TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

Machine Building Faculty

Habilitation Thesis

Domain: Engineering and Management

Lifecycle and Services Management

Prof. Dr.-Ing. Dipl.-Wirt. Ing. Jörg Niemann

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Rezumat

Teza de abilitare prezintă în rezumat activităţile autorului în domeniului managementului ciclului de viaţă şi managementul serviciilor.

Prof. Dr.-Ing. Dipl.-Wirt. Ing. Jörg Niemann, este născut în 1970 şi din 2012 până în prezent este Profesor la Universitatea de științe Aplicate din Düsseldorf Germania (Düsseldorf University of Applied Sciences).

Capitolul 1 din teză descrie cariera autorului, scoţând în evidenţă realizările stiinţifice şi din industrie, precum şi îndelungata colaborare cu Universitatea Tehnică din Cluj-Napoca. Până în prezent autorul a scris peste 150 de articole științifice recenzate, publicate în reviste internaţionale sau prezentate la conferinţe. Este editorul a 5 carţi şi alte 5 sunt în curs de elaborare. A supervizat peste 100 de lucrări de licentă şi master şi în prezent este implicat în activitatea de co-tutelă a 3 studenţi doctoranzi.

In 2017 a fost nominalizat ca membru pentru certificarea institutelor de învățământ din Northrhine-Westphalia, în această calitate Prof. Niemann este responsabil în cadrul Düsseldorf University of Applied Sciences pentru programele de studii ale liniile de inginerie mecanică şi de business, atât pentru nivelul de Bachelor cât şi pentru cel de Master.

Prof. Niemann este fondatorul şi directorul centrului de excelenţă pentru ciclurile de viaţă FLiX (Research Centre for Life Cycle Excellence), precum şi diretor executiv (Managing Director) al institutului de dezvoltare de produs şi Inovare FMDauto (Institute for Product Development and Innovation). Cele două institute generează anual un venit anual de aproximativ 700.000 Euro p.a. (Euro Payment Area, zona de plată în euro) din activităţi de cercetare destinate clienţilor publici sau industriali (land, federaţie sau comunitatea europeană).

Autorul este membru în biroul VDI (Asociaţia Inginerilor o Germani), asociaţia districtuală Lower Rhine

In perioada celor 4 ani în care a lucrat ca şi Directorul departamentului de management al ciclului de viaţă (Head of Service Lifecycle Management) la firma ABB (ASEA Brown Boveri, corporaţie multinaţională Elveţiaono-Suedeză, cu centrala în Zurich, Elveţia,

ce operează în special în domeniul roboticii), a avut ca sarcină permanentă dezvoltarea şi vânzarea de produse inovative pentru servicii de privitoare la ciclul de viaţă, responsabilitate concretizată în conducerea unei echipe proprii care a realizat vânzării de 5 Mio. € p.a (vezi, anexele CV).

In cadrul carierei a dezvoltat numeroase proiecte majore de cercetare cu industria (vezi, lista proiectelor Cap. II 1.3), experienţa industrială constituind o continuă sursă de date şi inspiraţie pentru prelegerile susţinute.

Pentru rezultatele obţinute, profesorului Jörg Niemann i-au fostacordate numeroase premii academice şi din partea mediului economic (vezi, anexele CV).

In capitolul II, se face o trecere în revistă asupra profilului de cercetător şi a rezultatelor obţinute. Aici sunt evidenţiate domeniile de cercetare legate de managementul ciclului de viaţă, pentru demonstrarea a particularităţilor şi a posibilităţilor de integrare a serviciilor.

Domeniul de cercetare acoperă întregul ciclu de viaţă al produsului şi a sistemelor de producţie din leagăn şi până în mormânt. Pornind de la stadiul actual a fiecărei faze a ciclului de viaţă, autorul a dezvoltat în activitatea curentă de cercetare noi domenii şi abordări privitoare la impactul tehnic şi economic. Abordarea ciclului de viaţă a fost extinsă şi completată cu componenta relativ nouă de (smart) srvicii sub amendamentele Industry 4.0. Aceste potenţiale trebuie să fie descoperite prin cercetare academică şi implementate industrial prin viitoare activităţi doctorale.

Capitolul III conţine planul de dezvoltare ştiinţifică şi academică. Pentru viitoarele activităţii de cercetare şi teze doctorale, autorul identifică 5 domenii de cercetare, derivate din cercetările prezentate în Capitolul II.

Subiectele identificate, pot fi parte a realizărilor şi conducerii de activităţii de doctorat în cadrul Scolii Doctorale a Universităţii Tehnice din Cluj-Napoca, Romania (cf. chapter III.1).

Conceptul de educaţie continuă se concluzionează cu o viziune asupra integrării proiectelor de cercetare şi a şcolii doctorale într-o reţea internaţională de cercetare, benefică pentru educarea viitorilor studenţi ai Şcolii Doctorale din Cluj-Napoca, România (cf. chapter III.2).

Abstract

The submitted habilitation thesis summarizes the activities of the author in the field of life cycle and services management. Prof. Dr.-Ing. Dipl.-Wirt. Ing. Jörg Niemann, born 1970, currently works as a full professor at the Duesseldorf University of Applied Scienes in Düsseldorf, Germany since July 2012.

Chapter I deals with the career of the author and highlights his long-term activities with the TU Cluj-Napoca as well as his scientific and industrial achievements after his Ph.D.. In his career the author by now wrote more than 150 reviewed scientific articles in international magazines and conference papers. He is the editor of 5 books and 5 further books are planned. He holds an h-score of 10 in the scientific community. He supervised more than 100 students' papers at a Bachelor, Master and Diploma level and he is currently involved in the co-tutelage of three doctoral projects. In 2017 he was appointed a member of the graduate institute in the state of Northrhine-Westphalia. Prof. Niemann is responsible for the study programme of mechanical engineering and business on both, bachelor and master level at the Duesseldorf University of Applied Sciences. Prof. Niemann is the founder and head of the FLiX - Research Centre for Life Cycle Excellence as well as the managing director of the FMDauto – Institute for Product development and Innovation. Both research institutes together generate research revenues of around 700k€ p.a. through research assignments by public and industrial customers (state, country, and EU). The author is a member in the board of the VDI (district association Lower Rhine).

During his four-year occupation at ABB as Head of Service Lifecycle Management he was in charge for the development and sales of innovative life cycle service products and responsible with his team for a sales volume of 5 Mio. € p.a. (see CV in the appendix). In his career he acquired and handled numerous major industry and research projects (see list of projects chapter II 1.3). His industrial experiences continuously serve as a continuous practical input for his lectures.

For his outstanding achievements Prof. Niemann was awarded with several prizes on academic and industrial levels (see CV in the appendix).

Chapter II gives an overview about the research profile and achivements of the author. Thereby the particular fields of the research area Lifecycle Management are illuminated and the particularities and integration possibilities of the services are turned out. The research field covers the entire lifecycle of products and production systems from cradle to grave. Starting from the state-of the art in every life cycle phase the author derives new fields and approaches in current research with regard to technical and economic impact. The life cycle approach has been extended and complemented by the integration of the relatively new field of ("smart") services under the constraints of industry 4.0. These potentials shall be uncovered for academic research and the industrial implementation through future doctoral works.

Chapter III contains the scientific and academic development plan. The autohor identifies five research areas for further research needs and and derives future doctoral projects from the findings in chapter II. The identified topics shall be part of the execution and supervision of doctoral works at the Doctoral School of the TU Cluj-Napoca (cf. chapter III.1). The concept for the continuing education concludes with a vision for the integration of the research projects and the doctoral school into an international research network with benefit for the education of future students of the doctoral school at Cluj-Napoca/Romania (cf. chapter III.2).

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I Motivation and personal achievements

1. Partnership with TU Cluj-Napoca

The author and the TU Cluj-Napoca/ Rumania are connected by a meanwhile 21-year partnership. 1998 the author was involved in a tempus project with the faculty of machine engineering at TU Cluj-Napoca during his occupation at Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) and University of Stuttgart. The goal at that time was to establish an institute for long distance education lead by the TU Cluj-Napoca. The institute (DECID) was established successfully and temporary was the biggest institute of this kind in Romania. The ties with Romania and a large number of TU Cluj-Napoca professors were also maintained after the completion of the prject as years went by. In year 2002 the author was awarded the title of a “Honorary Professor” by the faculty for machine building. Besides regular lectures in the German course of studies machine engineering of the TU Cluj-Napoca, the author realized numerous national and international projects with different partners of the TU Cluj-Napoca. As years went by -beside the the jointly executed projects- a joint basic book for the education in mechanical engineering and numerous joint publications with the colleagues of Cluj-Napoca emerged (see also list of publications in the appendix: „Planning and Operation of Production Systems“). Meanwhile a cooperation contract has been signed between the TU Cluj-Napoca and the Dusseldorf University of Applied Sciences. Within this framework regular student exchanges, a joint supervision of Bachelor and Master thesises as well as an exchange of lecturers with mutual lectures is realized in both directions. Due to the strong presence of German companies in the region of Cluj companies increasingly wish for students and graduates in the automotive field who are accustomed to both cultures. Via the established network internships for students in the region Cluj and Dusseldorf are realized on a regular basis.

In total by now the partner-like cooperation of the TU Cluj-Napoca and the Hochschule Dusseldorf is a network of industrial partners, associations and research institutes and expertise emerged that actively participates in international research tenders (e.g. EU Horizon 2020) and industry projects (e.g. Daimler/STC, Continental AG, Bielomatik AG, etc.).

The long-term partnership of both institutions shall from now on be expanded and lifted to a new level by a joint supervision of doctoral works, in order to satisfy the industry's need for more qualified graduates.

There is an increasing demand for specialists in both countries especially in the field engineering in combination with economical questions. This demand though is currently not facing sufficiently high qualified graduates who occupy with questions of economic product optimization under the paradigm of industry 4.0 or the digitization of services.[1]

2. Personal Background

The author, born 1970, worked in research as well as in the industry for many years and thereby led a variety of research and industrial projects (see also following chapter).

After his studies of industrial engineering and business management at the University of Paderborn he started his career as personal assistant to the managing director (Prof. Westkämper) of the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) Stuttgart, Germany (see Figure 1 and CV in the appendix). After ten years of academic and applied research he left Fraunhofer to join ABB Automation GmbH, a global manufacturer of power and electricity equipment. He served there as the head of Lifecycle Services Management, responsible with his team for a revenue of >5 M€ per year. During his assignment he was responsible for the development and productization of services. In 2011 he was appointed a member of the supervisory board of ABB Automation GmbH.

In 2012 he was appointed full Professor of the Düsseldorf University of Applied Sciences (HSD) for the chair for business administration and mechanical engineering. The author is the founder of the FLiX – Research Centre for Life Cycle Excellence and simultaneously managing director of the institute FMDauto – Institute for Product Development and Innovation.

[1] (N.N. 2017), p.3

Addtionally the author is member of the board of the VDI (Association of German Engineers). In 2017 he was appointed a member of the graduate institute of the state of Northrhine-Westfalia)

Prof. Dr.-Ing. Dipl.-Wirt. Ing. Jörg Niemann

Director of

FMDauto Institut für Produktentwicklung und Innovation

FLiX Forschungsstelle Life Cycle Excellence

Since 07/2012	**Full Professor for Mechanical Engineering and Business Management** Teaching and research: • Life Cycle and Services Management • International Technical Sales • Production Optimization & Investment Planning • Business Plan Development • Founder of FLiX – Research Centre for Life Cycle Excellence • Managing director of the institut FMDauto - Institute for Product Development and Innovation
2008 -2012	• ABB Automation GmbH, Ratingen, Mannheim • Head of Lifecycle Service Management • Member of the Supervisory Board
1998-2008	• Fraunhofer Institut for Manufacturing Engineering and Automation(IPA), Institute of industrial Manufacturing and Management University of Stuttgart (IFF)
1990-1996	• Studies of Industrial Engineering and Business Management , Paderborn

Figure 1: Personal background at a glance

The following chapers will give a more detailed overview about the author´s academic and industrial achievements.

2.1 Academic and scientific achievements

During his career the author supervised more than 100 students' final theses at Bachelor, Master and Diploma level. Currently the scientific adivsor/supervisor of three doctoral projects (co-tutelage). Since 2002 he is assigned honorary professor at the TU Cluj-Napoca at the faculty of machine building.

