

2 Conceptual Background

In order to explore how graduate education contributes to a further development of PSS and IPS^2 work systems, we integrated the institutionalization of study programs as one important input variable in our analysis. Moreover, we considered graduates' competencies as an important output variable of university teaching. This focus is aligned with recent concepts and frameworks on teaching in higher education.

In general, teaching is a complex process of transforming inputs, such as the curriculum, into desirable learning outcomes [13]. More precisely, student outcomes can be defined as "those aspects of the student's development that the institution either does influence or attempts to influence through its educational programs and practices" [14, p. 38]. While focusing on student learning, these outcomes concentrate on special skills, knowledge and abilities that a student should demonstrate after graduating from university [15].

Broadly speaking, the importance of the input side of the teaching process is not questioned [16]. However, the high complexity and the dynamic of modern working environments lead to the fact that the question about "What graduates learned in higher education" becomes less important compared to the question of "What graduates are able to do in their working environments" [17-18]. This ongoing change leads to the new output-based orientation of the teaching process and the redefinition of the role of students in this process. Each study program should be orientated towards the competencies that students should have after their graduation. The process of university teaching and development should be led by the key competencies which are relevant in today's working environments. The significance of each course must be defined in terms of its contribution to these competencies [19]. This reorientation of higher education teaching in Europe is reinforced by the Bologna process and is based on the modularization of the curricula [20]. Consequently, we are aiming towards an answer to the question: What competencies do today's graduates need for their upcoming tasks and challenges in their job? We follow this question with respect to work systems integrating production and services. Regarding our focus on upcoming challenges in working environments due to the growing importance of PSS and IPS^2, individual competencies are considered as a prerequisite for an ongoing improvement and development in the engineering sector [10]. Since PSS and IPS^2 depend on the integration of the customer, provider and supplier, bringing together different expertise is a key characteristic of such work systems. As a result, there is a high demand for coordination, communication and knowledge integration. This is what Blacker [21] characterizes as a communication-based work system with challenges in integrating the expertise of individuals for collective problem-solving activities. "Especially, preventing information losses and coordinating across boundaries appear as main problematic inhibitors at the side of the supplier, while goal conflicts are addressed for the customer side" [22 with reference to 23]. The growing importance of coordination and collaboration in the working process indicates a higher relevance of competencies needed to establish, manage, maintain, and run heterogeneous, dynamic and sometimes also ambiguous systems throughout daily work [22]. Specific competencies of individuals and teams with respect to social and cognitive abilities can be considered as even more crucial for successful processes and competitive advantages in product-service work environments than in systems with a higher degree of division of labor and sequential processes.

Erpenbeck and Rosenstiel [24] define the following competencies as a broader set of social and cognitive dispositions that can be specified for certain job environments: personal competencies, activity- and implementation-oriented competencies, professional skills and methodical competencies, and social and communicative competencies.

Personal competencies are the dispositions of a person to reflect on their own behavior and to assess their own attitudes and values. They allow their owners to learn and develop their motives and talents within their working environments and outside these environments.

Activity- and implementation-oriented competencies are dispositions that allow a person self-organized actions directed at the implementation of their intentions, projects and plans. This implementation can be important, not only for the person themself, but also for other people in their team or in the whole organization. These competencies show the capability of a person to integrate their emotions, motivations, abilities, and experiences with the other kinds of competencies in order to act successfully in their working environment.

Professional skills and methodical competencies are the dispositions of a person to act in a self-organized way by solving factual problems with the help of instrumental knowledge, skills and capabilities. These competencies are based on the ability to structure and assess one's own knowledge, on the one hand, and to implement it in order to find applicable solutions to different tasks, on the other hand. The professional and methodical competencies allow not only the usage of the existing methods, but also the modification and further development of these methods according to the relevant tasks in the working environment.

Social and communicative competencies are dispositions allowing their owners to act in a communicative, cooperative and self-organized way in their working environments. These competencies make a person able to deal with other people within a group in a relationship-oriented way.

This established framework of a four-dimensional competence model that can be traced back to Erpenbeck and Rosenstiel [24] allows the presupposition of what competencies would be highly relevant in PSS or IPS^2. The model faces interdisciplinary capabilities of individuals and teams which empower actors to deal with new and complex situations within a dynamic working environment. Therefore, the model can be used for PSS and IPS^2work systems.

Answering the question of how teaching in higher education can foster the further development of engineers' future working systems requires both a closer look into the education system with respect to study programs and modules, on the one hand, and how this focus on teaching content is combined with a specification of the competencies required for PPS and IPS^2 work systems, on the other hand.

The framework of our analysis is the modified presage-process-product model of student teaching and learning [13, 25]. We start with the analysis of the presage or the input side of the university teaching process. This side is represented through the teaching activities of PSS- or IPS^2-relevant content of different universities. It is clear that such inputs should play an important role in the development of students' competencies that are important for successful coping with new challenges of PSS and IPS^2 systems. The second part of our analysis concentrates on the product required or output side of the university teaching process. We analyze the relevance of different competencies in different engineering working environments depending on the estimations of graduates who are employed in such work environments. With the help of these findings, we will be able to make suggestions along the whole process from the input to the output side, while also taking the processes of teaching and learning in higher education into account.

3 Developing Competencies for Product-Service Solutions

3.1 The Institutionalization of Related Study Programs

In order to identify relevant study programs referring to the PSS or IPS² application area, we firstly conducted extensive internet research across the 300 highest ranked universities using the *Academic Ranking of World Universities (ARWU) 2011* [26]. Even though university rankings, in general, are discussed quite critically due to their differing methodologies and scopes [27], they allow a systematic sample selection. The ARWU was chosen – instead of other comparable university rankings – due to its partial adjustment towards education quality [28] which runs in line with our research scope. Employing the top 300 universities of this ranking is supposed to assemble a representative sample of the world's most influential universities. There is a focus on the top 300 out of the 500 listed universities since it can be assumed that this group of universities will sustain their places in the ranking for a long time and will be continuously recognized as influential international universities.

The goal of the internet research was to detect PSS- and IPS^2-relevant content within the universities' curricula. Additionally, we also focused on the universities' PSS and IPS^2 research activities, assuming a potential spillover from research into teaching, even if these topics have not (yet) been institutionalized within the teaching curricula.

The search itself consisted of four major steps:

- Firstly, we made use of the internet search engine Google by searching for "name of the university" and "product service system" as a general framework.
- Secondly, we checked the results for relevant information in terms of PSS or IPS^2 activities at the institutions.
- Thirdly, we took a deeper look at the universities' own websites by scanning for information about "product service system," "product-service system," "industrial product service system," and "industrial product-service system."
- Finally, we accumulated the information collected into the categories *Teaching* and *Research* and processed our findings into a world map.

We see that at least 51 (17%) of the top 300 universities are engaged in PSS- or IPS^2-related activities. This indicates a worldwide institutionalization of the subject. Thirty-four (11.33%) of these universities are only engaged in research activities concerning PSS or IPS^2. Nevertheless, this can be regarded as a first step towards an institutionalization of PSS- or IPS^2-related teaching programs. There are 17 (5.67%) of the top 300 universities conducting both research and fully institutionalized teaching programs in this field. Twelve (4%) of the world's 300 best universities engage more visibly in teaching activities concerning PSS or IPS^2 than in research-related subjects. The universities engaging in research and/or teaching activities concerning PSS or IPS^2 are distributed across several industrial states with centers in Europe, North America, Asia, and Australia.

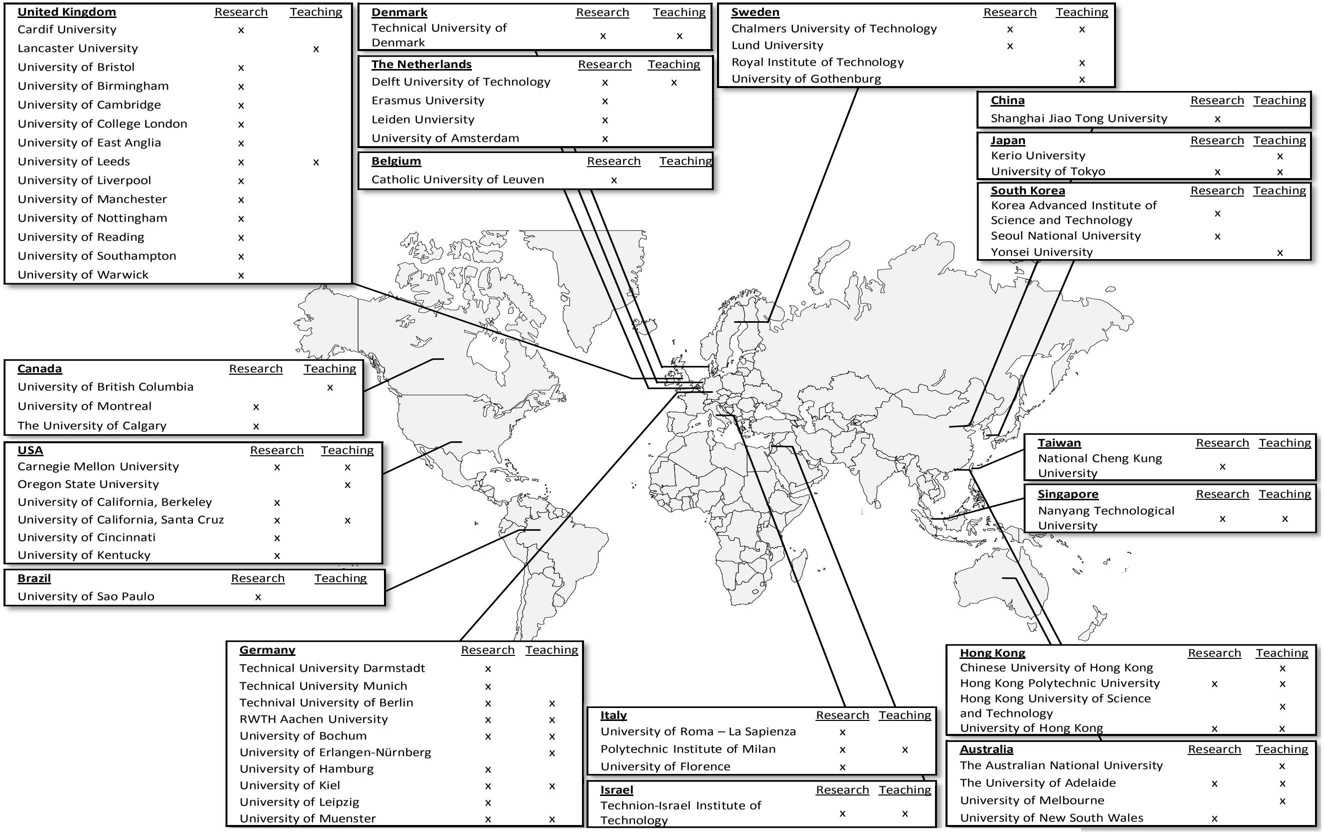


Fig. 1. World map of top universities with research and teaching in PSS or IPS²

The largest number of top universities engaged in PSS or IPS^2 research is located in the UK. The greatest number of top universities engaging in both research and teaching activities is located in Germany (see world map).

The worldwide distribution of universities with curricula related to “product service system,” “product-service system,” “industrial product service system,” or “industrial product-service system” shows an already existing high interest in this subject. This underlines that there is a common understanding of the relevance of PSS and IPS^2 issues. At the same time, the results show that countries from Northern Europe give especially high emphasis to this topic in their research and teaching activities. There is obviously a high awareness of the opportunities leading to a competitive advantage from solution-orientated offerings. Concurrently, universities from other continents are starting following this trend. A further exploitation of product-service solution opportunities worldwide can be expected.

The results of our analysis show that there are increasing activities in preparing students for the challenges of upcoming engineering working environments with respect to the input side. The second part of our analysis concentrates on the question of what competencies are crucial as teaching output in emerging programs. We focused on practitioners who have already been working in the field of PSS or IPS^2 environments for several years to gain systematic knowledge about this perspective. There is a focus in this part of the analysis on Germany as the country where teaching in the area of product-service solutions is most advanced. There is a comparably higher probability of being confronted with PSS or IPS^2 work environments and demands of PSS or IPS^2 work systems in Germany as a necessary prerequisite for the second part of our analysis.

3.2 Graduates’ Evaluation of Required Competencies in Product-Service Work Systems

In order to analyze the proliferation of changing working environments in the field of engineering in Germany and the relevance of different kinds of competencies as antecedents for successful working in PSS or IPS^2 work systems, we used the data of a survey conducted by the HIS Institute for Research on Higher Education (HIS-HF) in Germany in 2012. The HIS-HF graduate survey is a systematically conducted longitudinal study with the examination year of 1989 as a starting point. It is representative for the population of German graduates in engineering studies. The survey is conducted in three waves – one year, five years and ten years after graduation. We used the data of the third wave, asking participants who graduated from their universities in 2001. We selected this group of participants and excluded job starters because it allows the acquisition of information about competence demands in the engineering sector on the basis of the extended work experience of the respondents.

The survey is based on a broad set of items describing competencies. We selected those items from the survey which describe the perceived importance of different kinds of competencies enabling participants to act in rather unknown and heterogeneous work environments as an assumed key prerequisite in PSS or IPS[2] work environments.

We expected from the results of the following analysis that the participants of the survey who work in an environment where the integration of products and services to a solution is becoming increasingly important see a higher relevance for the competencies we mentioned as critical success competencies in such work systems.

We subsumed the competence-relevant items under the four dimensions of the competence model developed by Erpenbeck and Rosenstiel introduced already [24]. The data evaluation is based on these items. The assignments of the items to the kinds of competencies mentioned are shown in Table 1.

Table 1. The summary of the competence scales

Competencies	**Items from HIS-HF survey**	**α coefficient**
Personal competencies	ability to assume responsibility	-*
	adapt oneself to changing environmental conditions	
Social and communicative competencies	ability of cooperation	0.81
	negotiation skills	
	leadership	
	communication	
	written comprehension	
	conversation	
	conflict management	
Professional skills and methodical competencies/activity- and implementation-oriented competencies	Area-specific knowledge: special expert knowledge which is important for a respective area general basic knowledge knowledge of academic methods	0.40
	Professional skills: multidisciplinary thinking foreign languages software knowledge business knowledge	0.36
	Methodical competencies: ability to: organize things solve problems work independently manage time effectively apply existing knowledge to new problems see and fill own knowledge gaps analyze or structure complexity	0.78

* It is only possible to calculate the α coefficient for a number of items over two

The α coefficients of area-specific knowledge and of professional skills are lower than the conventional level of 0.7 due to the fact that they are complex multidimensional facets depending on an individuals' work-place characteristics and not homogeneous constructs.

New items which are relevant for characterizing solution-orientated product-service work systems were integrated into the HIS-HF survey for the first time. We developed these items on the basis of the theoretically based descriptions of PSS and IPS^2 work environments and suggested their integration in the survey. HIS-HF pretested and accepted the items. With the help of these items, we are able to separate those respondents who work in PSS or IPS^2 work environments from those who do not. The following items have been used to identify the participants of the survey working in an environment which shows PSS- or IPS^2-relevant characteristics:

- Within my job, I have to deal with new challenges which often cannot be handled by a linear solution.
- Only the combination of specific knowledge from different experts leads to success during my work.
- The colleagues with whom I work have very different professional backgrounds.
- The output of my work is required by others before they are able to fulfill their tasks.

Based on the α coefficient of these, the scale amounts to 0.65 and does not reach the conventional level of 0.7 so that we could not use these characteristics of the work system as a homogeneous construct. However, the results of the factor analysis show that all these items load on the same factor with factor loadings ranging from 0.50 to 0.77. That is why we can conclude that these work characteristics represent one factor.

A total of 734 engineers took part in the survey. The PSS- or IPS^2-related job characteristic items were answered by 474 (65%) of them. Fifty-two (11%) of the respondents were women and 422 (89%) were men; 147 (31%) respondents graduated in electrical engineering, 256 (54%) graduated in mechanical and process engineering and 71 (15%) graduated in business engineering. The mean year of birth is 1974 and the standard deviation is about 2.5 years; subsequently, the mean age is about 38 years.

We analyzed the frequency of different elements of the job characteristic items in order to discuss to what extent these characteristics are important in German engineering working environments. The results of the frequency analysis show that 166 (35%) participants have to deal with new challenges in their working environments which often cannot be handled by a linear solution. A total of 109 (23%) participants say that only the combination of specific knowledge from different experts leads to success during their work; 95 (20%) participants work together with experts having very different professional backgrounds; and 76 (16%) say that the output of their work is required by others before they are able to fulfill their tasks. Therefore, we can conclude that the four characteristics of new engineering working environments mentioned above are differently widespread in a considerable number of participants' traditional working environments. The most widespread characteristic is the necessity of searching for new non-linear solutions. The least widespread characteristic in the participants' working environments is the necessity of providing the input for colleagues as an indicator that the components of a solution provided determine each other. About ten participants (2%) say that their working environments can be characterized by all of the elements mentioned above. These are the engineers we consider to be working in environments which can be described as more dynamic and challenging environments in terms of specific demands from PSS and IPS^2 work settings. It becomes obvious that there is a relevance of these job characteristics but that the full range of these characteristics so far describes the social reality of a rather small group of engineers.

As a next step of the analysis, we take a closer look at those competencies which correlate with these job characteristics in order to answer the question: Which competencies should the higher education sector (in Germany) emphasize to prepare for PSS or IPS^2 work environments and their challenges. In order to tackle this question, we conducted a correlation analysis of the job characteristics and of the competence items. The results of the correlation analysis show that the factor indicating PSS and IPS^2 working environments is strongly positively associated with the importance and the presence of all kinds of competencies listed in Table 1. The correlation coefficient between the PSS- or IPS^2-related job characteristics and the importance of methodical competencies indicated shows a correlation of 0.31 ($p < 0.01$). The job characteristics and the importance of social competencies perceived also show a significant positive correlation ($r = 0.26$, $p < 0.01$). Furthermore, there is a significant positive correlation with the indicated importance of area-specific knowledge ($r = 0.27$, $p < 0.01$), of professional skills ($r = 0.27$, $p < 0.01$) and of self-competencies ($r = 0.24$, $p < 0.01$).

These results are supported by the results of the linear regressions. Firstly, we used the factor indicating PSS and IPS^2 working environments as the independent variable to predict the perceived importance of different kinds of competencies. The results of these regression analyses show that the job factor is significantly positively related with the indicated importance of methodical competencies ($t = 5.37$, $p < 0.01$, $\beta = 0.31$), of social competencies ($t = 4.77$, $p < 0.01$, $\beta = 0.26$), of area-specific knowledge ($t = 4.40$, $p < 0.01$, $\beta = 0.27$), professional skills ($t = 5.54$, $p < 0.01$, $\beta = 0.27$), and self-competencies ($t = 4.76$, $p < 0.01$, $\beta = 0.25$). The factor indicating PSS and IPS^2 working environments turned out to be a good predictor of the relevance of these kinds of competencies.

In summary, it can be said that some elements of PSS or IPS^2 job characteristics can already be observed in every fourth work-place in the engineering sector in Germany, and that about 2% of German engineers have to face all characteristics of these work environments as far as they could be included in the HIS-HF graduate survey. Engineers working in such environments perceive all kinds of competencies concerned as more important than their colleagues working in conventional environments in the engineering sector. Due to this reason, we see a necessity and also a possibility to highlight the competencies that should be taken into consideration in existing and emerging study programs dedicated to PSS or IPS^2.

4 Discussion and Conclusion

Our analysis shows that even though PSS and their special form IPS^2 are considerably new subjects in research, they have succeeded in achieving a considerable international distribution. A total of 17% of the top 300 universities from four continents are engaged in PSS- or IPS^2-related activities. Certain teaching activities can be identified. The worldwide emphasis given to the subjects can be treated as an indicator of its relevance and sustainability.

It has often been argued that Western European engineering companies could strengthen their competitiveness by solution-selling activities [29]. Universities, especially those with specific programs in PSS or IPS^2, can be considered as important partners for this further development. These academic partners can be identified and prepared for the related challenges due to their current activities. The world map of universities presented can help to locate these academic partners. However, it should also be taken into consideration that Western Europe cannot count on the uniqueness of its PSS or IPS^2 activities and related competitive advantages. The relevant knowledge is distributed all over the world.