In 2007 the author earned his doctorate degree at the University of Stuttgart, Germany in cooperation with the Fraunhofer IPA on the topic of: „A method for the dynamic life cycle controlling of manufacturing systems“, (grade: very good). In his doctoral thesis he dealt with the long-term cost optimization of capital goods and their lifecycle. Within the research works he furthermore defined the new term of life cycle controlling which is now an “integral term” it in the scientific community.[2]

In his scientific career the author is/was involved in the organization and realization of the following conferences:

- International Conference on Competitive Manufacturing (COMA´19), Stellenbosch, South Africa (Member of the International Programme Committee)
- 1st International Conference on Advanced Production Management and Process Control (APMPC) - AHFE2018, Orlando, Florida, USA (Founding member oft he Advisory Board)
- International Conference on Manufacturing Engineering and Process (ICMEP 2018), Barcelona, 2018 (Member of the Technical Comittee)
- International Conference on Mechanical and Aerospace Systems (ICMAS 2018), March 16-19,2018, Chengdu, China (Technical Comitee)
- International Conference on Manufacturing Engineering and Process (ICMEP 2017), Lisbon Portugal, 2017 (Member of the Technical Comittee)
- The 4th International Conference on Manufacturing and Industrial Technologies (ICMIT 2017), Lisbon Portugal, 2017 (Member of the Technical Comittee)
- International Conference on Production Research, Regional Conference Africa Europe and the Middle East (ICPR- AEM), Cluj, Napoca, Romania, 2016 (Member of the International Scientific Comittee)
- 4th International Conference on Quality and Innovation in Engineering and Management (QIEM), Cluj, Napoca, Romania, 2016 (Member of the International Scientific Comittee)
- 84. AFSMI Conference on Service Engineering & Management: Service Life Cycle Management - Theorie und Praxis im Wechselspiel, 2014, Düsseldorf, Gemany (Chairman of the Conference)
- International Conference on Production Research, Regional Conference Africa Europe and the Middle East (ICPR- AEM), Cluj, Napoca, Romania, 2014 (Member of the International Scientific Comittee)
- 3rd international Conference on Quality and Innovation in Engineering and Management (QIEM), Cluj, Napoca, Romania, 2014 (Member of the International Scientific Comittee)

[2] (Niemann 2007), p. 1

- 6th International Conference on Engineering Design and Automation: Engineering Practice & Education. Maui, USA, 2002 (Member of the International Scientific Comittee)
- 5th International Conference on Engineering Design and Automation, Las Vegas, USA, 2001 (Member of the International Scientific Comittee)
- 4th International Conference on Engineering Design and Automation, Orlando, Florida, USA, 2000 (Member of the International Scientific Comittee)
- 17th IEEE Conference on Business Informatics, Lisbon, Portugal, 2015 (Member of the Programme Comittee)
- Co-Chairman and Host of the European System, Software & Service Process Improvement & Innovation Conference (EuroAsiaSPI[2]), Düsseldorf, Germany, 2020 (in planning)

In his scientific career the author wrote more than 150 refereed publications, among them also a number of books with international authors (see list of publications in the appendix). His h-score (Hirsch-Score) is currently at 10[3], so that he is one of the most efficient scientists at the University of Dusseldorf in the field of mechanical and process engineering.

The author is founder and head of FLiX – Research Centre for Life Cycle Excellence and simultaneously managing director of the FMDauto – Institute for Product Development and Innovation. FMDauto is the largest institute of the Dusseldorf University of Applied Sciences. The research focuses of the author therefore are on product and production development as well as their lifecycle oriented optimization. Furthermore both institutes deal with the development and delivery of services for academic and industrial research partners (see Figure 2).

Both institutes together generate an annual turnover of more than 700 k€ p.a, for which the author is directly or indirectly responsible. Clients come from public authorities (EU, state, country) as well as to a great extent from the industry (see list of projects in the appendix).

[3] (GoogleScholar 2019)

Regarding the lecture the author is engaged in the subjects Investment Planning, Production Optimization, Lifecycle & Services Management and Technical Sales. Aditionally he leads/supervises a number of lecturers (also international). Furthermore since many years the author in his position as program manager is responsible for academic studies programme of Business and Mechanical Engineering on both Bachelor and Master level.

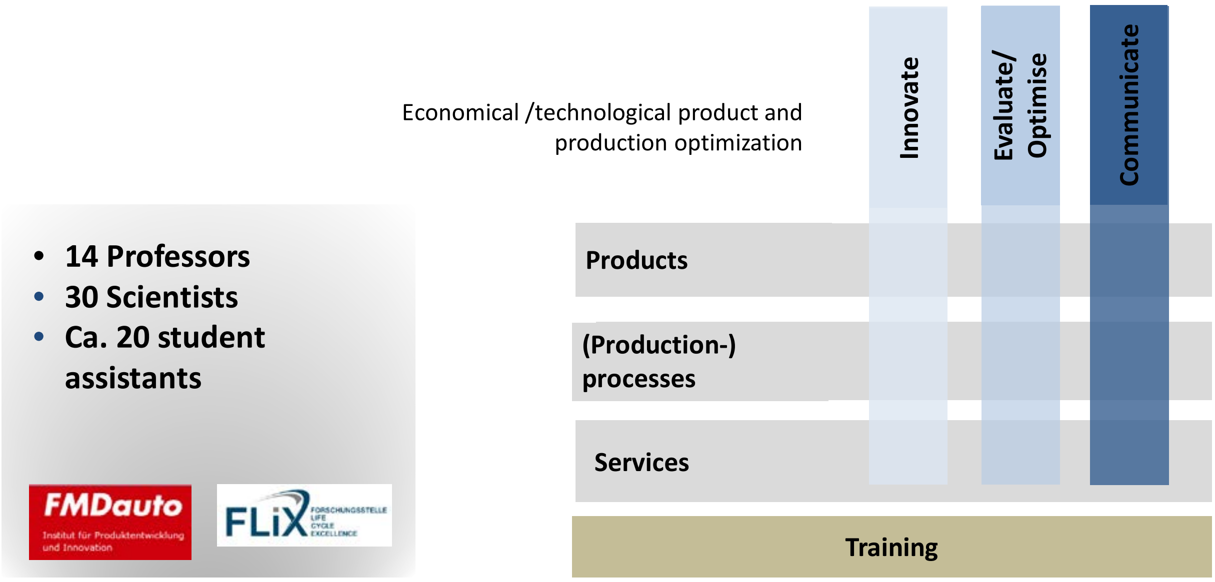

Figure 2: Prof. Niemann – research ressources and portfolio

For the development and implementation of a teaching and educational concept the author in 2014 was awarded with the High-Tech-Service Know how Transfer special award by the AFSMI (Association for Service Management International). The developed education concept including lectures, laboratories and industrial internships constitutes a unique characteristic of the University of Dusseldorf for the whole region.

Via FLiX the author in the meantime developed an international network for the exchange of students and teachers and developed a research cooperation that includes leading institutes in different countries. Upon his initiative the following partnership agreements have been closed with the following universities:

South Africa:

- University of Stellenbosch (SUN)
- Cape Peninsula University of Technology/ Cape Town (CPUT)

Malaysia:

- University of Malaya (UM)
- Universiti Kuala Lumpur (UniKL)

Austria:

- FH Technikum Wien (FHTW)
- FH Johanneum Graz (Johanneum)

Romania:

- TU Cluj-Napoca (TUC-N)
- Universitatea Politehnika Timisoara (UPT)

Currently in planning:

- Tecnológico de Monterrey Campus Saltillo, Mexico
- Universidade Federal do Rio de Janeiro (UFRJ), Brazil

Those partnerships operate on a regular exchange of students and tutors. Furthermore international project calls are addressed via the partnerships (e.g. “ELIC” in cooperation with Johanneum; “Holotrack” in co-operation with TUC-N, UPT, SUN).

With some partners, like for example the Johanneum and the department Engineering & Management of the TUC-N, for the future deeper cooperations through double degrees in the studies Business and Mechanical Engineering are planned to be established.

2.2 Industrial Achievements and co-operations

After completing his doctoral thesis the author worked for ABB Automation GmbH, the German branch of ABB AG, between 2008 and 2012. ABB is a globally leading technology company in the field of energy supply, industrial automation and transport. Due to his experiences from research and project works at Fraunhofer IPA/ University of Stuttgart the author was appointed Head of Lifecycle Management and with his six employees responsible for the development and distribution of service performances in the field of process control engineering and a turnover of 5 Mio. € p.a.

In 2009 the author was awarded with the ABB Award for the successful development and the global rollout of an innovative service product (“Life Cycle Index”). The author developed a tool that until today is successfully used at ABB worldwide for the analysis and consulting of customers.[4]

In 2011 the author was awarded by ABB for the development of an IT Security Fingerprint Tool as part of an international team.

Besides the development of service products the author was also responsible for the services sales. The practical work experience of those times continuously flows into today's research and lecture of the author at the Hochschule Dusseldorf. Via the network of industrial contacts of those times the author today supervises 15 industrial internships annually (duration 5 months each) as well as around 15 Bachelor and Master thesises of students on both, national and international levels. Through the academic/industrial exchange with students theses as well as his extensive academic and contract research the authors is in permanent contact and exchange with his large portfolio of industial partners.

[4] (Niemann 2012), p. 386, (Niemann et al. 2012), p. 7

3. Acquired fundings and research projects

The following list of research projects represent and proof the extensive exchange of the author with industrial and academic partners in Germany on national and international level. Fundings for projects come from both, public and industrial sources.

Research project	Funding	Volume	Period
CE3: Crossborder Entrepreneurial Energy Education (CE3)	EU Interreg Programme	1,5 M€	2019–2022
Interactive body-near production technology (iKPT4.0)	Federal Ministry of Education and research	890 k€ (incl. 260k€ from industrial sources)	2017–2019
Fellowship for innovations in practise of digital academic teaching	Stifterverband Northrhine Westfalia	50 k€	2019
EnerFlow II– Lifecycle orientated evaluation and optimisation of energy flows in mobil production machines on the example of a forage harvester	Federal Ministry of Education and Research	300 k€	2018-2020
Engineering Literacy Online - Teachers as Medium for Change (ELIC)	EU ERASMUS+, Cooperation for Innovation and the exchange of good practises	228 k€	2018-2019
Competence centres for automotive engineering and sales management Argentina, Brazil and Mexico (Ascent)	EU ERASMUS+, Cooperation for Innovation and the exchange of good practises	992 k€	2017-2020

Research project	Funding	Volume	Period
Study of the working environment and imrovement of an automotive supplier in Romania	Industry	10 k€	2016
Experimental and theoretical basic research of cutting processes in farming industry	German research foundation (DFG)	200 k€	2016-2019
Digitisation of academic environments	Internal research fund, Duesseldorf University of Applied Sciences	40 k€	2017-2018
Administrative Support & Advisory in third party funding research activities	Internal research fund, Duesseldorf University of Applied Sciences	120 k€	2016-2018
Service concept for an international manufacturer of ropeways	Industry	20 k€	2015
Concept for the production optimisation of an automotive supplier in Romania	Industry	40 k€	2015
Establishment of a participative planning environment for the optimisation of production structures	Ministry of Economics, State of Northrhine Westfalia	40 k€	2014
Study to improve labour conditions in the final inspection of coating results in car manufacturing by the application of eye tracking	Industry	40 k€	2016

Research project	Funding	Volume	Period
Development of a service index to measure and improve service quality in industrial companies (Total Care Index)	Industry	50 k€	2015
EnerFlow I– Life Cycle orientated evaluation and optimisation of energy flows in mobil production machines on the example of a forage harvester	Federal Ministry of Education and Research	300 k€	2014-2017
Extension of the Service Engineering Lab NRW	Ministry of Economics, State of Northrhine Westfalia	90 k€	2014-2016
Establishing of the first Service Engineering Lab in NRW	Ministry of Economics, State of Northrhine Westfalia	40 k€	2014
Logistic-oriented participative factory and production planning	Ministry of Economics, State of Northrhine Westfalia	50 k€	2012
Development of a consulting tool to evaluate the IT-Security Levels of cumstomer plants	Industry	100 k€	2011-2012
Global roll-out of the life cycle index® within a worldwide operating company	Industry	150 k€	2011
Development of a method to analyse and evaluate the productivity status of process control systems („Life Cycle Index®“)	Industry	250 k€	2008–2009

Research project	Funding	Volume	Period
Establishment of a researcher group in the area of energy efficiency	Federal Ministry of Education and Research	360 k€	2009–2011
Lifecycle calculation for measurement systems („WiMess“)	AiF	140 k€	2006–2008
Life Cycle Management in production (Network of excellence „VRL KCiP“)	EU, Network of Excellence	200 k€ (Consortium total: 6,4 Mio. €)	2004 -2008
Electronic services for production optimisation (Network of excellence „VRL KCiP“)	EU, Network of Excellence	200 k€ (Konsortium total: 6,4 Mio. €)	2004- 2008
Establishment of a web-based learning environment in mechanical engineering	EU	40 kT€	2002
Development of a business concept for an innovative heat management system in private households	Federal Ministry of Education and Research	60 k€	1999 - 2000
Establishment of a Center for long distance studies at the TU Cluj Napoca (DECID)	EU	60 k€	1998 - 2001

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(GoogleScholar 2019) https://scholar.google.de/citations?view_op=list_works&hl=de&user=s7Bo45IAAAAJ&cstart=0&pagesize=20. Checked 25.05.2019.

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(Niemann et al. 2012) Niemann, Jörg et al., (Mitarb.), ZVEI Zentralverband Elektrotechnik- und Elektroindustrie e.V. Fachverband Automation (Hrsg.): Life-Cycle-Management for Automation Products and Systems. A Guideline by the System Aspects Working Group of the ZVEI Automation Division, Frankfurt, ZVEI, 2012

II Research profile

The increasing globalization as well as economic and ecological problems challenge companies in the 21st century. Facing the existing and emerging competitors and competition due to opening markets, companies have to provide excellent results to stand out and secure their market position.

Furthermore sustainable development needs to be ensured, that satisfies "…the needs of todays' generations without adversely affecting the possibilities of future generations..".[5]

Customers of the capital goods industry demand increasingly individual solutions to their problems. Further new forms of added value are required, that fit the specific customer needs. The offer of integrated products and services up to hybrid service bundles can become a key competence in maintaining competitive. In addition the development of new markets holds various potentials, as the revenue generated by services can be increased many times over. According to VDMA the annual maintenance effort accounts for 4,7% of a new investment, therefore after a life cycle of 20 years it can be calculated with a maintenance effort in the amount of almost a new product investment.[6]

In order to fulfill those challenges as well as to secure constant growth in the product and service market, extensive expertise along the whole lifecycle of a product is necessary.

This calls for a reference framework for an integrated lifecycle management along the whole product lifecycle with the corresponding service disciplines. Thereby the guiding principle of sustainability needs to be considered and information flows need to be integrated.

The structure of this paper is based on Figure 3. In the first upper left box the lifecycle phases are presented in the classical threefold division. Furthermore the service factor is mentioned. It is directly connected with the design phase, as services in this phase

[5] (Hermann 2010), p. 10
[6] (Meier/Uhlmann 2012), p. 22

at best are developed in parallel with the product. In addition to that the service supports the individual phases of the product lifecycle.

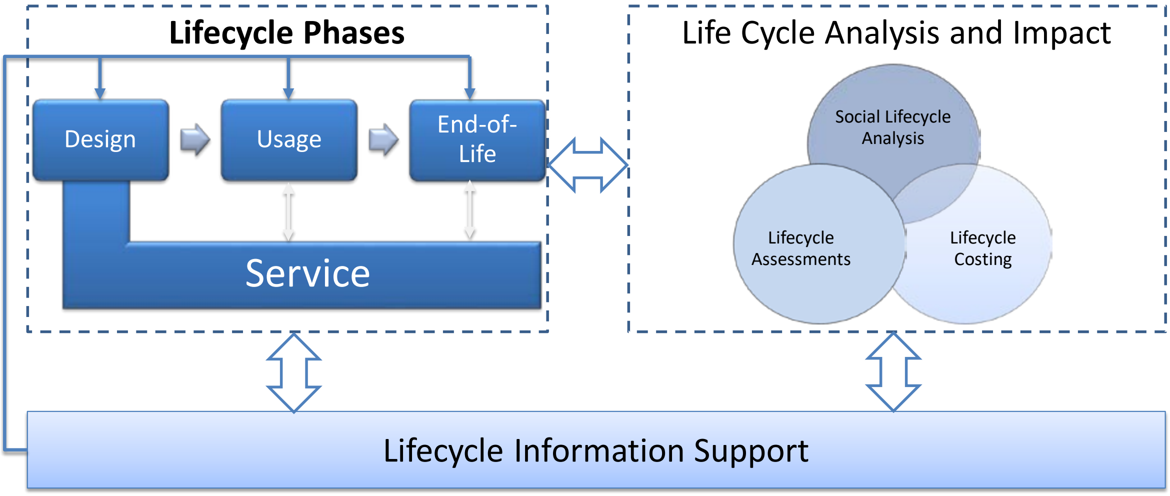

Figure 3: Interrelation of the topics[7,]

The information generated from the product lifecycle, are being analyzed and evaluated in box "Lifecycle analysis and impacts". The three portrayed bubbles contain the social, economic and ecological aspects. The resulting interface signifies sustainability.[8] To support the collection, processing and administration of the information, the lifecycle information support is intended. Moreover it is significant that a cross-functional access to the information is secured. The information of previous products is the base for new products. Consequently a continuous improvement process is guaranteed.

[7] Source: Enhanced according to (Niemann 2009), p.12, (Hermann 2010), p.36 (Aachener Stiftung 2015), p. 34ff

[8] (Aachener Stiftung 2015), p. 23.

1. Product Lifecycle & Services Management

First the basics of the fields product lifecycle management and service management are explained.

1.1 Product

By the term product basically all kinds of products can be understood, as for example the machine, the transportation, the production plant, the used good or the service. [9] In this paper it is referred to a product, when talking about a machine, a capital good or a production plant.

1.2 Product Lifecycle

The life cycle of a product contains all phases that a product is going through, that means "[…] from the idea over the development and construction, production as well as distribution and service to the decommissioning of a product […]".[10]

In the following the product lifecycle is divided into the classical threefold division:

- **Design Phase** (acquisition phase) – Conception and definition, design and development, production, installation
- **Usage Phase** – Operation and maintenance of products
- **End-of-Life Phase** (continued use and disposal phase) – modernization, recycling, disposal[11]

1.3 Product Lifecycle Management

The product lifecycle management can be defined as follows:

"Product Lifecycle Management (PLM) is the business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of. PLM is the management system for a company's products. It doesn't just manage one of its products. It manages, in an integrated way, all of its parts and products, and the product

[9] Cf. (Sendler 2009), p. 6
[10] (Arnold et al. 2011), p. 9
[11] Cf. (Kuhrke et al. 2009), p. 56

portfolio. PLM manages the whole range, from individual part through individual product to the entire portfolio of products. At the highest level, the objective of PLM is to increase product revenues, reduce product-related costs, maximise the value of the product portfolio, and maximise the value of current and future products for both customers and shareholders”[12]

Logically this means: effective management of a product along the whole lifecycle, means from the first idea to the disposal of the product. It is about a management system for products of companies. All parts, products as well as the whole product portfolio of a company are managed in an integrated way. The goal at the highest level of the product lifecycle management is to increase product turnover, reduce product-related costs, maximize the value of the product portfolio as well as the products’ current and future value from a customer and shareholder view.[13]

1.4 Service Management

The term service is difficult to narrow down as there is no clear existing definition. However there are different approaches to define the term.[14]

Services in contrast to material goods are not tangible, consequently they are immaterial goods and from this follows that it is impossible to store services. At the moment when the service is delivered it is also consumed. The term “Industrial service” is a service that is closely linked to a capital good and is provided by a company. An industrial service can enable or improve the benefit of a product.[15]

1.4.1 Definition of terms

The service business can generally be subdivided into the following fields:[16]

- Pre-Sales-Services
- At-Sales-Services
- After-Sales-Services
- Independent-Services

[12] (Stark 2015), p. 1
[13] Cf. (Stark 2015), p. 1
[14] Cf. (Pepels 2005), p. 18
[15] (Seiter 2013a), p. 7
[16] (Niemann 2016), p.17

First services are differentiated according to the demand. Then the services are subdivided according to their connectedness. Regarding Pre-Sales-Services, At-Sales-Services and After-Sales-Services it is differentiated according to the date of the service provision. Those services are connected with own products. Independent services on the contrary comprise all services connected with external products.[17]

Figure 4 illustrates the individual differentiations.

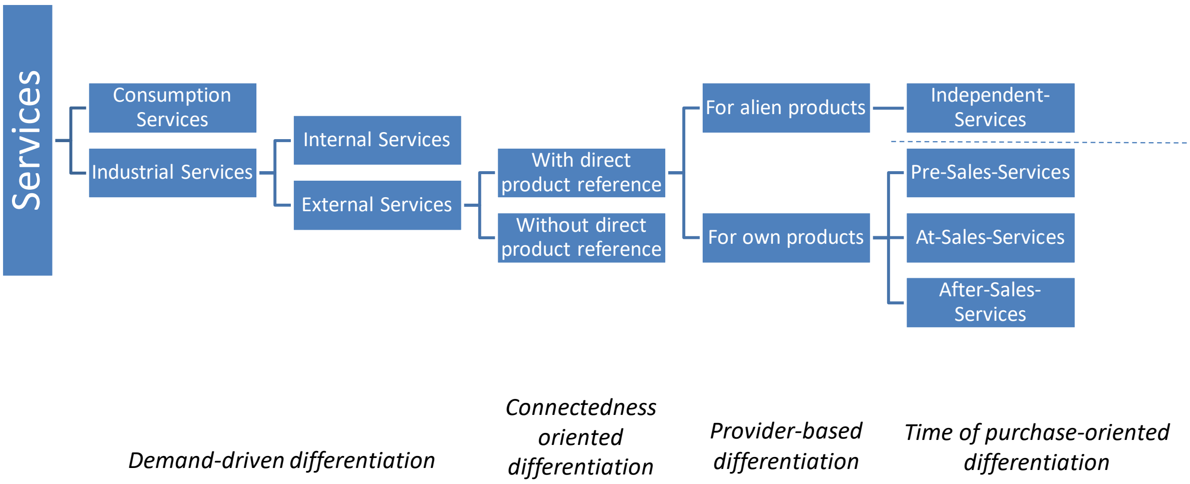

Figure 4: Differentiation of services[18,19]

Pre-Sales-Services

The term pre-sales service describes services that are delivered before the product is being sold. The usage of the product is enabled through the pre-sales service.[20,21]

At-Sales-Services

At-sales services comprise all services that are delivered directly when purchasing the product.[22]

After-Sales-Services

The term after-sales service comprises all technical or commercial services, which are delivered after purchasing the product. Through the use of after-sales services the value of the product can be maintained or improved. In the field of capital goods the

[17] Cf. (Seiter 2013a), p. 22
[18] Own source, modified according to (Dauner 2012), p. 106
[19] Own source, modified according to (Seiter 2013a), p. 22
[20] Cf. (Seiter 2013b), p. 22
[21] Cf. (Kenning/Markgraf 2017b)
[22] Vgl. (Stiller 2017)

after-sales service is of enormous significance. It is the basis for the replacement part and maintenance business.[23,24]

Independent- Services

Independent services comprise all services that a company offers but that are associated with products of external companies.[25]

1.4.2 Importance of service business

The significance of the service business is constantly growing. Figure 5 shows a customer survey[26] that displays the reasons for a change of supplier.

- Dissatisfaction with the service during the whole life cycle
- Technically superior product availabe
- Cheaper/more economical product available

…are the three main reasons for changing the supplier. Though it needs to be emphasized that 65 % of the respondents stated that they change the supplier due to dissatisfaction with the service along the whole life cycle.

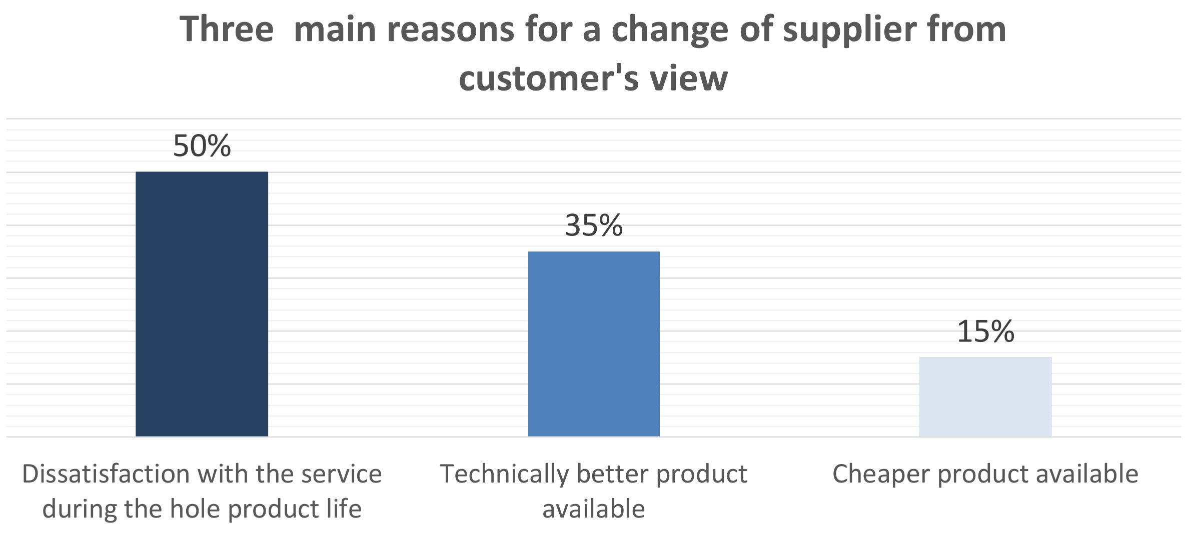

Figure 5: Main reasons for a supplier change[27]

On the contrary 20 % of the respondents stated that they choose a new supplier because a technically superior product is available. Only 15 % changed the supplier because of a

[23] Cf. (Seiter 2013b), p. 22
[24] Cf. (Kenning/Markgraf 2017a)
[25] Cf. (Seiter 2013b), p. 22
[26] (Service 2003), p. 40
[27] (Service 2003), p. 40

cheaper product. It can therefore be concluded that the service along the whole product life cycle is of special significance when it comes to the decision of a new investment by the customer.