The next steps towards a further advancement of PSS or IPS^2 teaching programs can be supported by the findings of the graduate survey introduced. The survey allows the specification of the relevant competencies for work systems integrating production and services that should be taken into consideration and made use of in existing and emerging teaching activities in higher education. These competencies are listed in Table 1. Particular methodological competencies, such as applying existing knowledge to new problems – seeing and filling one's own knowledge gaps, analyzing or structuring complexity – or social and communicative competencies, such as cooperation, conflict management and leadership, are crucial for coping with the challenges of PSS or IPS^2 work systems. Consequently, it will be necessary to develop interdisciplinary study programs integrating elements from engineering, management and social sciences. Moreover, the findings show that it will be especially important to give emphasis to teaching methods in higher education that should especially foster the methodological and social competencies. At this point, we see the chance to create specific learning settings and environments in higher education in terms of dealing with complex scenarios, discovering new solutions, creating knowledge in collective problem-solving activities, and providing the ability to work in very heterogeneous and interdisciplinary teams.

It could be interesting for future research to compare the perceived importance of competencies depending on the years of job experience, and whether there are systematic differences between engineers with one, five or ten years on the job. Additionally, a comparison between findings concerning engineers and concerning other professions, such as business economists, computer scientists or others who are supposed to work in solution selling environments with similar characteristics to those described for PSS and IPS^2, could be considered as fruitful.

References

1. Velamuri, V., Neyer, A., Möslein, K.M.: Hybrid value creation: A systematic review of an evolving research area. J. Betriebswirtsch 61, 3–35 (2011)
2. Meier, H., Roy, R., Seliger, G.: Industrial Product-Service Systems – IPS^2. CIRP Annals – Manufacturing Technology 59, 607–627 (2010)
3. Rese, M., Karger, M., Strotmann, W.: The dynamics of Industrial Product Service System (IPS^2) – using the Net Present Value Approach and Real Options Approach to improve life cycle management. CIRP Journal of Manufacturing Science and Technology 1, 279–286 (2009)
4. Van Halen, C., Vezzoli, C., Wimmer, R.: Methodology for Product Service System Innovation – How to develop clean clever and competitive strategies in companies. Van Gorcum, Assen (2005)
5. Meier, H., Uhlmann, E., Völker, O., Geisert, C., Stelzer, C.: Reference Architecture for Dynamicl Organization of IPS^2 Service Supply Chains in the Delivery Phase. In: CIRP IPS^2 Conference (2010)
6. Laurischkat, K.: Product-Service Systems: IT-gestützte Generierung und Modellierung von PSS-Dienstleistungsanteilen. Shaker Verlag, Aachen (2012)
7. Matzen, D., Tan, A.R., Andreasen, M.: Product/Service-Systems: Proposal for Models and Terminology. In: 16th Symposium "Design For X", Neukirchen, October 13-15 (2005)
8. Meier, H., Uhlmann, E. (eds.): Integrierte Industrielle Sach- und Dienstleistungen. Vermarktung, Entwicklung und Erbringung hybrider Leistungsbündel. Springer, Heidelberg (2012)
9. McAloone, T.C.: A Competence-Based Approach to Sustainable Innovation Teaching: Experiences within a New Engineering Programme. Journal of Mechanical Design 129, 769–778 (2007)
10. Meier, H., Völker, O., Funke, B.: Industrial Product-Service Systems (IPS^2). Paradigm shift by mutually determined products and services. Springer, London (2010)
11. Jonnaert, P., Barrette, J., Masciotra, D.: Revising the Concept of Competence as an Organizing Principle for Programs of Study: From Competence to Competent Action. International Bureau of Education, IBE/UNESCO, Geneva (2006)
12. Light, G., Cox, R.: Learning and Teaching in Higher Education. The Reflective Professional. SAGE Publications, London (2005)
13. Biggs, J.B.: Approaches to the Enhancement of Tertiary Teaching. Higher Education Research & Development 8, 7–25 (1989)
14. Astin, A.W.: Assessment for excellence: The philosophy and practice of assessment and evaluation in higher education, p. 38. Macmillan, New York (1991)
15. Council for Higher Education Accreditation (CHEA): Statement of mutual responsibilities for student learning outcomes: Accreditation, institutions, and programs, Washington, DC, p. 5 (2003)
16. Schaeper, H.: Lehr-/Lernkulturen und Kompetenzentwicklung. Was Studierende lernen, wie Lehrenden lehren und wie beides miteinander zusammenhängt. In: Zimmermann, K., Kamphans, M., Metz-Göckel, S. (eds.) Perspektiven der Hochschulforschung, pp. 197–214. VS Verlag für Sozialwissenschaften, Wiesbaden (2008)
17. Bouslama, F., Lansari, A., Al-Rawi, A., Abonamah, A.: A novel outcome-based educational model and its effect on student learning, curriculum development and assessment. Journal of Information Technology Education 2, 203–214 (2003)
18. Tucker, B.: Literature Review: Outcomes-focused Education in Universities. Learning Support Network, Curtin University of Technology (2004)

19. Witte, J., Schreiterer, U., Otto, E., Müller-Böling, D.: Die Umstellung auf Bachelor- und Masterstudiengänge als Herausforderung für die deutschen Hochschulen: Handlungsfelder und Aufgaben. CHE-Positionspapier II (2003), http://www.che.de/downloads/Positionspapier2BMS.pdf (retrieved on September 17, 2012)
20. Ceylan, F., Fiehn, J., Paetz, N.-V., Schworm, S., Harteis, C.: Die Auswirkungen des Bologna-Prozesses – Eine Expertise der Hochschuldidaktik. In: Nikel, S. (ed.) Der Bologna-Prozess aus Sicht der Hochschulforschung: Analysen und Impulse für die Praxis, pp. 106–122. CHE, Gütersloh (2011)
21. Blackler, F.: Knowledge, knowledge work and organisations: an overview and interpretation. Organization Studies 16(6), 1047–1075 (1995)
22. Externbrink, K., Lienert, A., Wilkens, U.: Identifikation von Mitarbeiter- und Teamkompetenzen in hybriden Leistungsbündeln. Industrie Management 3, 65–69 (2012)
23. Beverungen, D., Kaiser, U., Knackstedt, R., Krings, R., Stein, A.: Konfigurative Prozessmodellierung der hybriden Leistungserstellung in Unternehmensnetzwerken des Maschinen- und Anlagenbaus. In: Proceedings zur Multikonferenz Wirtschaftsinformatik, München (2008)
24. Erpenbeck, J., von Rosenstiel, L. (eds.): Handbuch Kompetenzmessung (2. Aufl.), p. XXIV. Schäffer-Poeschel, Stuttgart (2007)
25. Prosser, M., Trigwell, K.: Understanding learning and teaching. SRHE and Open University Press, Buckingham (1999)
26. Academic Ranking of World Universities 2011, http://www.arwu.org/ (retrieved on August 14, 2012)
27. Marginson, S.: Global University Rankings: Implications in general and for Australia. Journal of Higher Education Policy and Management 29, 131–142 (2007)
28. Huang, M.-S.: A Comparison of Three Major Academic Rankings for World Universities: From a Research Evaluation Perspective. Journal of Library and Information Studies 9, 1–25 (2011)
29. Rese, M., Gesing, J.: Selling Solutions Needs an Understanding of Dynamic Business Models – Towards a Systematic Framework. In: Proceedings of the 19th International Colloquium in Relationship Marketing. Rochester, New York (2011)

Preventing Erroneous Operator Behavior and Supporting Optimal Operating Procedures within Industrial Product-Service Systems

Anne Wegerich, Michael Beckmann, Ulrike Schmuntzsch, and Matthias Rötting

Chair of Human-Machine-Systems, Berlin Institute of Technology, Berlin, Germany
{awe,mbe,usc,roetting}@mms.tu-berlin.de

Abstract. The performance of Industrial Product-Service Systems (IPS²) relies – in addition to many technical factors – on the optimal performance of the human operators. This can be supported through the detection of erroneous behavior and user-centered warnings before injury or damage occurs.

The detection of such behavior is based on the simulation of cognitive models which describe behavior as a combination of body movements combinations of the operator. A comparison of the simulation with the tracked movements leads to the identification and classification of possible dangerous actions of the operator. Error codes then trigger action-specific warnings. In addition to the warnings, the system automatically generates documentation in the form of avatar videos. These can be used for task demonstration and to ensure the operators compliance.

The paper details the integrative system setup for this erroneous behavior detection and the resulting warning generation. It also demonstrates the integration of these systems into IPS².

Keywords: Operating Procedure Monitoring, Preliminary Error Detection, Multimodal Warning Strategies, Avatar Instructions.

1 Introduction

Current Industrial Product-Service Systems (IPS²) combine the concepts of highly customer-adapted products and integrated services. This allows the provision of availability and performance guarantees for the machine instead of only selling standard products. Thus, the integration of services is of main interest for the necessary adaptation of business models and distribution as well as marketing strategies.

The focus of selling IPS² thereby concerns every single section of the manufacturer's organization and nearly every employee. Therefore, typically reorganization is needed to accomplish service tasks for the customer who bought a specific machine with guaranteed availability. The employee of the manufacturer requires more specific and new knowledge about the highly adapted product because in most cases he has to fulfill tasks like maintenance or trainings for different customers at different (international) locations.

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 635–645.
DOI: 10.1007/978-3-642-30820-8_53

These new business relations between the manufacturer and its customers lead to higher commitment on the part of the manufacturer. The manufacturer has to provide people who fix problems at anytime and anywhere in the world where its IPS² have been sold. For this reason the manufacturer has to train its employees or hire employees with very specific knowledge about their machines. This makes personnel deficits or fluctuation very expensive.

This paper reports research concerning two specific forms of IPS² enhancements to make the IPS² more intelligent and to help the operator at the machine to avoid erroneous behavior. Thus, system downtime and costs are reduced by preventing machine damages and injuries. The first enhancement consists of cognitive models and its simulation as well as sensory data processing for the operator's movements and machine data. This together is used to simulate optimal operating procedures which lead to the generation of error codes if the interpretation of the movement or machine data differs from this procedure or erroneous behavior is likely within the next steps of task execution. The error code leads to a specific warning strategy which is presented before damage or injury occurs. Based on the optimal task execution also an avatar guidance approach is developed to ensure the operators compliance for accomplishing the right action.

The article first presents IPS² background and the states of the art for error detection in human action recognition as well as for multimodal warnings. The following two sections provide details about the two approaches. Section 5 explains the integration of the two approaches. Section 6 shows the principles and background of the avatar documentation method. Finally, a summary and an outlook for further work and open issues are given.

2 Setting the Scene – Enhancing IPS²

IPS² are complex constructs which satisfy diverse demands to provide products and services in an integrated form. Classic and novel services must be incorporated into the organization of IPS² manufacturer and customer and their business models. In addition, the product must be adopted in a customer-centered way.