2. Lifecycle Phase Design

The lifecycle design phase is of great importance regarding the integrated consideration of the product lifecycle. Empiric studies showed that 70 % to 85 % of the total costs are determined in this phase. In this phase it is possible to actively influence the lifecycle costs of a product at minimal effort. Configuration and the system's range of functions as well as the utilized materials, purchased parts and production processes are determined in this early phase. The costs resulting out of those decisions predominantly accrue in the usage phase. Like this an optimized machine or plant regarding the total costs can only be developed if the long-term expectable costs and performances are estimated and taken into account. Furthermore in this lifecycle phase the ecological as well as social dimensions of a product are determined and like that the greatest part of the environmental and social impacts over the whole lifecycle is defined.[28,29]

2.1 Generic approach in product development

The goal of the product development is to create a technical solution which fulfills the required functions for the planned lifetime. Decisions about the product structure, connection and joining technologies as well as materials are made. The general problem solving cycle is used as a basis for a general procedure. It is comprised of four phases:

1. Analysis of problem and situation – gathering information
2. Formulation of problem and goal – formulation and specification of problems
3. Synthesis of system – determination of characteristics
4. Evaluation and decision – assessment of the solution

A subdivision of the product development process in different phases increases the clarity.[30]

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[28] Cf. (Herrmann 2010), p. 257–258
[29] Cf. (VDI 2884 2005), p. 2
[30] Cf. (Herrmann 2010), p. 247–248

Figure 6 illustrates the general procedure model regarding construction and design according to VDI 2221.

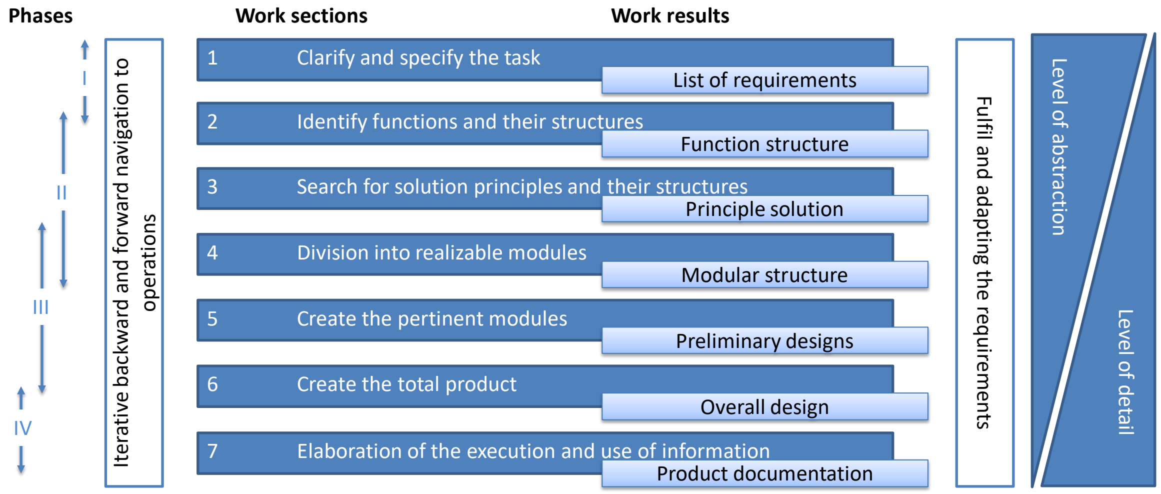


Figure 6: General procedure for development and construction[31,32]

Here the overall approach is subdivided into seven work steps out of which seven working results emerge. The working steps are being run through iteratively several times. Further those working steps are assigned to phases.[33,34]

2.2 Interdisciplinary collaboration

Figure 7 shows the lifecycle costs of a product. Further the conventional product manufacturing is compared to the interdisciplinary product manufacturing and cost as well as time effects are presented. Due to an often not coordinated, consecutive approach in the conventional product manufacturing, frequently expensive and suboptimal products occur. Through an integrated and interdisciplinary product manufacturing in a project team shorter development times, a faster product manufacturing, cost reduction as well as an improvement of quality are possible. Like this the so called dilemma of construction can be reduced.[35,36,37]

Figure 8 illustrates this dilemma of the product development. In the initial phase the costs can be influenced to the greatest extent, though at that time the least about future costs is

[31] (VDI 2221 1993), p. 9
[32] (Herrmann 2010), p. 248
[33] Cf. (VDI 2221 1993), p. 9
[34] Cf. (Herrmann 2010), p. 248
[35] Cf. (Ehrlenspiel et al. 2014), p. 13
[36] Cf. (Bhagwati 2016)
[37] Cf. (Feldhusen et al. 2013a), p. 32

known.[38] A project team out of all areas that are participating in the product development process is put together.

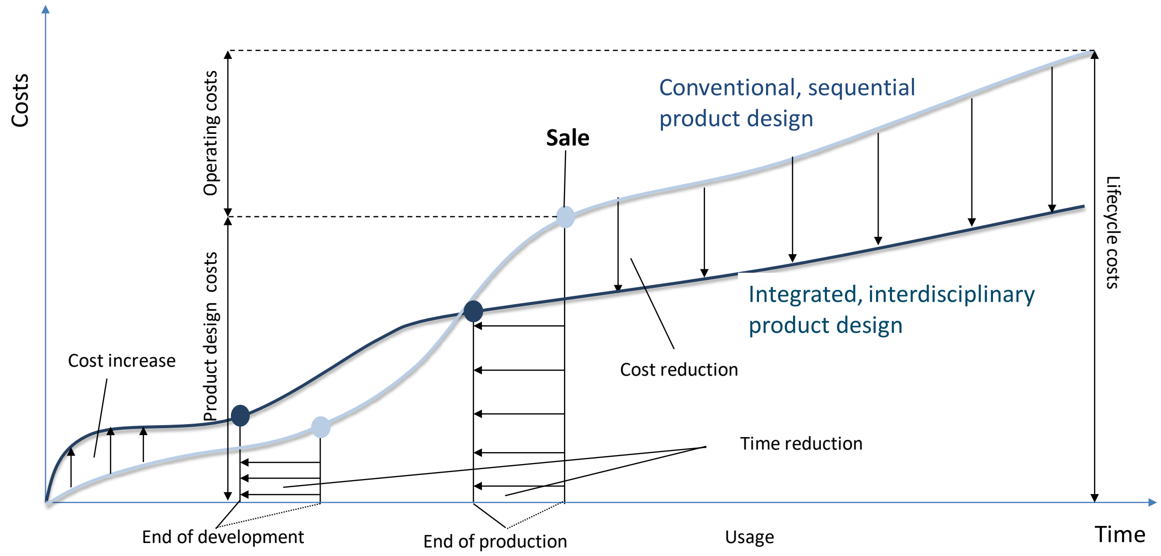


Figure 7: Cost and time effects[39]

The team is working independently led by a project manager. Like this departmental boundaries can be overcome.

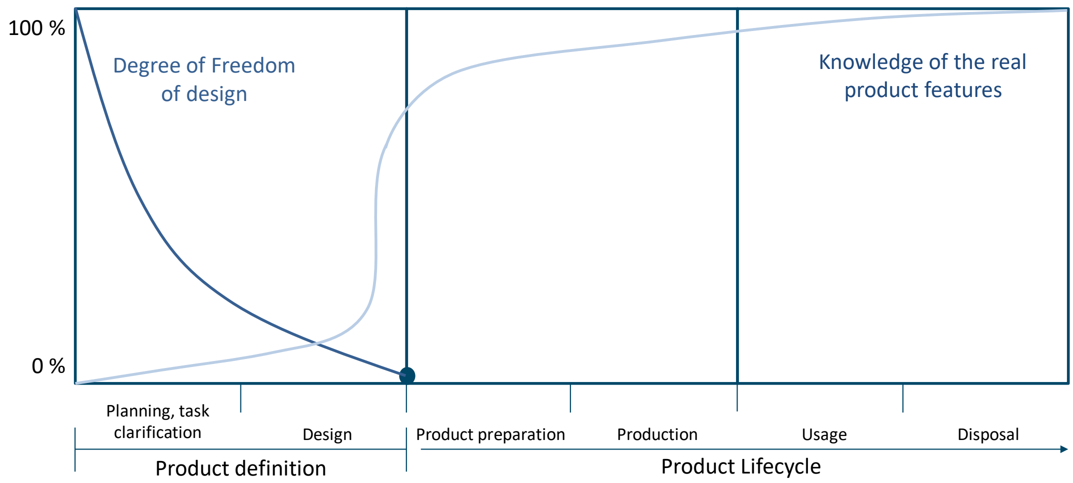


Figure 8: Dilemma of product development [40]

Initially a small core team is formed, which is made up of experts of the areas construction, work preparation, marketing and sales. If needed this core team is complemented by experts of the areas quality assurance, assembly, control and regulation, recycling

[38] Cf. (Ehrlenspiel et al. 2014), p. 13
[39] (Bhagwati 2016)
[40] (Ehrlenspiel et al. 2014), p. 13

and environment. Like this in such a project team also insights and knowledge bases of neighboring disciplines are implied. In order to lead such a team, the project manager needs professional as well as social competences like for example:

- Ability to plan complex processes
- Ability to judge complex processes
- Awareness and early detection
- Employability
- Ability to concentrate statements
- Abiltiy to continuously observe as is and taget parameter
- Leadership skills in a team[41]

2.3 Lifecycle Design

2.3.1 Definition of terms

In a lifecycle-oriented product development technical, economic and ecological requirements of all phases of the product lifecycle are taken into account. This constitutes an extension of the so called simultaneous engineering.

The term lifecycle design can be defined as the

> „[…] Process of the systematic consideration and optimization of technical, economic and ecological characteristics and impacts of a product over the whole lifecycle within the product development process. The goal is, by making use of the decision-making scope in the product development, to satisfy the extended product responsibility, which enables the maximum product value for customers and producers over the lifecycle at the lowest possible economic, ecological and social expense and risk.“[42]

2.3.2 Cost allocation and their targeted manipulation

For many purchasers the main focus is the procurement price of a machine. Though more and more customers decide to consider and calculate the whole lifecycle costs. In the future the consideration of the lifecycle costs will play an always bigger role

[41] Cf. (Feldhusen et al. 2013a), p. 32–34
[42] (Mansour 2006), p. 69–70

regarding purchase decisions. Figure 9 displays a possible cost distribution for a product regarding technology and lifetime.

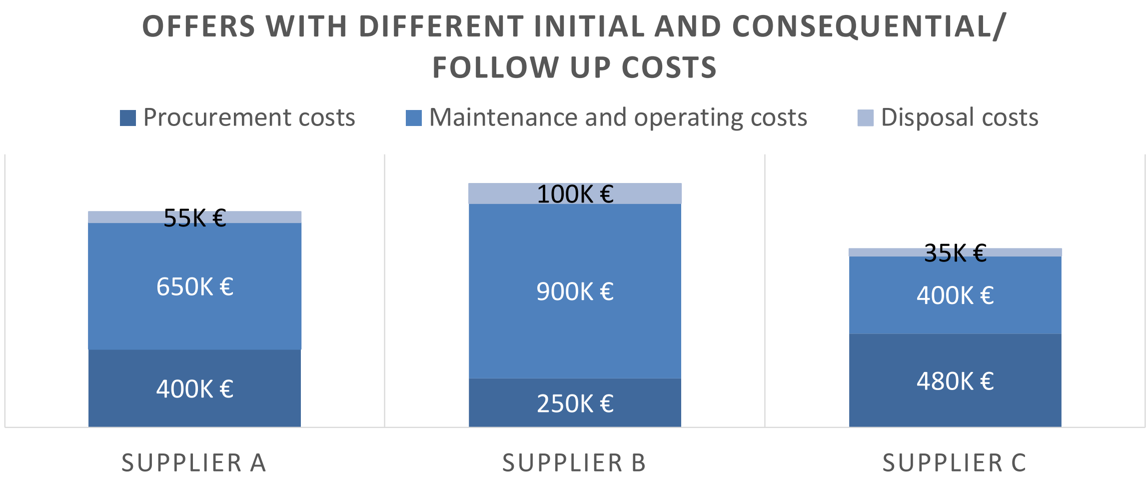


Figure 9: Exemplary offers with different one-off costs and follow-up costs[43]

In case of a procurement-based decision-making procedure the buyer would decide for supplier B, though he has the highest operating, maintenance and disposal costs.