The IPS² enhancements developed in this research project add components for intelligent error prevention mechanisms and technologies to the IPS². They enable the avoidance of errors and thus reduce service demands on the part of the customer or the supplier, depending on the business model. The enhancements additionally offer user-centered and integrated help which does not distract the operator from his or her original task and supports his or her knowledge about the task and the machine. By doing so the operator and the machine are able to build up the unity IPS² require for efficient product lifecycles. Other possible enhancements can be provided by remote maintenance systems [3], [4] or ubiquitous knowledge data bases for product and service integration. So the available digital information in IPS² is used to offer individual support to the operator for specific tasks in different environments [12].

The first enhancement concerns the development of technical components for the machine which recognize human actions and compares them to optimal action strategies for given tasks, e.g. for a scheduled maintenance. Thus, the system is able to detect errors before damage or injury occurs. The so extended machine generates error codes which are further processed by the second enhancement. An operator for example takes a wrong tool to tighten a specific screw. The error code for this situation consists of the machine state (configuration of moveable parts and sensory data), the identifier of the executed action, the identifier or the currently executed process step, a list of valid actions, an identifier for the error type as well as criticality and urgency values of the observed or expected erroneous behavior.

For recognizing erroneous behavior manual tasks are modeled using the cognitive architecture Adaptive Character of Thought – Rational (ACT-R) [1]. The cognitive theories incorporated into the architecture allow forecasting of erroneous behavior for cognitive reasons. The rules based nature of this architecture allows the modeling of tasks with maximum degrees of freedom to the operator, because preconditions define whether a rule or action may be executed. When running a simulation of the model the next valid actions can be easily recognized by the rules which interact with the environment and are verified by the actual actions, making automatic error reporting possible.

The actual human actions can be tracked by employing motion capture suits [2] or other technologies to capture human movement and the additional information about the environment is provided by sensors of the technical systems, like heat sensors. The movement data is further processed to extract gestures or actions from the data, using techniques like gesture spotting [5]. This enables the recognition of e.g. screwing actions or grabbing of an object. The recognition can be verified by the simulation together with the sensory data.

The research work for the second enhancement focuses on the user-centered presentation of multimodal and action-specific warnings according to the error code. Studies have shown the advantages of multimodal warnings [6]. Thus, warnings are presented in multimodal forms and at the location where the wrong action is about to happen (action-specific via glove). For the example concerning grabbing the wrong tool, a glove the operator wears is able to present a warning light, a vibration, and an acoustic sign to bring the possible error to the operator's attention and helps to resolve the situation.

The second enhancement will allow generic documentation preparation for task guidance in an IPS² context. Therefore, a user-centered and digital adaptive solution is determined in the form of an avatar. The developed avatar framework provides modular action entities which can be built up to different kinds of action procedures for various tasks and the appropriate guidance. This approach is able to substitute trainings and descriptions of tasks in a user adapted form also to reduce service demands.

3 Detection of Erroneous Behavior

The goal of this IPS² enhancement is the recognition of operator errors when executing a manual process before the erroneous behavior leads to injury, causes damage to the technical system, or makes additional repair services necessary. An example of such invalid behavior is grabbing an Allen wrench of the wrong size or trying to interact with a heat source. When such a situation occurs an error code is transferred to the second system enhancement for the generation of warningss (see chapter 4).

The system for an automatic detection of erroneous behavior or errors consists of the simulation of the executed task as wells as data about the human actions and machine data. Figure 1 illustrates the system concept. The simulation forecasts all possible actions of the operator and has risk values attached to actions which are error prone. The simulated actions are compared with the action of the human operator (see below). If the system recognizes a deviation between the actual and the modeled actions, the discrepancy is evaluated with consideration to the system data, and is classified as an error. An error is also reported when the simulation forecasts that an error prone action is likely be executed. The kind of (possible) error is described in an error code which is transferred to the system part that generates the warnings.

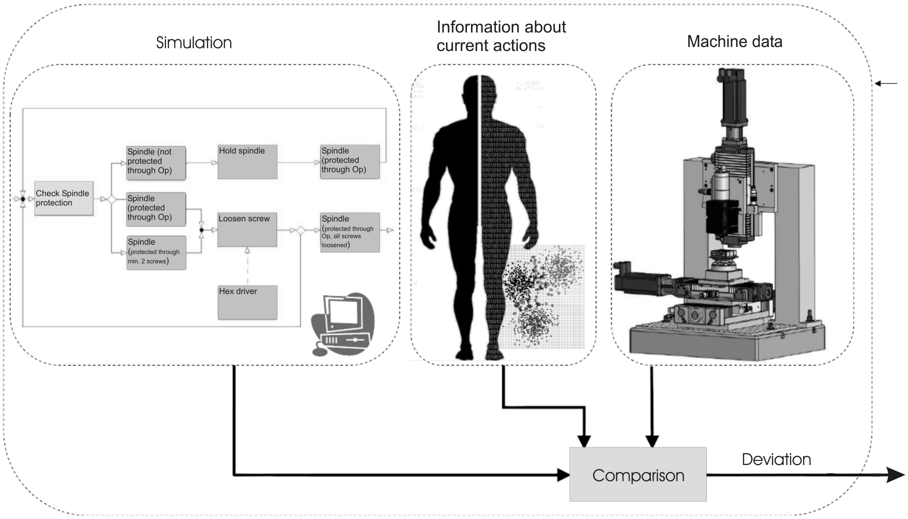


Fig. 1. System setup for the detection of erroneous behavior

The described components itself incorporate various technologies and subcomponents. The simulation is based on the low-level architecture Adaptive Character of Thought – Rational (ACT-R). This architecture is rule-based, making it easy to account for human flexibility during task execution because only the precondition needs to be checked to determine whether a rule may fire. The different components in ACT-R allow the simulation of human information acquisition (eyes, ears), information processing and memory, the execution of a task, and a representation of the environment (machine). On the cognitive level this allows the prediction of improper task execution due to memory decay. In the case of action implementation, the time for movement data can be estimated and the actions can be subdivided into small steps, which make an early recognition possible. Improper actions can be accounted for by rules which associate actions under specific environmental conditions (e.g. wrong movement in a task step or moving a hand in a hot area). The parallel simulation of these rules therefore is needed to compare the real detected actions with the correct ones to recognize deviations from them.

For the system which recognizes erroneous behavior by the operator, movement data and executed actions need to be supplied. Thus, a motion capturing component is part of the system to record the movements of the human operator. For motion capture different technologies are suitable (optical, mechanical, inertial sensors, etc.). Within this project a motion capture suit and glove are used to get raw data about changes of body part locations, e.g. acceleration data from the arm or hand.

This raw movement data is pre-processed to handle the tolerance of the sensors and to compensate small, involuntary movements. In the next step a machine learning module segments the data and determines the performed actions, which are then forwarded to the simulation. To optimize the performance of this system the position of the operator in the system is observed by adjusting the set of actions, which need to be identified.

Apart from human data the simulation also needs to monitor the environment. All available data about the placement of interaction objects in the environment and sensory data about the system is incorporated in system data. These data are collected by connecting sensors to measure heat, positions, status, etc. In the maintenance case we used optical sensors, heat sensors, CAD data of the machine (component position detection), and the state of the machine. The flow of information is shown in Figure 2.

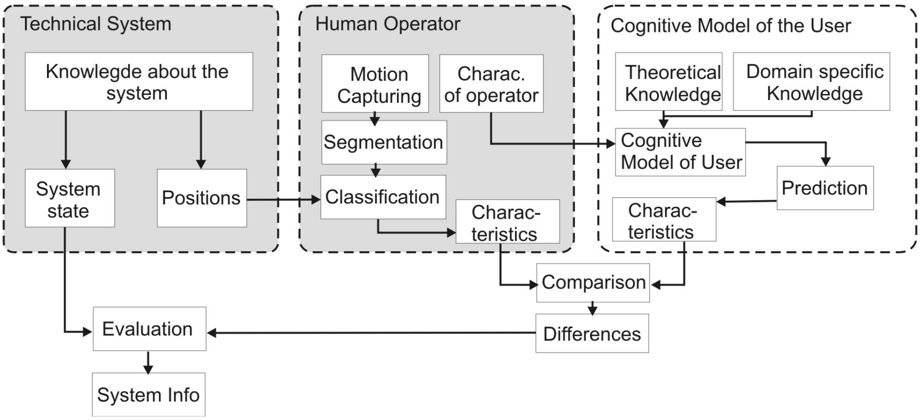


Fig. 2. Detailed flow of information in the erroneous behavior detection system (grey means real data)

In summary, this IPS² enhancement consists of sensors for the machine and the working environment as well as motion tracking sensors for the operator. The motion suite with inertial sensors can be substituted by a different technology, i.e. less intrusive optical tracking. In addition to the simulation and the data sources, a computing component is part of the system to compare the expected with the executed actions and generate a detailed error code in case of erroneous behavior to provide appropriate feedback to the human operator.

4 Prevention of Erroneous Behavior

This IPS² enhancement provides assistance for the user to increase the reliability and the performance of the whole human-machine system. After the detection of erroneous behavior (see chapter 3) the multimodal warning system is able to present a warning before damage or injury occurs and thus supports the right interpretation of what should be done. The time from triggering a warning to its presentation is only a few milliseconds.

Crucial for the prevention of erroneous operator behavior is the time between the detection of an error condition and the operator's interpretation of the risk which is connected to it. This IPS² enhancement therefore concentrates on an action-specific warning strategy. It presents the warning at the point where the error probably will happen and supports the right interpretation of what is wrong and how the right action should look like.

Earlier research results showed that multimodal warnings can have many advantages, like faster detection times [7]. The enhancement uses human-centered studies and appropriate results concerning the optimal detection and interpretation of the multimodal presentation. Additionally, instructions are designed so that the user satisfactorily accomplishes his or her task and understands the system better.

Current warning systems often work with multimodality but do not incorporate system components which are able to provide warnings in an action-specific way. In detail, action-specific means the presentation of a warning adapted to the situation and the current possible error as well as the presentation at the location where the error or misbehavior is about to happen. As a result of the non-action-specific warnings the detection time is decreased but the interpretation time and quality of the (coded) warning is worsened where action-specific warnings can optimize both [7]

The components of the multimodal warning system are shown in Figure 3. The error code of the erroneous behavior detection module is transferred to a glove. The glove presents the warnings at the point where the error probably will occur ("location adapted warning"). Additionally, a warning message is shown on a display informing the operator about what is wrong and what the correction would be. The warning generator matches the forwarded code with already existing codes in a data base. These codes are dependent on criticality and urgency of the current situation taking into account the specific operator (e.g. existing knowledge), environmental state (e.g. noise level) and machine type.

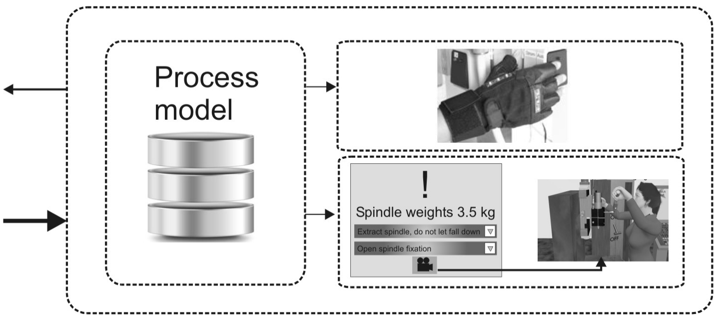


Fig. 3. System setup for warning generation

The glove is worn by the operator and provides three modalities. Two LED rows are arranged orthogonally. In this way, visual warnings are easily visible. A speaker and a vibrating element are used to transfer sounds and vibrating signals in different modes of repetition schemata (see Figure 4).

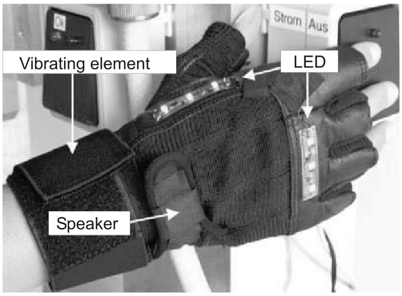


Fig. 4. Warning glove

The results from the first studies have shown that the approach of using the glove and different combinations of modalities is able to support the right interpretation of an error or erroneous behavior. Furthermore, the user is able to detect the signal as fast as traditional displays in the field of view of the user [10].

5 Integrative System Setup for IPS² Extensions

The integrative setup is shown in Figure 5. It connects the two previously described system components (see Figures 1 and 3) as extensions of an IPS². Products and services are extended with components for the preliminary knowledge about the process, the machine, and the human (process model). A computational unit is added to process the simulation of this process model, the machine data, and the human data. Finally sensors and actuators (LEDs, vibrating element, and speaker) are connected to the human and the machine.

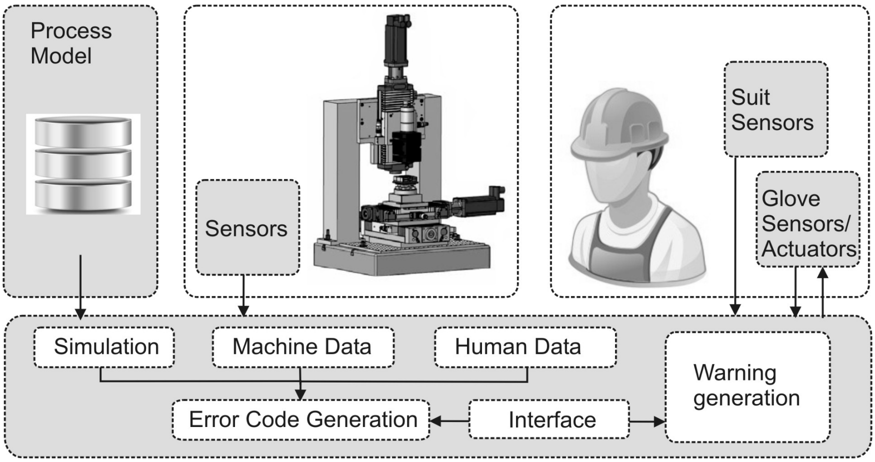


Fig. 5. Integrative System Setup

So the setup consists of fixed and mobile parts which in most cases are connected via wires. Typically all the computer and hardware parts are arranged in a small area to keep ways short. But also other (centralized) information processing units are suitable. In this case radio connections would be the best solution for all connected system parts.

As shown in Figure 5 the interface is of great importance to transfer the error code and feedback information. The error code contains information about the system state, like heat sensor reading, the identifier of the invalid action (if any), the identifiers of the expected actions, an identifier of the executed sub process, an error identifier, information about the place where the erroneous behavior occurred and an estimation of the criticality and urgency of the situation. This code is forwarded to the warning generator which interprets the error with consideration to the specific operator who is executing the task. Proper modalities and warning level are selected and provided to the human operator. After the situation was resolved the control returns to the error recognition system.

5.1 Exemplary Scenario

This scenario illustrates the detection and prevention of erroneous behavior with the task of spindle removal of a micro milling machine. The task involves one operator. In the scenario, a technician with one year of working experience will do the task. He already performed maintenance on a micro milling machine but is usually responsible for other machines. The task can be subdivided into preparation, bringing the machine and workplace in condition for removal, and the actual removal of the spindle. The actual removal consists of detaching all cables from the spindle, remove fixation and the extraction. For this scenario the operator already finished the preparation and the removal of the cables and engages in the remove fixation sub process. For this sub process the screws of the fixation clamp holding the spindle must be loosened. Following the course of events is described.

Movement of the operator towards the toolbox is observed, followed by a grabbing action, which is according to the simulation. From the sensory data of the toolbox the grabbed tool can be identified as a jaw wench. The simulation expected an Allen wrench, which is the appropriate tool. The component for error generation then emits an error message with the description of the error. In this case the important information in the error code is the incorrect action of grabbing a jaw wrench, the correct action of grabbing an Allen wrench and that the criticality and urgency of the situation is low (only time loss and no immediate danger). So, on the glove a low-frequented tri-modal sign occurs indicating to the operator that something is wrong and that he has to take a closer look at the display where at the same time a hint is shown. Here, the operator is informed that he has chosen the wrong tool and that he has to grab the Allen wrench.

The technician now loosened all screws of the fixation clamp except one and is fixating the spindle with his free hand. The system observes the movement of the hand with the Allen wrench towards the last screw and the simulation forecasts the removal of the last screw as the next action. Because the technician is unfamiliar with the micro milling machine this rule has a high risk value attached and the simulation reports that high risk is expected for the following action and an error is generated in advance. This action is risky, because the heavy weight of the spindle might be unexpected, which would lead to dropping and destroying the spindle. In this case the error message would contain that the removal of the screw is a valid action, but a high risk situation was discovered. The contained information for criticality is high and medium for urgency. As a result, the glove emits a high-frequency tri-modal sign which indicates the criticality of the situation. The warning on the monitor informs about the heaviness of the spindle and gives the advice to hold the spindle firmly all the time when loosening the remaining clamping bracket.

6 User-Centered Documentation Strategy – Avatar Guidance

Beside the prevention of erroneous behavior or errors during maintenance tasks or during daily operations, the enhancement of knowledge about the machine is an additional goal of the research of the project. It focuses on optimal documentation strategies to qualify the operator for accomplishing unknown or difficult tasks. It is assumed that better understanding of the machine leads the user to better performance and higher commitment.

Different user study results show a preference for avatar guidance in the form of a video while maintaining a complex machine which involves a lot of different (dangerous) steps [11].

For the video the avatar is well chosen to fit the needs of the operator. It is implemented as a collection of atomic actions to provide the possibility of generating avatar videos for nearly every human action (sequence) automatically. This enables avatar guidance for more than one specific scenario and lowers the costs for the production of the videos for all the different products and customer settings a manufacture has to consider.

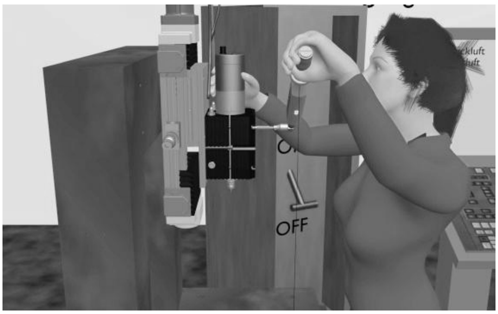


Fig. 6. Screenshot of Avatar Video Guidance shown on a display in the field of view of the operator

7 Summary and Outlook

IPS² represent new forms of business models, organizational structures, customer requirements, and product and service marketing. The connected challenges address first of all the human operator and the optimization of his or her performance in an IPS² context and behind this it addresses the requirements on the part of the manufacturer. For this reason the research presented in this article has the goal to reduce in situ service demands, absence, or downtime of the machine and thus to reduce the huge costs which are connected with human resource fluctuation or non-available workers with a specific knowledge on the part of the manufacturer.

As a solution the IPS² extensions presented in this article are able to detect and prevent errors or erroneous behavior of an operator before they happen. The first extension enables the misbehavior detection on the basis of cognitive models and real-time motion capturing of the operator. The second extension optimizes warning strategies based on the current error in an action-specific and multimodal way. Therefore, a glove is used with visual, vibrating and acoustic signals. Furthermore a documentation strategy has been developed to assist working processes in the meaning of automatically generating avatar video guidance by connecting atomic action steps.

The integration of the IPS² machine extensions are solved by decomposing the components to extend all kind of assistance scenarios where the operator does not have enough knowledge to avoid all possible mistakes and thus damages. The exemplary scenario showed a possible procedure of detections and warnings to optimize the process of changing a spindle on a micro-milling machine.

In the future, frameworks will be developed to help the manufacturer to set up IPS² extensions apart from the example of the micro-milling machine for its own products and the costumer's operators to reduce in situ costs and to reduce the long-term requirements of the customer.

Acknowledgments. We express our sincere thanks to the Deutsche Forschungsgemeinschaft (DFG) for funding this research within the Collaborative Research Project SFB/TR29 on "Industrial Product-Service Systems – dynamic interdependency of products and services in the production area". We thank our colleagues on continuous input for improving the work.