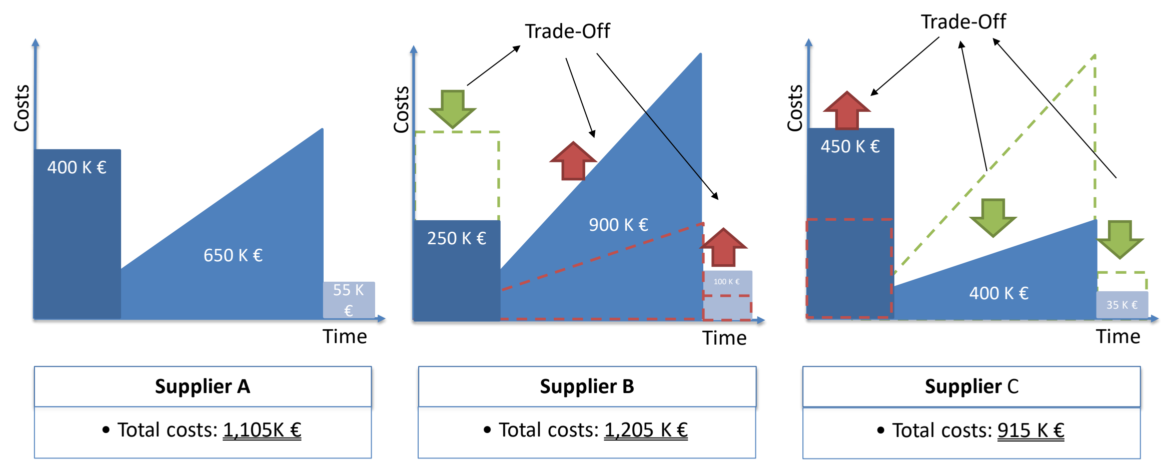


Figure 10: Comensation of costs – trade-offs[44]

On the contrary regarding a lifecycle-oriented decision supplier C performs best.[45] Figure 10 once again shows the suppliers. In this illustration the compensation of costs can be recognized. Regarding an interdisciplinary lifecycle-oriented product development higher costs occur, which though can be compensated in the usage and disposal phase. On the contrary within the traditional product development other phases are not

[43] Own source modified according to (Noske/Kalogerakis 2009), p. 137
[44] Own source modified according to (Manja 2005), (Niemann 2016b), p. 387
[45] Cf. (Noske/Kalogerakis 2009), p. 136

taken into consideration. This can lead to increased operating, maintenance and disposal costs.[46] A lifecycle-oriented product development integrates other phases of the lifecycle. One-time costs like transport costs can be reduced by the direct consideration of packaging guidelines. With regard to operating costs energy can be saved and losses as well as costs for auxiliary and operating materials can be reduced. This can be reached for example by avoiding energy conversion, reducing friction losses or the use of standard lubrications. Maintenance costs can be lowered for example by an appropriate arrangement of components and assembly and an accompanying good access to replace positions as well as an avoidance of special tools. With regard to the selection of materials a low variety of materials should be paid attention to in order to further utilize materials at a low loss in value.[47]

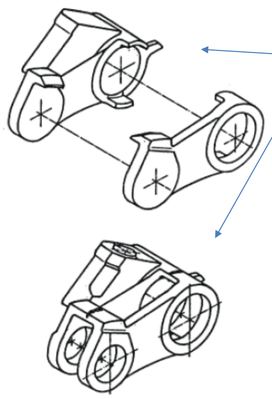
2.3.3 Examples of adjustment contructions and their impact on the lifecycle

In the design phase it is possible to actively influence the individual phases of the product lifecycle. Subsequently three examples of adaptive constructions and the related effects on the product lifecycle are shown.

Adaptive constructions in order to reduce manufacturing costs

The example displayed in Figure 11 shows a potential for cost-savings, which occurs in the design lifecycle phase. A rocker arm of a diesel engine of the company MTU running at medium-speed is shown. Here a cost reduction of 33 % of the production costs could be reached by a revision of the component's construction. Developers should not only consider the pure function during the construction but also develop a cost-awareness.[48]

[46] Cf. (Manja 2005)
[47] Cf. (Ehrlenspiel et al. 2014), p. 135
[48] Cf. (Ehrlenspiel et al. 2014), p. 17–18



Before - 2 parts	After - 1 part
2 forged parts Ck 15	1 forged part 16 MnCr 5
Finished part	Finished part
Production process: 1. Prepare both halves 2. Welding 3. Straightening 4. Mechanical processing 5. Re-welding of the pressure surface 6. Mech. proc. after re-welding 7. Heat treatment (Ck15 bad) 8. Straightening after heat treatment 9. Grinding	Production process: 1. Mechanical processing 2. Heat treatment (16 MnCr 5 well) 3. Grinding
Material costs 15.00 € Production time / piece: 161 min Production costs 320.00 € (100%)	Material costs 15.60€ Production time / piece: 106 min Production costs 210.00 € (67%)

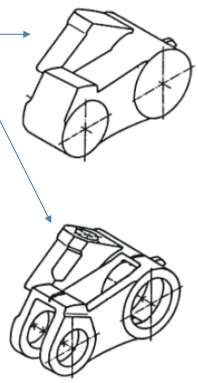


Figure 11: Cost reduction through integral[49]

Adjustment construction optimized for usage

Abbildung 12 shows labeling machines, which are used in filling and packaging machines. The illustration shows an integrated construction, which was not common before. After extensive market research and customer surveys, a claim for increased flexibility in the processing of different tank constructions was determined.

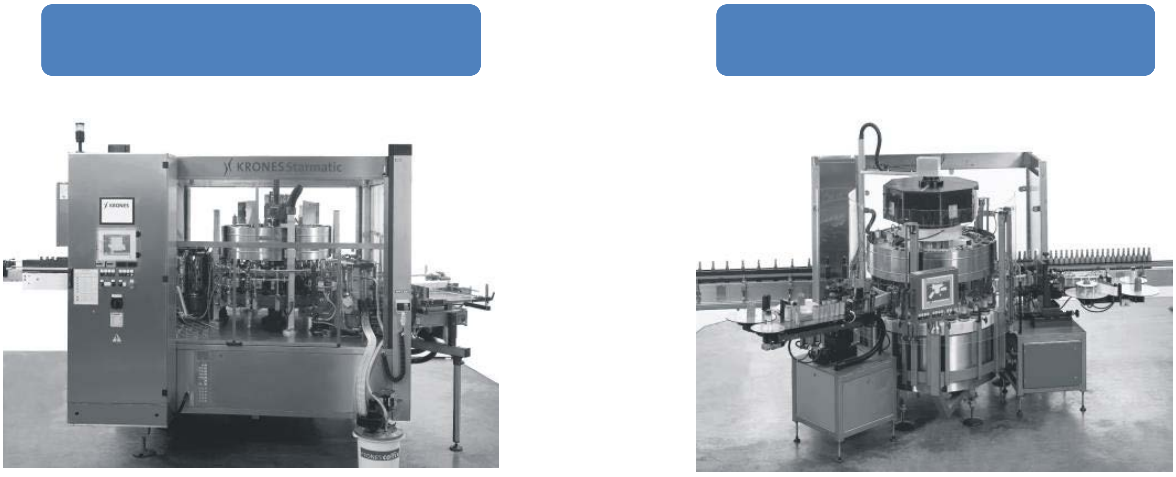


Figure 12: Conventional "integrated construction" before – after[50]

Therefore a labeling machine in a modular design was developed. Through this modular design changeover times are reduced to a considerable extent. Like this the ma-

[49] (Ehrlenspiel et al. 2014), p. 17
[50] (Ehrlenspiel et al. 2014), p. 139

chine is quickly convertible to different labeling systems. A good access of the aggregates is given. They can be exchanged and upgraded quickly and are transportable for maintenance and configuration works.51

Adjustment construction with economical disposal

In this example a Siemens coffee machine TC 22 was developed under the condition of a good decomposability and reduction of used materials. The goal of this product development was that the machine splits into its usable parts by one precisely focused hammer stroke.

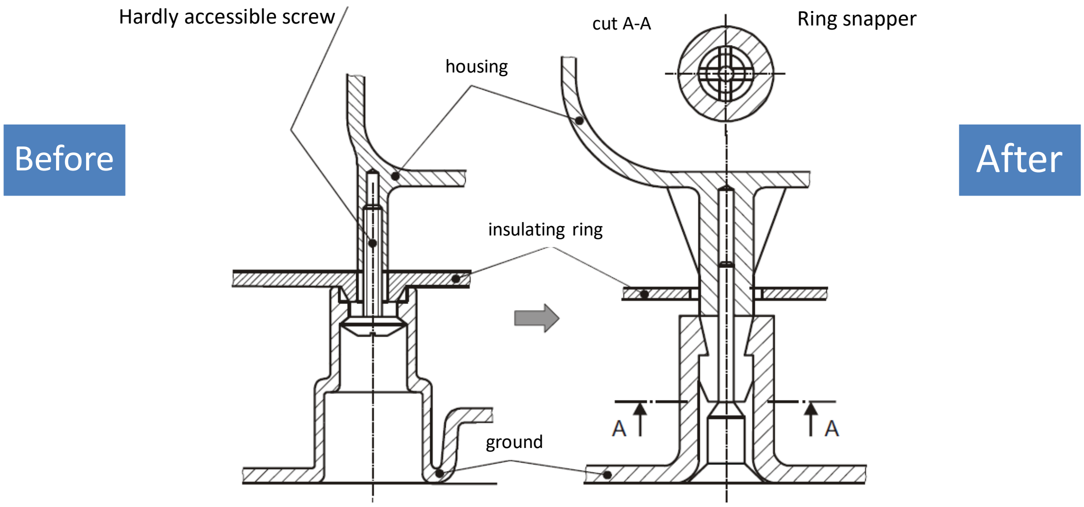


Figure 13: Adaptive construction of the bond ground/case[52]

The screw connection was identified as the weak point (Figure 13, left). As a solution the screw connection was replaced by a ringsnapper (Figure 13, right). Like this no more unscrewing is needed and the connection can be unfixed by a focused hammer stroke on the heating plate. The disposal costs like this can be lowered from 0,29 €/device to 0,17 €/device.53

2.4 Services in the design phase

Already in the design phase services are offered. Though it cannot always clearly be differentiated between a service and an activity in the product business. In the following exemplary services in the design phase are presented. Services in the design phase

[51] Cf. (Ehrlenspiel et al. 2014), p. 139–140
[52] (Ehrlenspiel et al. 2014), p. 415
[53] Cf. (Ehrlenspiel et al. 2014), p. 410–414

can be classified in the categories pre-sales-services, at-sales-services or independent-services.

2.4.1 Feasibility analyses

Within a practicability analysis possible solution approaches for a determined project are examined regarding their practicability. Hereby solution approaches are analyzed and judged, risks are identified and prospects forecasted. It is questioned if with the given framework conditions and considered solution approaches the agreed project solutions can be realized.[54]

Figure 14 illustrates the purposes and results of feasibility studies.

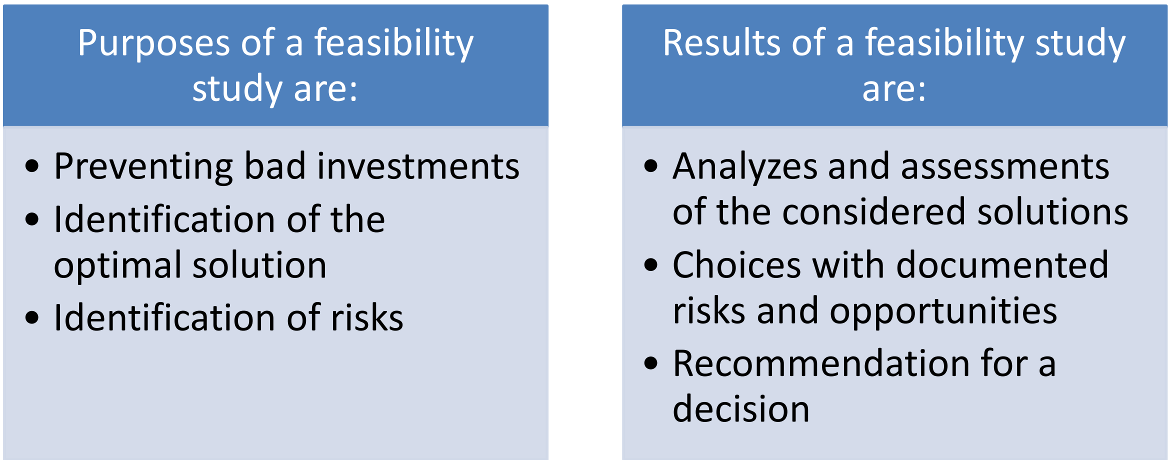


Figure 14: Purposes and results of feasibility studies[55]

Feasibility studies as a service can be categorized into pre-sales, because such services will be executed close before the buying decision.

2.4.2 Financial services

Some companies have own financial divisions and offer their own financial services to the customers playing the role of a financial service provider. One example is machine leasing. Financial service can be categorized in at-sales services as the customer at the time of the service delivery has already decided for a product. In the case that the customer decides for an external leasing company, this service could be categorized as independent service.