References

1. ACT-R Theory and Architecture of Cognition, `http://act-r.psy.cmu.edu`
2. Bregler, C.: Motion Capture Technology for Entertainment. Signal Processing Magazine 24(6), 160–158 (2007)
3. Hoege, B., Schlatow, S., Roetting, M.: Shared Vision - State of the Art and Future Application. In: Tagungsband des 17. World Congress on Ergonomics IEA 2009, Beijing, China, August 9-14. CD-ROM (2009)
4. Hoege, B., Schlatow, S., Roetting, M.: A Shared-Vision System for User Support in the Field of Micromanufactoring. In: Proceedings of HCI International 2009, pp. 855–859. Springer, Heidelberg (2009)
5. Junker, H., Amft, O., Lukowicz, P., Tröster, G.: Gesture Spotting with Body-Worn Inertial Sensors to Detect User Activities. Pattern Recognition 41(6), 2010–2024 (2008)
6. Oviatt, S.: Designing Robust Multimodal Interfaces for Universal Access. In: Proceedings of the Workshop on Universal Accessibility of Ubiquitous Computing 2001, Alcacer do Sal, Portugal, pp. 71–74 (2001)
7. Oviatt, S., Bernard, J., Levow, G.: Linguistic Adaptation during Error Resolution with Spoken and Multimodal System. Language and Speech, Special Issue on Prosody and Conversation 41(3-4), 415–438 (1999)

8. Rickel, J., Johnson, W.L.: Animated Agents for Procedural Training in Virtual Reality Perception. Cognition and Motor Control, Applied Artificial Intelligence 13, 343–382 (1999)
9. Rickel, J.: Intelligent Virtual Agents for Education and Training: Opportunities and Challenges. In: de Antonio, A., Aylett, R., Ballin, D. (eds.) IVA 2001. LNCS (LNAI), vol. 2190, pp. 15–22. Springer, Heidelberg (2001)
10. Schmuntzsch, U., Sturm, C., Roetting, M.: How Can Multimodality be Used to Design Usable Interfaces in IPS^2 for Older Employees. In: Proceedings of the 18th World Congress on Ergonomics IEA 2012, pp. 3533–3540 (2012)
11. Schmuntzsch, U., Sturm, C., Reichmuth, R., Roetting, M.: Virtual Agent Assistance for Maintenance Tasks in IPS^2 – First Results of a Study. In: Proceedings of the 4th International Conference on Applied Human Factors and Ergonomics, San Francisco, USA, pp. 221–231 (2012)
12. Wewiór, J., Schmuntzsch, U., Seliger, G., Roetting, M.: Knowledge-based multimodal user support to increase availability in Industrial Product-Service Systems. To appear in the Proceedings of the 4th CIRP Conference on Industrial Product Service Systems, IPS^2 (2012)

A Rating for Customer Participation during the Process of Service Co-creation

Wolfgang Seiringer

Vienna University of Technology, Institute for Software Technology and Interactive Systems, Favoritenstr. 16, A-1040 Vienna, Austria
wolfgang@seiringer.info

Abstract. A company needs reliable costing information for the service part of a Product Service System (PSS). Especially the mandatory customer integration introduces uncertainty and requires a costing method designed for services. To rate the impact of a customer on service costs we developed our concept of a Customer Integration Factor (CIF). With the developed rating method uncertainty in forecasting of service costs should be reduced and the currently missing customer perspective in service costing will be introduced. In this paper we present our evaluation results applying the CIF rating on a service scenario obtained from an existing manufacturer. To test the correctness of our method we used a set of generated test data. Our research question is whether costs in a Service System as part of a PSS shall be accounted in a different way to integrate customer's point of view.

Keywords: customer integration rating services, Customer Integration Factor (CIF), costing accounting, Service-Dominant (S-D) Logic, service co-creation, Service System.

1 Introduction

The increasing competition on the market and additional customer demand forces companies to offer new and innovative product solutions. One consequent is that companies offer Product Service Systems (PSS) to increase the value for the customer, to stay competitive and to achieve sustainability [1]. The service part of the offered PSS confronts companies with special challenges in cost accounting. A problem is that existing costing methods designed for physical products are not directly applicable on services and calculation methods for services do not consider the full service spectrum especially customer integration. So there is a lack of costing methods and cost accounting tool support for services. Furthermore the concept of Service Dominant (S-D) Logic and due to mandatory customer integration during the process of service co-creation there is a need for a costing method which is designed for services [2]. In S-D Logic the most important resources for value co-creation are competences and knowledge of provider and customer.

Services have contributed significantly to the economic growth in the last years. Regardless of the economic importance of services, a goods-centered view called Goods-Dominant (G-D) Logic was the predominant concept when thinking about economic exchange. In the G-D Logic goods are playing the central role in economic

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 647–658.
DOI: 10.1007/978-3-642-30820-8_54

exchange while services are just a special form of goods. This fact is considered in the concept of Service-Dominant (S-D) Logic where every company is seen as a service company and where always services are exchanged [3]. In a goods-centered view, the production of goods is separated from the consumption of goods to maximize the production output. Such a separation is contrary to customer-oriented marketing as well as the S-D Logic [4].

A service customer is actively participating in the process of service co-creation by providing external factors [5]. During the process of service co-creation, a Service System is formed [7]. In this Service System both partners provide resources which are combined to co-create the demanded service. Human resources are the most important resource and cost factor in the context of such a Service System. The amount of the required resources depends directly on the provided external factors. Consequently without integration of external factors, a major cost-influencing and uncertainty factor is not being taken into account. This decreases reliability and value of service cost information.

Given these assumptions, we investigate whether costs in a Service System as part of a PSS shall be accounted in a different way to reflect the change in view. We also want to find out how the consequences of customer participation can be measured. Activity-based costing models seem to be appropriate at a first glance. We argue that an extension is necessary, because during the process of co-creation resources of service provider and customer are required. Furthermore, activities performed by the customer are not under full control and therefore uncertainty has to be considered.

Our target is the development of a rating for customer participation in the process of service co-creation to reduce the uncertainty introduced by the customer in forecasting of service costs. This rating helps to consider customer's activities (external factors) and customer's point of view. The research question is whether the developed rating for customer participation provides accurate results and information about the degree of customer participation. We also want to find whether our developed rating can help to reduce uncertainty in forecasting of customer participation. We illustrate our developed rating method in a scenario derived from an existing manufacturing company. This paper describes the evaluation of our rating method using self generated test data and the application on our service scenario.

2 Scenario

Service provider and service customer provide input and cooperate in the process of service co-creation. For our paper we investigate a maintenance/repair service for medical devices which is offered from an existing manufacturer. The depth and intense of customer's participation depends on the provided resources from a customer. With a valid Service-Level-Agreement (SLA) the service provider has to bear a part or the full costs for a repair or maintenance of a medical device. Otherwise the customer must accept the costs.

In our scenario the customer contacts the provider if maintenance is due or a problem occurs. The customer care classifies and documents the inquiry and checks who has to pay. After acceptance spare parts and human resources are organized and sent to the customer. Finally after repair an invoice can be submitted to the customer. See also Fig. 1 for details.

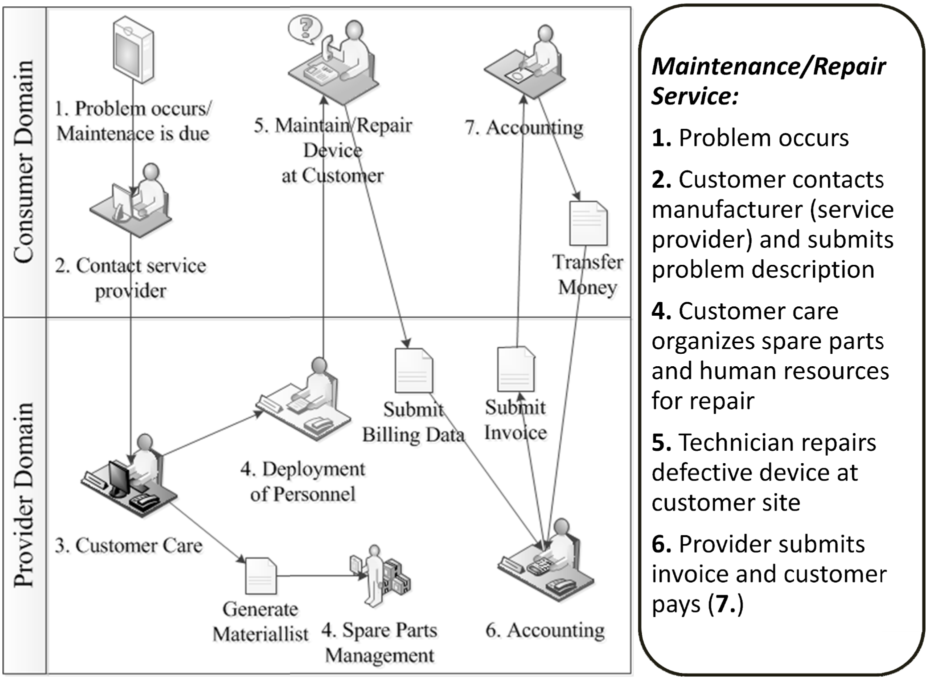


Fig. 1. Simplified example of maintenance/repair service scenario

3 State of the Art

In many cases services and goods cannot be separated. Some services have a tangible output like an online processed repair service. A service like maintenance requires a physical part. Without a physical part it cannot be offered to customers. An interesting approach for the understanding of services is Service-Dominant (S-D) Logic which has been proposed by Lusch and Vargo [2], [3]. The S-D logic has its origin in the service marketing and is currently based on nine foundational premises, which define the scope of the concept [4]. These nine foundational premises describe that everything is viewed as a service, including goods. A company only provides services. Each company is viewed as a service provider and they always exchange services and not goods. The fundamentals of services are knowledge and competencies, and the application of them produces services. In the S-D logic a service provider cannot determine the value of a service. Only the customer determines the value and a company can only offer promises for a service. The S-D logic can help companies to get a new view on the own business activities. Due to a missing separation between goods and services, in S-D Logic a company is rather viewed as a solution provider, which is right when thinking on Product Service Systems.

A definition for Product Service System is "… *a PSS should be defined as a system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than* *traditional business models.*" [1]. Target of Product Service Systems is to „…*'sale of use' rather than the 'sale of product'.*" [6]. Our used maintenance service is an example for a PSS where a physical component and a service offer a unique and specific value for a customer. In the co-creation of the offered service a customer and a service provider are involved. Compared to the production of physical products the role of the customer is somewhat different. The integrative nature of services requires an active participation of the customer in the process of service co-creation.

Compared to goods it is said that services have some special characteristics. These are inseparability, perishability, heterogeneity and uncertainty [8]. Inseparability describes the simultaneous production and consumption of services. The customer defines when the service production starts and when the customer is needed by the provider during the co-creation process. Perishability describes the fact that a service is not storable. This implies complications to plan resources for service co-creation. The heterogeneous nature of services makes it difficult to standardize the service co-creation because services are often produced only once.

3.1 Service Co-creation

The output and process of service co-creation depends on the mandatory customer integration. The integration is expressed in form of external factors provided by the customer [5].

Service co-creation can be separated into three different parts. These are production factors, factor combination and form of output [11]. The final output of service co-creation can be something tangible like a repaired device or just information about a failed repair. The production factors are all the entities which are necessary to co-create a service. The production factors are split up in internal and external factors. Basically, a production factor can be something tangible or intangible for example a defective device, information or the customer who is necessary to create the service. The internal factors are those factors that are provided by the service provider and the external factor are supplied by the service customer. It is not possible for the service producer to produce or buy an external factor on the market. This means the external factor and also the associated knowledge is under control of the service customer. Different customers mean different activities providing different external factors. The service provider is forced to integrate it into the process of service co-creation to provide the demanded service. Because of the important role of an external factor, it is necessary to integrate it into the costing of services. During the co-creation different activities are carried out to combine internal and external factors (factor combination) and to obtain the desired output. This means also that both sides (customer and provider) are integrating resources into the co-creation process. To obtain the whole service costs, we have also to account costs for the customer. This allows afterwards service cost comparison between different customers [12], [13], [14].

Three kinds of uncertainty in service co-creation are disposal uncertainty, production uncertainty and integration uncertainty. Disposal uncertainty occurs when the service customer knows the quantity, quality, time and location of the external factor, but the service provider is not sure whether the customer can provide it. Production uncertainty describes problems creating the external factor. Integration uncertainty regards problems of how to integrate the external factor into the production process of the service provider [9].

4 Customer Integration Factor (CIF)

The target of our Customer Integration Factor (CIF) is to get a rating for integration intensity. We try to measure the expected resource consumption (pre-calculation) and the real resource consumption (post-calculation). As mentioned we consider a customer as the dominant uncertainty factor in the process of service co-creation. In our approach a service is co-created by a set of activities carried out to fulfil customer satisfaction with a tangible or intangible output. These activities are not under full control of the provider and thus uncertainty about the performance and service costs have to be considered. We also consider that knowledge about external activities is often vague and not precise. This assumption is based on the difficulty to standardize a service co-creation process.

A service model for our CIF rating can include activities from the customer domain. Consequently a CIF rating can be split up into provider and customer domain. For a service it is only necessary to sum up these two values, see also Fig. 2. Our considerations are based on the assumption that provider integration is also required into activities on customer domain. An example is when a technician repairs a defective device at the customer and the customer supplies resources during the repair process. When activities on customer domain are required for a service provider and both partners are involved they are included into a service model. Activities on customer domain without active provider participation are not part of the investigated service model. These activities are excluded because we regard them as not cost effective and they have no direct relation to a specific service model.

We talk about a high customer integration level when a service provider is forced to integrate a customer relatively deep into the own value chain which causes higher resource costs compared to a low integration. For example when a service case can be solved by a helpdesk employee the customer integration is low compared to the case when an additional technician or expert is required to solve this service case.

A central point of our rating is the correlation between the CIF and service activities, see Fig. 3. The CIF is designed to be independent from an activity but it is related to it and it is used to measure the customer's impact on a single activity or a complete service. The pre-calculated activity utilization represents the expected resource consumption and consequently the costs for an activity. The sum of the involved activities corresponds to the pre-calculated service costs. During service co-creation data about the performed activities are recorded from which the real value of the CIF parameter and activity utilization can be derived. The recorded data are used to make a post-calculation of real service costs. The results of pre- and post-calculation can then be compared and represent valuable costing information including a rating of the customer's service participation in form of our CIF value.

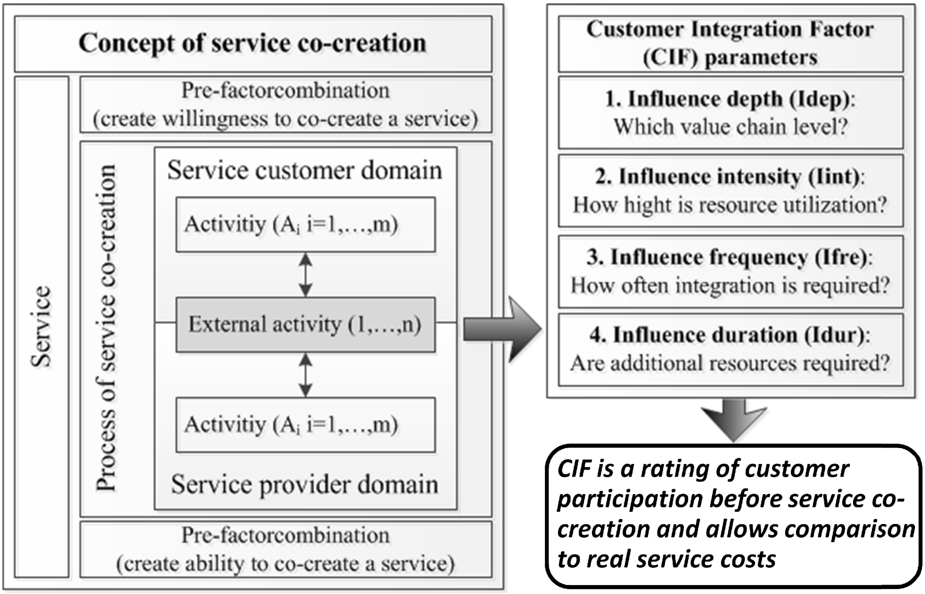


Fig. 2. Concept of service co-creation and CIF parameters

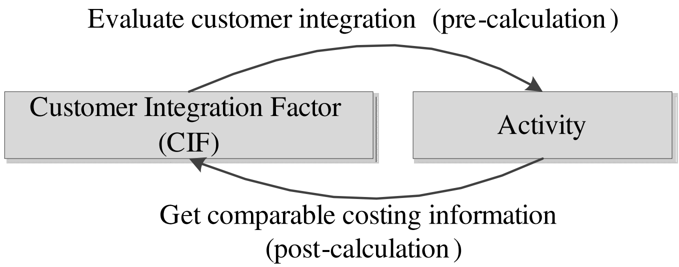


Fig. 3. Correlation between CIF and a service process activity

The CIF is based on four different and independent parameters, see also Fig. 2. Based on a literature analysis and a case study using existing services of a manufacturer and a software company we have derived four parameters. For more details about customer integration and integration intensity we refer to [5], [12] and [15][1]. We have selected these four parameters because they express potential resource consumptions during service co-creation and consequently it is possible derive the required costing data for our subsequent service cost calculations. For service costing we require information about how oft a resource, how much of a resource and which kind of a resource are involved in the process of service co-creation.

[1] Please note [15] is only available in German.

Influence Depth (Idep): $Idep_{A_i} \in R, Idep_{A_i} > 0$ and measures how deep external activities must be integrated into the value chain of during process of service co-creation. We consider that with increasing value chain depth resource costs for integration of external activities rise. This means Idep value for an activity allows to make an association to responsible resource and related resource costs. This is an important correlation for the comparison of pre- and post-calculation. From Idep we can derive which kind of a resource is required e.g. a technician or a helpdesk employee. An Idep value increases or decreases with the corresponding value chain level and is derived from the associated resource. Idep values are individual for each service scenario of a company.

Influence Intensity (Iint): $Iint_{A_i} \in R, 0 \leq Iint_{A_i} \leq 1$ and is used to quantify how intensive a resource of service provider will be utilized by an external activity during process of service co-creation. An influence intensity of 1 means a resource utilization of 100 %. From Iint we can derive how much of a resource is required.

Influence Frequency (Ifre): $Ifre_{A_i} \in Z, Ifre_{A_i} \geq 0$ and indicates how often a specific activity will be required during service co-creation. From Ifre we can derive how often a resource is required. A high Ifre value indicates an activity which is required very often during service co-creation and consequently increases resource consumption.

Influcence Duration (Idur): $Idur_{A_i} \in R$ and is used to evaluate how long additional external activities are part of the service co-creation. Basically Idur is declared as time e.g. minutes. Idur is used to add additional resources to the time equation which are not covered by the standard service process. This can be done for individual customers or customer classes. Idur was added to get a lever which can be used to increase or also decrease the service costs independent from the standard service process. This can be necessary when the standard activity time is too low or too high for a customer. With Idur it is also possible to modify a CIF value and the other three parameters remain unchanged. This can be necessary for specific business scenario.

For a service activity the pre- and post-calculation CIF is computed using Formula 1 where $A_i, i = 1,...,n$ are different activities. It is independent for which activity of a domain the rating is calculated. The function $f_{A_i} \in R$ is calculated for each activity A_i and each CIF parameter owns the A_i index to express individual CIF values per activity. The order of our parameters in Formula 1 expresses which kind of resource is required $Idep_{A_i}$, how much of a resource is required $Iint_{A_i}$, how often a resource is required $Ifre_{A_i}$ and finally are additional resources required $Idur_{A_i}$. Only in this order the CIF parameters express the intended semantics of our customer participation rating. Which is usable for subsequent service cost calculations e.g. pre- and post-calculation comparisons.

$$f_{A_i}(Idep_{A_i}, Iint_{A_i}, Ifre_{A_i}, Idur_{A_i}) = (Idep_{A_i} * Iint_{A_i}) * Ifre_{A_i} + Idur_{A_i}$$

Formula 1: CIF calculation for a single activity $A_i, i = 1,...,n$

5 CIF Evaluation

Based on the described service scenario we have evaluated our CIF rating. The used service process consists of 32 different activities. Based on this modelled service process we have generated random test data for 10 different service co-creations. Altogether we have generated 320 different CIF values for 32 different activities. Each service co-creation consists of simulated pre- and post-calculation data.

We used the following restrictions for test data generation for CIF parameters: Idep is between 0.01 and 10, Iint is between 0 and 1, Ifre is between 0 and 10 and Idur between is 0 and 180. These restrictions are based on results we have derived from a previous sensitivity analysis. We used a sensitivity analysis to find out which parameter ranges lead to the most realistic CIF values. From this sensitivity analysis we also know that Idur is the most dominating CIF parameter when the CIF parameter is high. The selected CIF parameter restrictions are not applicable for all service scenarios and have to be defined during the service modelling step. Especially the Idep value is specific for each company because it depends on the associated value chain level of a corresponding resource e.g. a technician has a higher Idep value as a helpdesk employee. Iint will always between 0 and 1 because a resource cannot be utilized more than 100 %. The height of Ifre depends on the service processes of a company and how the activity flow is organized. Idur depends on the related activity and service scenario. For example if the standard activity time is high enough it is not necessary to increase it by using the Idur value.