[54] Cf. (Angermeier 2015)
[55] Own source modified according to (Angermeier 2015)

A business relation between the three parties lessee (customer), supplier (producer) and lessor (leasing company) results. The lessee uses and owns a capital good but is not the proprietor. Thus no capital sum needs to be put on, but a monthly rate needs to be agreed upon.[56]

3. Lifecycle Usage Phase

In the lifecycle usage phase the after-sales services mentioned in the previous chapter are employed. After-sales services can generate additional turnover and margins through longt-term service contracts. Further will the customer loyalty be increased by regular interactions, whereby information is generated of the product use, which can lead to product improvements. In addition this constant contact generates information about product statuses and current customer needs, which play a significant role for follow-up businesses.[57]

In the following maintenance and its disciplines as well as the parts business are discussed.

3.1 Maintenance

The fundamental goal of maintenance from the economical point of view is to secure a high availability by increasing the maintenance intervals or reducing the maintenance times. Thereby the available maintenance downtime costs are taken into account.[58]

3.1.1 Definition of terms

The term maintenance according to DIN 31051 is defined as follows:

> „Combination of all technical and administrative measures as well as measures by the management during the lifecycle of a unit, which serve the preservation or recovery of a functioning state, so that the required function can be fulfilled.“[59]

[56] Cf. (Siemens 2017)
[57] Cf. (Helbling 2017)
[58] Cf. (Herrmann 2010), p. 260
[59] (DIN 31051 2010), p. 4

The maintenance is subdivided into the general measures maintenance, inspection, repair and improvement. Figure 15 illustrates this subdivision as well as the particular definitions.[60]

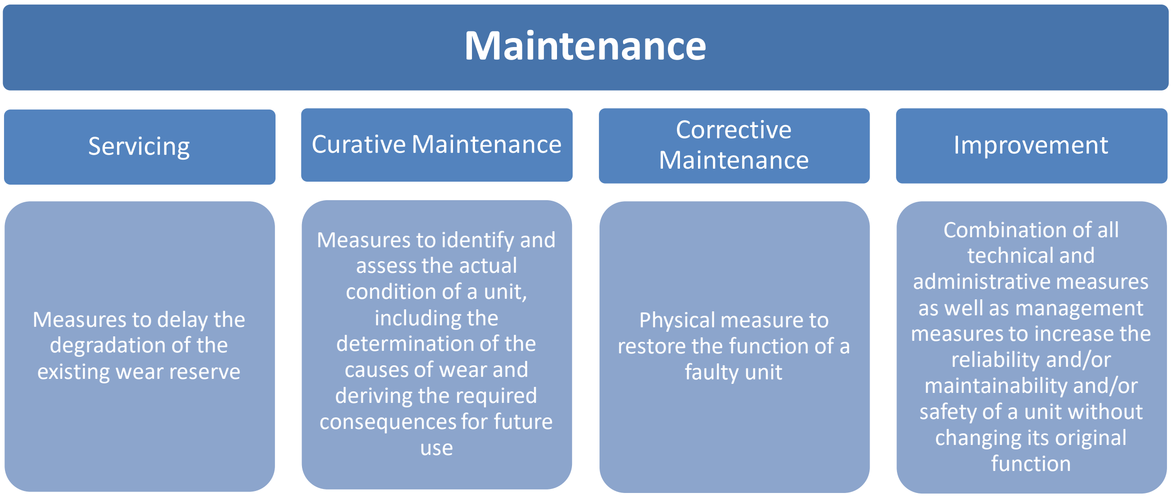


Figure 15: Subdivision and definition of maintenance[61]

Furthermore the important terms for this elaboration in connection with the wear are needed. They are displayed in Figure 16.

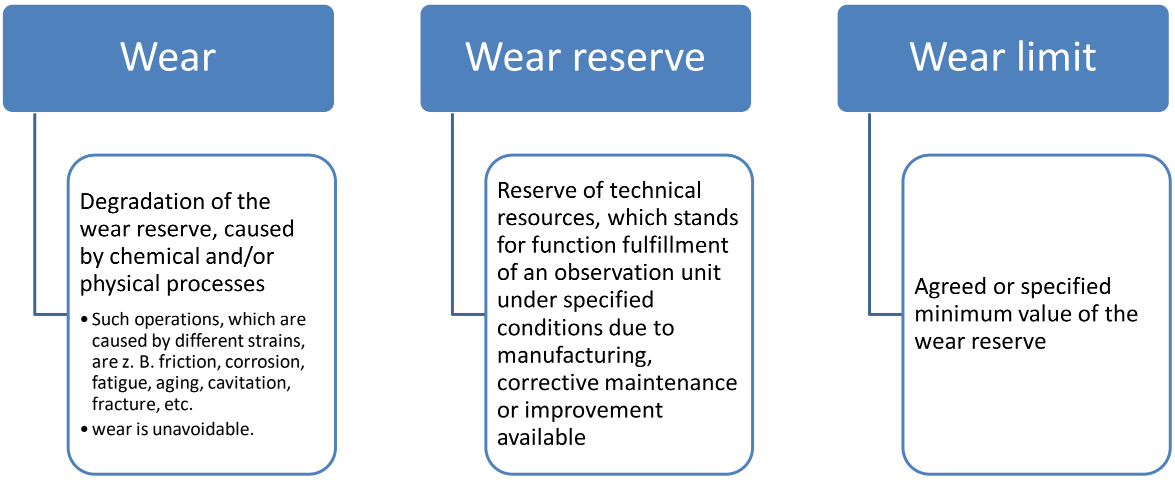


Figure 16: Explanation of the terms wear, wear reserve and wear limit[62]

After manufacturing a certain “wear reserve” exits, which over time will be “consumed” by utilization. When reaching the wear limit, this should be rebuild by determined repair or improvement works.

[60] Cf. (DIN 31051 2010), p. 4
[61] (DIN 31051 2010), p. 4–6
[62] (DIN 31051 2010), p. 7–8

Figure 17 shows the degradation of the wear reserve as well as its “re”-creation.

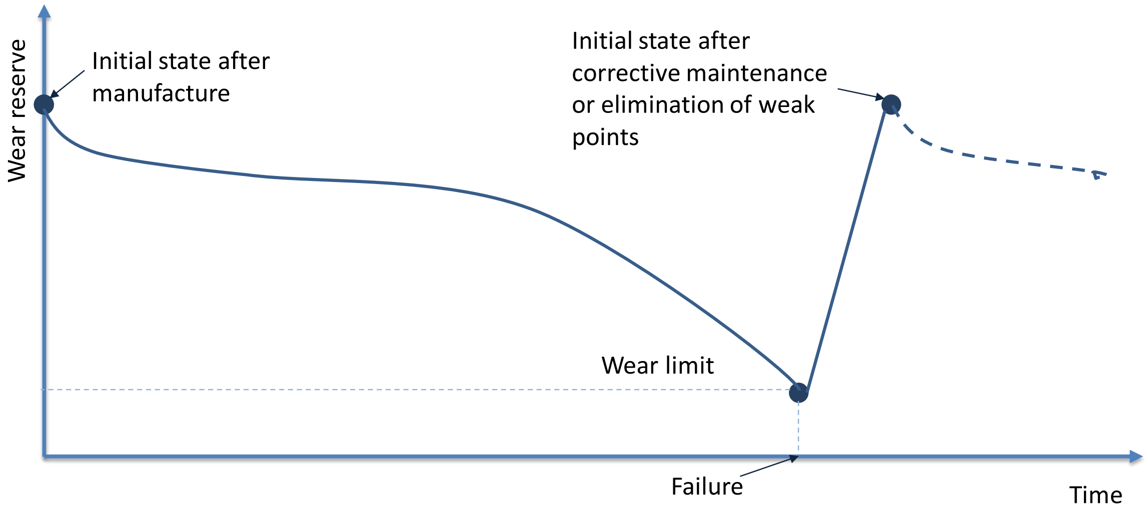


Figure 17: Degradation of wear reserve and its recreation[63]

3.1.2 Maintenance strategies

The term maintenance strategy can be defined as follows:

> „A maninenance strategy strives for the realization of an overall concept, defined by the management according to technically possible and economically beneficial aspects, in order to maintain the availability of existing plants.“[64]

In the following three significant maintenance strategies are presented and explained.

Failure-based maintenance (failure strategy)

Considering failure-based maintenance the failure is first awaited before action is taken. The operator does not influence the machine failure, consequently no relevant effort for maintenance and strategy is needed. As soon as during a failure consequential losses or damages to health can be expected, the choice of this strategy is not possible. The complete consumption of the wear reserve is characteristic for this strategy. The process of the wear reserve in combination with this strategy is seen in Figure 18.

[63] (DIN 31051 2010), p. 8
[64] (Strunz 2012), p. 294

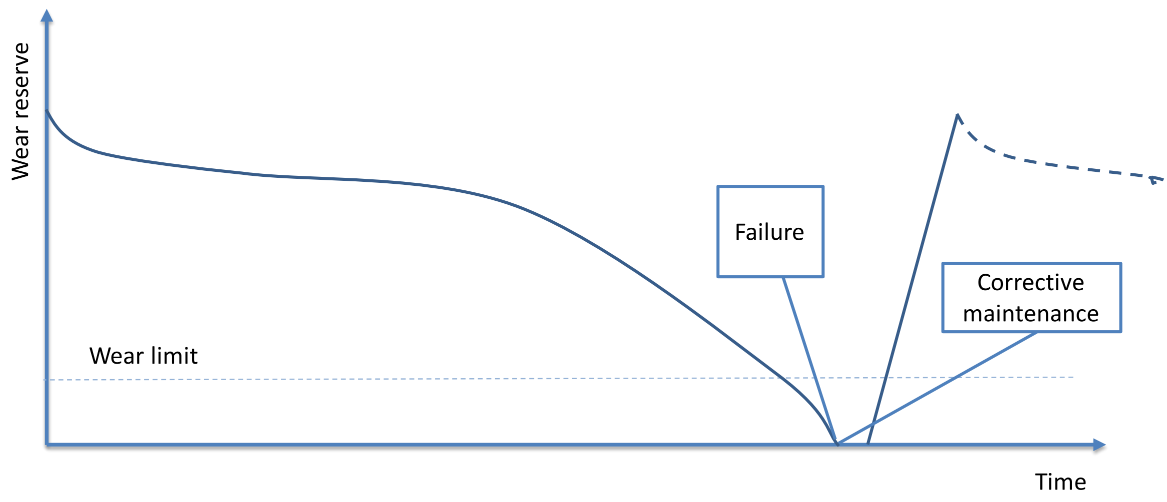


Figure 18: Process of wear reserve at failure-based maintenance[65,66]

Preventive maintenance (preventive strategy)

The preventive maintenance is a maintenance strategy in which, based on fixed intervals, the point of maintenance is determined.

Such intervals can for example be determined in the following ways:

- *performance-related* after the delivery of a determined production output
- *output-dependent* after the delivery of a determined amount of production

This strategy is suitable if in case of a failure high costs or a danger for people can be expected. In order to execute this strategy, a knowledge about failure behavior, use intensity and lifetime of the machine is necessary. The risk of a failure can indeed be minimized but not eliminated by applying this strategy. The repair is done independently of the current state, that's why a waste of wear occurs as components are exchanged too early. This can lead to increased costs of spare parts and repair. Abbildung 19 displays the process of the wear reserve at preventive maintenance and illustrates the waste of wear. As the repair is executed after a determined interval, a different consumption of wear reserve can be found.[67]

[65] Own source modified according to (DIN 31051 2010), p. 8
[66] Own source modified according to (Leidinger 2014), p. 20
[67] Cf. (Strunz 2012), p. 297

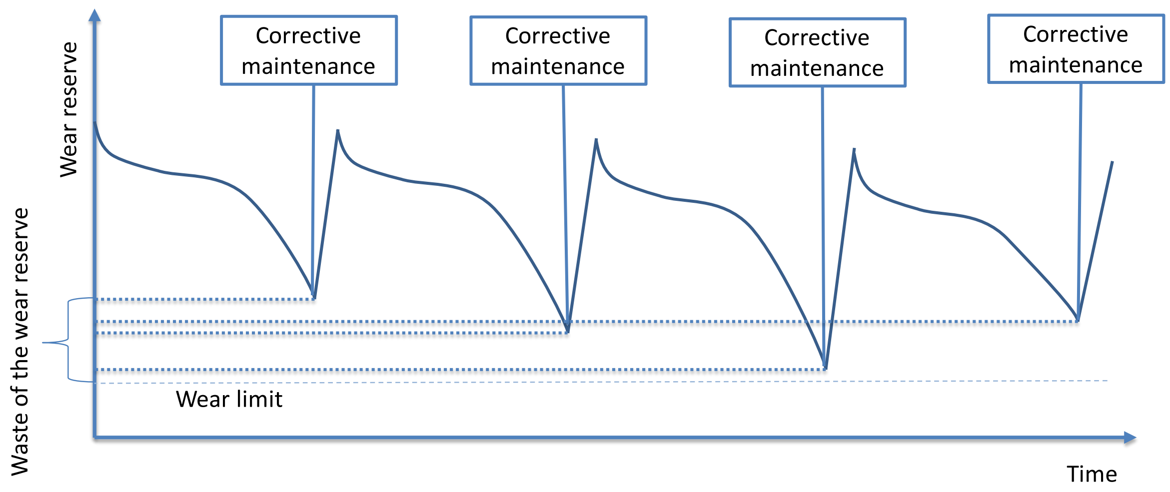


Figure 19: Process of wear reserve during preventive maintenance[68]

Condition-based maintenance (curative strategy)

The condition-based maintenance is oriented towards a determined state. The repair is done when reaching a determined limit of wear. Thereby the wear reserve is consumed to a great extent.

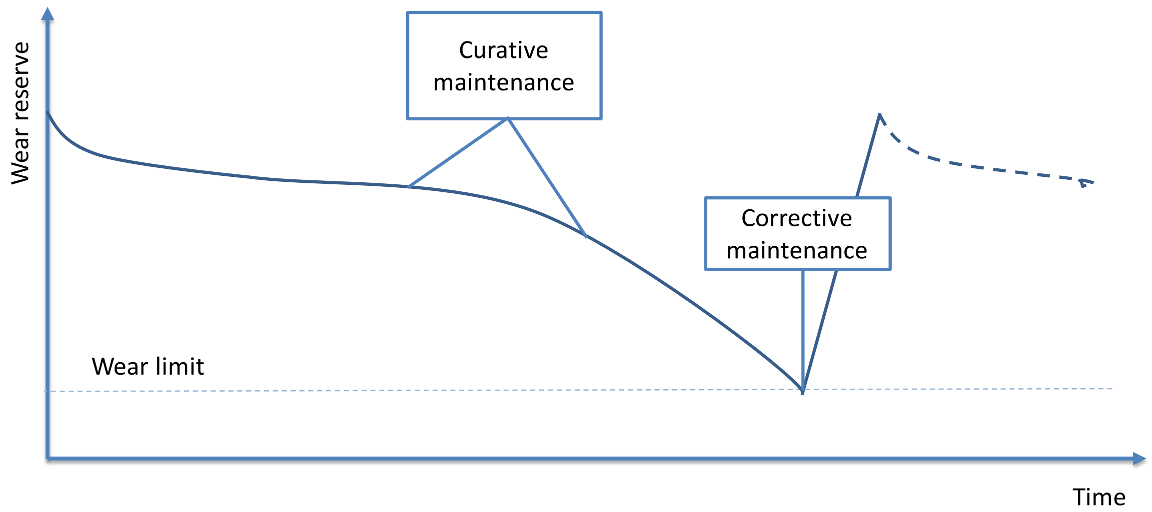


Figure 20: Process of wear reserve during condition-based maintenance[69]

By regular inspections the actual state is determined, whereby the development of the wear reserve can be assessed (forcecast). Thus mistakes can be found earlier and

[68] 68 Own source modified according to (DIN 31051 2010), p. 8
[69] 69 Own source modified according to (DIN 31051 2010), p. 8

failure progressions can be better diagnosed. Consequently failures can be avoided to a great extent and machine running times as well as operational safety can be increased. This strategy needs modern measure and testing techniques, qualified personnel and good knowledge about the wear process of a machine. Abbildung 20 shows the wear process during the inspection strategy.[70,71]

3.1.3 Introduction of a state-oriented maintenance

Figure 21 shows the reference model of the introduction of a state-based maintenance. Considering the description of the plant structure a functional model is set up.

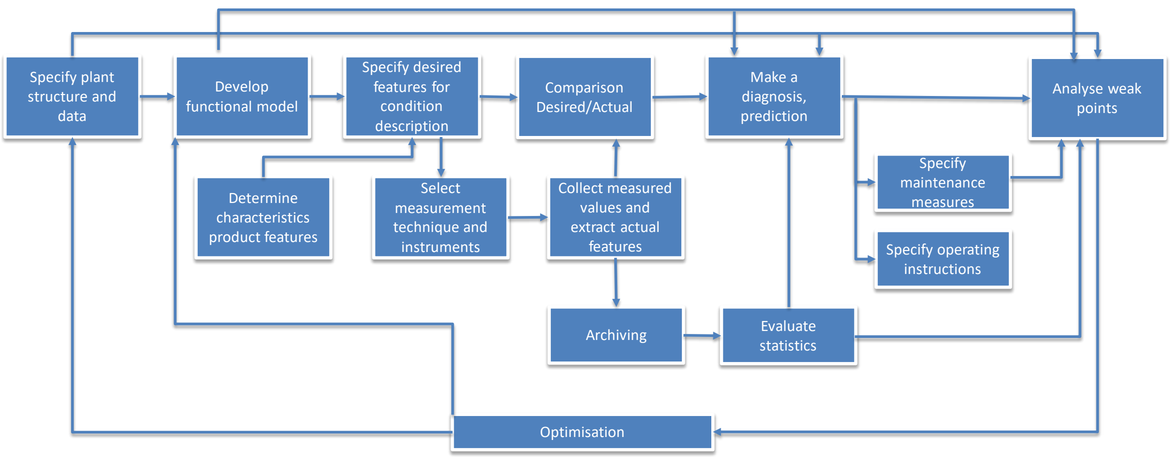


Figure 21: Reference model for the state-oriented maintenance[72]

By means of this model operating modes and states for selected parts are described and in case of failure complemented by information about the behavior. In the following the state describing target characteristics are determined. In order to measure the actual states, suitable measurement techniques and instruments need to be chosen. After each measurement procedure the generated measurement values are archived in order to determine possible trends. The determined actual states are then compared to the target states to judge the current state of the plant. If an impermissible value is attained with this comparison, a diagnosis starts and a connection between type of failure, cause and location is generated. Out of that operating instructions and maintenance measures can be derived. With those information, which are complemented by

[70] Cf. (Strunz 2012), p. 298
[71] Cf. (VDI 2888 1999), p. 3
[72] (VDI 2888 1999), p. 5

continuously archived measurement values, weaknesses can be identified and subsequently analyzed. In the following an optimization of the detected weaknesses can be achieved.[73]

The demand for contractually agreed maintenance services is increasing with the technical and economic development at a national as well as at an international level. Therefore it is important to exactly structure and write the maintenance contracts. DIN EN 13269 – maintenance – instruction for the creation of maintenance contracts contains proposals for the structure and the content of a contract. The following contract elements should be taken into account when making a maintenance contract:

- Contract header
- Target
- Contract-relevant definitions
- Scope of tasks
- Technical agreements
- Incoterms/ agreements
- Organizational agreements
- Legal agreements.[74]

[73] Cf. (VDI 2888 1999), p. 3–6
[74] Cf. (DIN EN 13269 2006), p. 2

3.2 Spare parts

Spare parts are interchangeable units of a product. They are a central part of the maintenance process. Spare parts maintain the functionality of a product or recreate it.[75]

A spare part according to DIN 13306 is defined as follows:

> „Unit as a replacement for an equivalent unit in order to maintain the originally required function of the device.“[76]

The goal of the spare parts management is to provide the correct amount of the right spare part in the correct location at the right point in time. The stocking and availability of spare parts are in conflict of objectives as the stocking constitutes a cost problem and the availability of spare parts is connected to the availability of plants. The task of the spare parts management is to secure a balance between low stocks and a high availability. In order to manage this task, the following subtasks need to be in the foreground.

- Optimal planning of spare parts in order to ensure an optimal stock level matching the chosen maintenance strategy
- safe storage and fast retrievability of spare parts or an optimal procurement of spare parts
- Demand-based povision of spare parts
- Continuous control and adjustment of stocks[77]

The main task of the spare parts logistic is to optimally manage the final stock and thus achieve an optimum in maintenance business. Thereby the focus should be on

> „[…] the cost-minimizing comparison of the opposing costs for a (potential) parts shortage and stock costs […]“[78]

The spare parts be classified in A, B and C parts according to their value and in X, Y and Z according to the demand. Depending on the classification of the spare part and which maintenance strategy is applied, a changed stocking strategy is applied. The

[75] Cf. (Strunz 2012), p. 569
[76] (DIN 13306 2010), p. 10
[77] Cf. (Strunz 2012), p. 570f
[78] (Schuh et al. 2013), p. 170

quality of the spare parts logistic, which is characterized by a high reliability or high competence, plays an important role. The costs of the spare parts logistic should be as low as possible, though a high delivery service with flexible delivery times and a high delivery loyalty are expected (i.e. 24h, 7 days/week) as well as a high flexibility (selective processing of the orders according to priority). The flexibility plays a significant role as a failure cannot always be foreseen and can be related to high failure costs.[79]

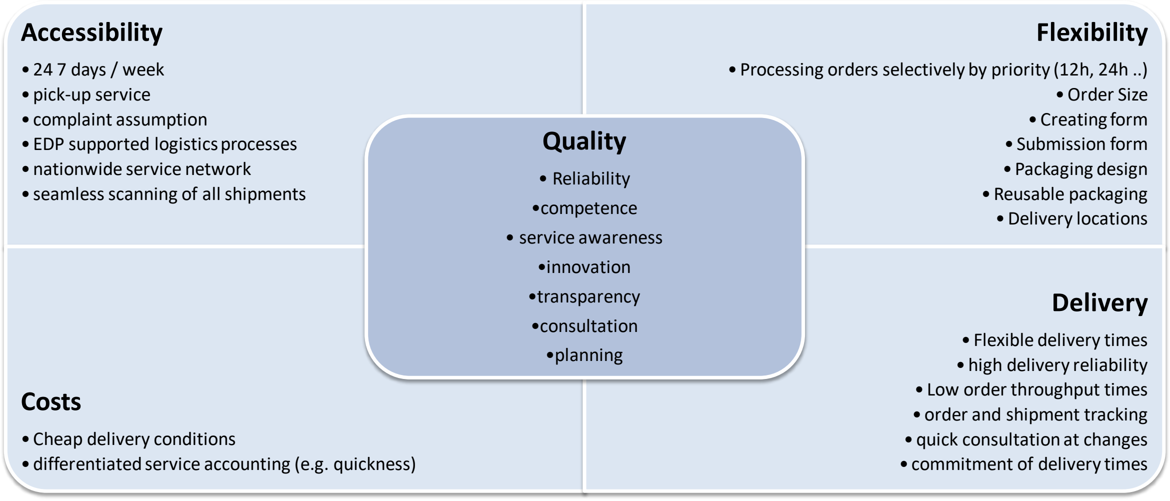


Figure 22: Requirements of the spare parts logistic[80]

Figure 22 summarizes the requirements of industrial suppliers to meet customers demand in spare part logistics. In order to meet/master the challenges of the spare parts logistic, companies exist that put together so called spare parts packages. Like this the customer is able to react to failures or other necessary maintenance measures on-site as quick as possible.[81]

[79] Cf. (Schuh et al. 2013), p. 170
[80] (Schuh et al. 2013), p. 171
[81] Cf. (Bühler 2017)

4. Lifecycle End-Of-Life phase

In this chapter a closer look is taken at the topics recycling and disposal, which occur at the end of a lifecycle.

4.1 Recycling

The term recycling signifies:

> „[…] The return of by-products and residues occurring during production and consumption back into the production/consumption cycle. This includes the collection, transport and the actual recycling of waste as well as the needed energy and resources for the disposal of waste.“[82]

Figure 23 shows and differentiates the different types of recycling.

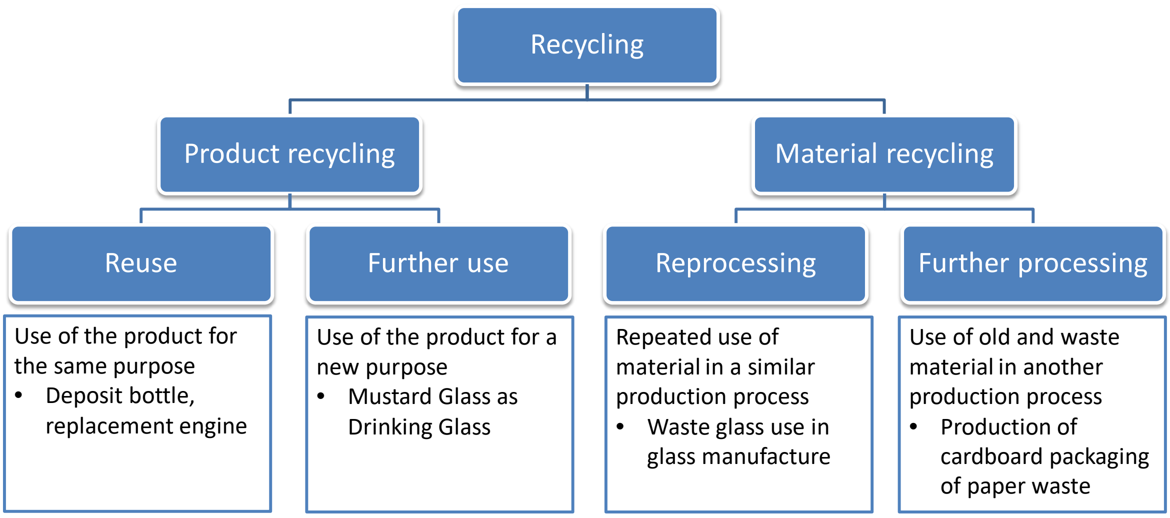


Figure 23: Differentiation of recycling types[83]

The term recycling can be subdivided into product and material recycling. The product recycling can also be subdivided

- **Reuse** - The product is reused for the same purpose – examples are the reuse of deposit bottles or exchange engines
- **Further use** – The product is reused with a new purpose. An example is the reuse of a mustard glass as a drinking glass.