To evaluate our CIF rating we have tested the following hypothesis:

H_0: The CIF rating indicates the intensity of customer integration and provides data about resource utilization and kind of required human resources. From the kind of required human resources we can derive resource costs and consequently service costs.

5.1 Result Discussion

In this section we describe our evaluation results and if we could validate our hypothesis. Please note in Fig. 4 and Table 1 the results of a whole service/service co-creation are documented but using our complete output dataset a drill down to a single activity and CIF parameter value is possible. The following information can be derived from our simulated service co-creation data:

- Individual CIF parameter ratings can be computed for pre- and post-calculations which can be traced from a service down to an individual activity. An important requirement for cost traceability in cost accounting. Our approach provides a cross domain CIF rating and independent CIF ratings for customer and provider domain.

- Based on Idep it is possible to derive estimated and real value chain level and consequently which kind of human resource is required. The connection between value chain level and human resource is possible because in our service model we assign each activity and each human resource such a level.
- We also can derive the estimated and real resource consumption for the Iint parameter. Real resource consumption can be derived from the time an employee needs for an activity. These data are usually provided by an external information system like an Enterprise-Resource-Planning (ERP) System. For our evaluation we have simulated these data. The same data can be used to compute Ifre and Idur for a post-calculation comparison. Consequently we can derive the information how often an activity (Ifre) was actually part of a service co-creation and if extra time was required (Idur).

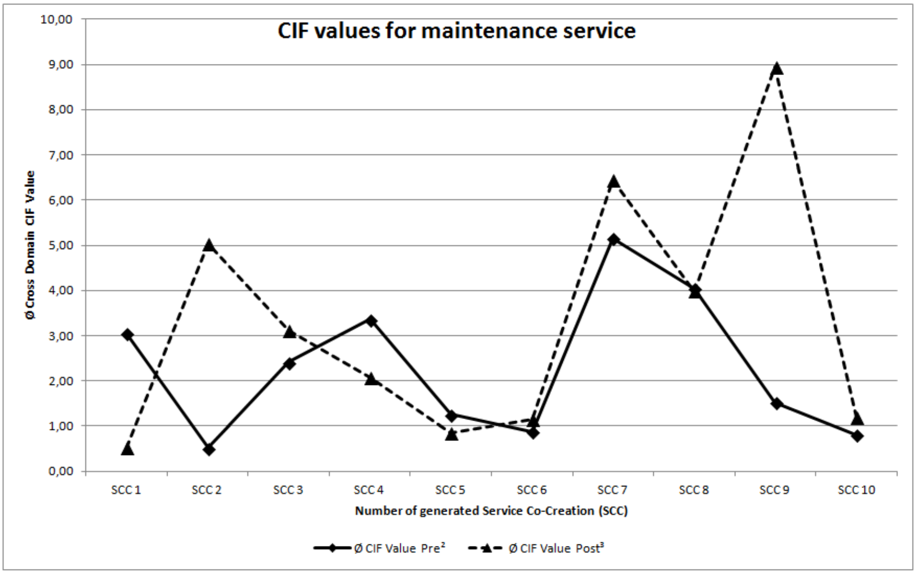


Fig. 4. Comparison of pre- and post-calculation data for simulated service co-creations (² Pre-Calculation, ³ Post-Calculation)

To answer our hypothesis H_0 we use the results illustrated in Fig. 4 and Table 1. On the Y axis of Fig. 4 the computed pre- and post-calculation CIF values are represented. This CIF value includes customer and provider domain and is the average CIF value of all individual service activities. The X axis illustrates the 10 different service co-creations we have simulated. In Table 1 a pre- and post-calculation summary including all 10 simulated service co-creations and customer and provider domain is illustrated. From our test results, see also Fig. 4 and Table 1, we can derive that a pre- to post-calculation difference is based on the change of the underlying CIF parameters and it is possible to trace this change down to a single activity and CIF parameter value. For example the post-calculation value of SCC2 is significant higher than the pre-calculation value. From Table 1 we can derive an increase in the post Idur value.

From our test dataset we also can derive that SCC6, SCC8 and SCC10 have nearly similar pre- and post-calculation. This means the forecasted CIF value corresponds to CIF values after service co-creation. Because of this traceability it is possible to compare our estimated CIF rating with a real CIF value which is based on objective respectively historical data. And consequently our CIF rating is a measurement which indicates the intensity of customer integration. As described at the beginning of this section we can also derive data about actual resource utilization and the kind of required resources. Based on these assumptions, we can answer our hypothesis positively.

Table 1. Aggregation of generated test data

SCC[1]	Ø CIF Value Pre[2]	Ø CIF Value Post[3]	DIFF[4]	Ø Iint Pre	Ø Idep Pre	Ø Ifre Pre	Ø Idur Pre	Ø Iint Post	Ø Idep Post	Ø Ifre Post	Ø Idur Post
SCC 1	3,05	0,51	-2,54	0,008	0,19	0,28	2,59	0,01	0,08	0,06	0,47
SCC 2	0,51	5,03	4,52	0,021	0,13	0,16	0,09	0,02	0,18	0,09	4,69
SCC 3	2,42	3,11	0,69	0,028	0,01	0,03	2,41	0,00	0,03	0,09	3,09
SCC 4	3,36	2,07	-1,30	0,021	0,16	0,13	2,94	0,02	0,09	0,09	1,84
SCC 5	1,25	0,84	-0,41	0,015	0,24	0,16	0,69	0,03	0,26	0,09	0,16
SCC 6	0,88	1,14	0,27	0,031	0,13	0,00	0,88	0,01	0,20	0,09	0,88
SCC 7	5,16	6,44	1,28	0,013	0,00	0,09	5,16	0,02	0,08	0,25	5,22
SCC 8	4,04	3,98	-0,06	0,000	0,13	0,31	4,03	0,01	0,11	0,16	3,22
SCC 9	1,52	8,94	7,41	0,008	0,27	0,16	1,19	0,02	0,28	0,28	5,41
SCC 10	0,81	1,19	0,38	0,014	0,25	0,13	0,34	0,02	0,08	0,16	0,69

[1]SCC (Service Co-Creation), [2] Pre-Calculation, [3] Post-Calculation, [4] Difference

6 Conclusions

In a Service System as part of a Product Service System a customer introduces uncertainty about performance and costing. Our developed Customer Integration Factor (CIF) is a rating to support a service provider in cost accounting and capacity planning to overcome these problems. Our CIF rating is based on four different and independent parameters trying to characterise customer's impact and point of view in a service co-creation process. We have presented our CIF rating based on self generated test data and have used them to evaluate our stated hypothesis positively.

Our CIF rating provides useful and realistic data about resource consumption and required human resources. It is also possible to conclude which competencies have to be provided by customer and provider to co-create a service to the estimated costs. The CIF rating is primarily designed for cost accounting of a service provider. Due to customer associated costing information a CIF rating can also be used in contract negotiations to offer a price which depends on the CIF rating. A low CIF rating means higher costs for the customer and a high CIF rating causes higher costs for the provider. Based on our evaluation results we can conclude that our CIF rating can be used as the claimed extension for Activity-Based Costing. The integration of CIF into Activity-Based Costing is part of our current research work. The CIF is a practical measure for the level of customer participation and the comparison of estimated and real costing data. Data provided by our CIF approach can be used to reduce uncertainty in service costing.

A next step in our research work is to provide real costing data about service co-creations for pre- and post-calculation. These data will be provided by an ERP-System. First integration tests with an existing ERP-System have been successfully completed. To improve pre-calculation ratings the integration of historical data is also planned. The integration of our CIF rating in our developed Cost Model for Services (CMFS) is part of our ongoing research work. Finally the CIF rating will be a part of the CMFS a costing method designed for services that covers the service modelling and costing tasks.

References

1. Mont, O.K.: Clarifying the concept of product-service system. Journal of Cleaner Production 10, 234–245 (2002)
2. Lusch, R., Vargo, S.: Evolving to a New Dominant Logic for Marketing. In: The Service-dominant Logic of Marketing: Dialog, Debate, and Directions, pp. 3–29. M.E. Sharp, New York (2006) ISBN 0-7656-1490-1
3. Lusch, R., Vargo, S.: Service-Dominant Logic: What It Is, What It Is Not, What It Might Be. In: The Service-dominant Logic of Marketing: Dialog, Debate, and Directions, pp. 43–56. M.E. Sharp, New York (2006) ISBN 0-7656-1490-1
4. Lusch, R., Vargo, S.: Service-dominant logic: reactions, reflections and refinements. Marketing Theory 6(3), 281–288 (2006)
5. Wattanakamolchai, S.: Managing Customer Participation in the Service Production Process (2009)
6. Baines, T.S., Lightfoot, H.W., Evans, S., et al.: State-of-the-art in production-service systems. Proc. IMechE, Part B: J. Engineering Manufacture 221 (2007)
7. Spohrer, J., Vargo, S., Caswell, N., Maglio: The Service System is the Basic Abstraction of Service Science. In: Proceedings of the 41st Hawaii International Conference on System Sciences
8. And de Vries, W., Kasper, H., van Helsdingen, P.: Service Marketing Management – An International Perpective, pp. 8–20. John Wiley & Sons, West Sussex (1999) ISBN 0-471-98490-6
9. Erkoyuncu, J.A., Roy, R., Shehab, E., Cheruvu, K.: Understanding service uncertainties in industrial product-service system cost estimation. The International Journal of Advanced Manufacturing Technology 52(9-12) (2010)
10. Wattanakamolchai, S.: Managing Customer Participation in the Service Production Process (2009)
11. Flandel, G., Blaga, S.: Elements of the production of services. In: Modern Concepts of the Theory of the Firm – Managing Enterprises of the New Economy, pp. 175–189. Springer, Heidelberg (2004) ISBN 3-540-40509

12. Helm, S., Kuhl, M.: Quality Uncertainty and Customer Integration – The Vendor's Perspective. In: Proceedings of the 13th IMP-Conference on Interaction, Relationships and Networks in Business Markets, Lyon, pp. 239–261 (1997)
13. Bruhn, M., Georgi, D.: Service Marketing – Managing The Service Value Chain, pp. 5–27. Person, Essex (2010) ISBN 978-0-27368-157,1
14. Frisch, R.: Theory of Production, pp. 3–5. Springer, Netherlands (2009) ISBN 978-9048183340
15. Fließ, S.: Die Steuerung von Kundenintegrationsprozessen: Effizienz in Dienstleistungsunternehmen. Deutscher Universitätsverlag (2001) ISBN 3-8244-9039-0

Author Index