[82] (Förstner 2008), p. 365
[83] (Janorschke et al. 2009), p. 468

Regarding material recycling also a subdivision is done:

- **Reprocessing** – Materials are used in a similar production process in a repetitive way. An example is scrap glass when producing glass
- **Further processing** – Materials are used in a not yet run through product process – an example of further utilization is the use of paper waste to produce cartons.[84,85]

4.2 Modernization

Complex products after their use phase can have a second use phase due to modernization works.[86] Regarding a machine modernization it is about product recycling, well said reuse. The product after a modernization is used for the same purpose.

Abbildung 24 shows a portal milling machine type FP 2000 SA. It was modernized by the company Rottler machine tools GmbH.[87]

Figure 24: Modernization of a portal milling machine type FP 2000 SA[88]

In the course of this machine modernization the following steps have been done by the company Rottler machine tools Ltd:

- Geometrically updated
- Equipped with a Siemens 840 D control system
- Extension of the tool magazine from 40 to 60 tool places.

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[84] Cf. (Förstner 2008), p. 367
[85] Cf. (Janorschke et al. 2009), p. 468
[86] Cf. (Walther 2010), p. 189
[87] Cf. (Rottler 2019)
[88] (Rottler 2019)

- Update of the CNC-fork type
- Newly designed KSS-supply, central lubrication system and hydraulic system[89]

Newly designed KSS-supply, central lubrication system and hydraulic systemIm Zuge dieser Maschinen Modernisierung wurden folgende Maßnahmen von der Firma Rottler Werkzeugmaschinen GmbH unternommen:

- Geometrisch überholt
- Ausgerüstet mit einer Siemens 840 D Steuerung
- Erweiterung des Werkzeugmagazins von 40 auf 60 Werkzeugplätze
- Überholung des CNC-Gabelfräskopfes
- Neu ausgelegte KSS-Versorgung, Zentralschmieranlage und Hydraulik[90]

Through this modernization an extension of the product lifecycle is reached. Well said, the machine gets a second use phase. A service like this machine modernization can also be classified in the category after-sales services. In this case though it is classified in the category independent services as this modernization was done for a foreign product.

4.3 Disposal

At the end of the product lifecycle an avoidance of waste according to the waste hierarchy is not feasible any more.

a) Avoidance
b) Preparation for reuse
c) Recycling
d) Other forms of energetic recycling
e) Disposal[91]

An exclusion of the economic cycle is the logical consequence. A disposal of waste can for example happen in the form of collection, combustion or depositing.[92]

[89] Cf. (Rottler 2019)
[90] Cf. (Rottler 2019)
[91] (European Parliament 2008), p. L 312/10
[92] Cf. (Walther 2010), p. 211–213

5. Lifecycle Analysis

A sustainable development through a holistic product lifecycle management requires an appropriate analysis of the effects of decisions along the whole product lifecycle. This analysis is done based on the three fields of sustainability. The fields with the corresponding overall phase of life analysis methods can be taken from Figure 25.[93]

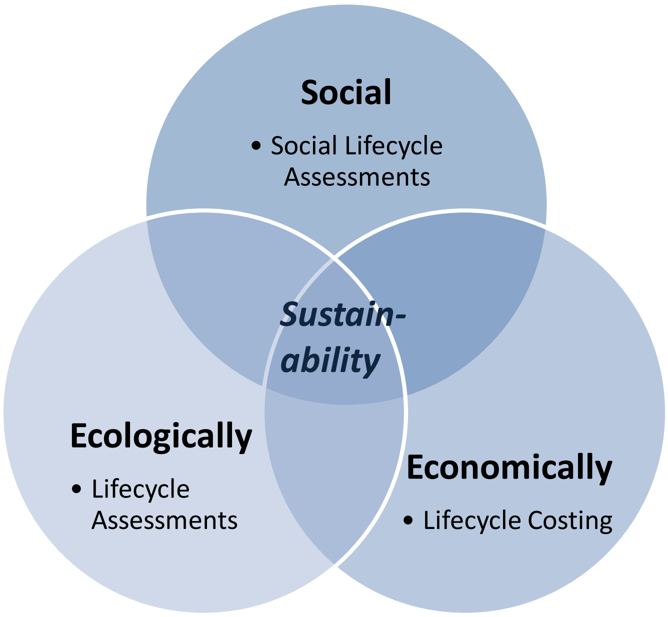

Figure 25: Three fields of sustainability[94]

This chapter deals with the subsections of the Method PROSA (Product Sustainability Assessment) as well as with existing standards, guidelines and standard sheets.

5.1 Lifecycle Assessments

The lifecycle of a product is connected with different influences and effects on the environment. Those can emerge from the raw material extraction, production, distribution, use to the recycling and disposal. To fulfill the model of a sustainable product lifecycle, a future-oriented environment protection in order to minimize risks for human beings and the environment is necessary and the motto is:

> p„[…] the follow-up care is to be replaced by precaution.“[95]

93 (Herrmann 2010), p. 131
94 Own source modified according to (Aachener Stiftung 2015)
95 Cf. (Herrmann 2010), p. 151

The society has an increasing environmental awareness. Therefore the customers want to be informed about the impacts on the environment related with the product. Consequently the method lifecycle assessment, has been developed. The definition of the lifecycle assessment is the following:

> „Combining and judging the input and output flows and the potential environmental effects of a product system throughout its lifecycle.[96]

This can help for example to show improvements of the environmental characteristics of a product in the individual phases of a lifecycle.[97,98]

A lifecycle assessment contains four phases. Those can be taken from Figure 26.

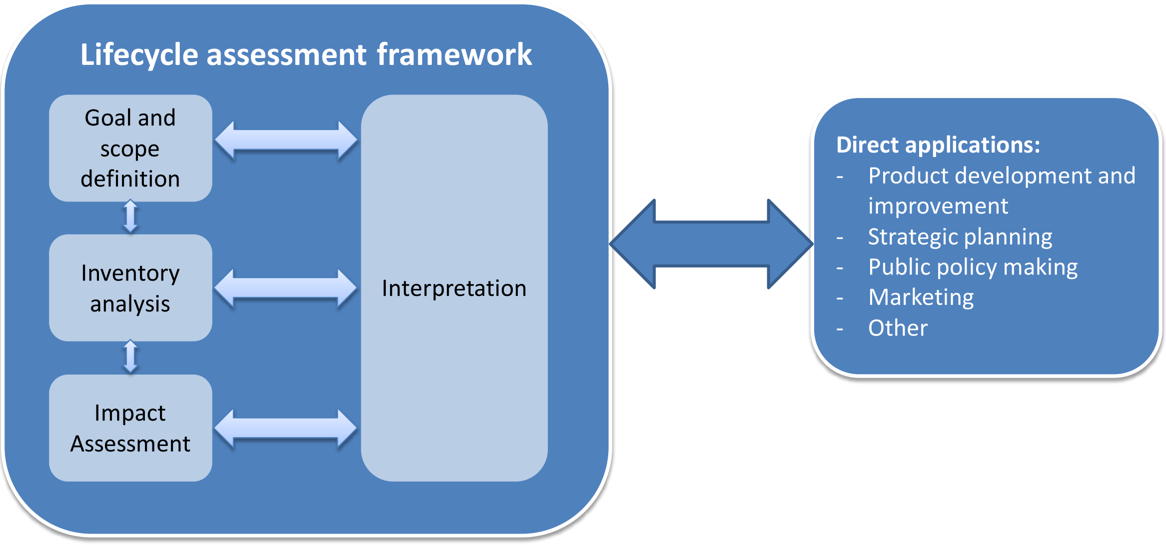

Figure 26: Phases of a lifecycle assessment[99]

In the first phase of the lifecycle assessment the goals as well as the framework of studies are determined. The framework depends on the object of investigation and on the application of the lifecycle assessment.[100]

The second phase of the lifecycle assessment, the creation of a factual balance sheet, serves as a survey of input and output data. Data are collected that are important to reach the set goals.[101]

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[96] (DIN EN ISO 14040 2006), p. 7
[97] Cf. (Herrmann 2010), p. 150f
[98] Cf. (DIN EN ISO 14040 2006), p. 4
[99] (DIN EN ISO 14040 2006), p. 16
[100] Cf. (DIN EN ISO 14040 2006), p. 5
[101] Cf. (DIN EN ISO 14040 2006), p. 5

The third phase of the lifecycle assessment is about the impact assessment. During this phase additional information in order to support the valuation of the factual balance sheets' results are provided. Like this the environmental relevance can be assessed in a better way.[102]

The final phase of the lifecycle assessment is the evaluation phase. The results of the preceding phases are judged and the resulting conclusions, recommendations and supports are discussed and documented.[103]

5.2 Social Lifecycle Assessments

Regarding the social lifecycle assessment the social aspects along the product lifecycle are investigated. They are of great importance for the analysis and the improvement of the sustainability of products. Social aspects are a big challenge regarding the product evaluation as they are very diverse and rated in different ways depending on different groups of interest, countries or regions. Every phase of the product lifecycle is connected with one or more geographic locations where process steps are carried out. Depending on the country or the region, it can be calculated with different social standards.[104],[105]

The methodic procedure regarding the social balance can be subdivided into four process steps as the lifecycle assessment:

1. Determination of the goal and the framework of investigation
2. Factual balance sheet
3. Estimation of impacts
4. Evaluation of results[106]

Most common the social aspects arise from the following fields:

- Hotspots during the production, usage as well as during the disposal (for example child labor, wages below subsistence level)
- Impacts during the product use (for example lopsided posture when operating a machine)

[102] Cf. (DIN EN ISO 14040 2006), p. 5
[103] Cf. (DIN EN ISO 14040 2006), p. 5
[104] Cf. (Herrmann 2010), p. 166f
[105] Cf. (Grieshammer/Droste 2019a)
[106] Cf. (Grieshammer/Droste 2019b)

- Indirect impacts on the society (e.g. use of mobile phones)[107]

The PROSA list of social indicators can help when chosing the aspects that need to be considered in greater detail. The list was created out of several dozen indicator lists with over 3000 social indicators and sorted according to four steakholder groups:

- Employees
- Neighboring or regional population
- Society
- Private, commercial and state users[108]

5.3 Lifecycle Costing

The goal of the lifecycle costing (lifecycle cost analysis) is a holistic and systematic consideration of the costs along the whole product lifecycle.

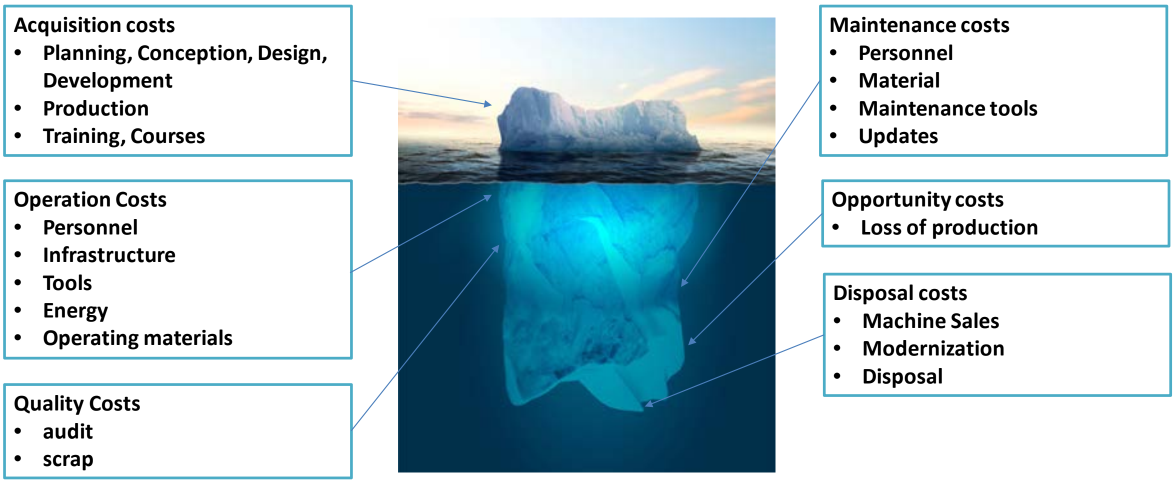

Figure 27: Lifecycle costs illustration[109]

The term "total cost of ownership" is applied in the field of information technique as a synonym for the term lifecycle costing. This analysis serves for example customers as a support when making decisions regarding investments, as not only the acquisition costs but all costs along the product lifecycle are considered.

The early information about the costs in the phases of the product lifecycle help the producer optimize the product.[110]

[107] Cf. (Grieshammer/Droste 2019c)
[108] Cf. (Grieshammer/Droste 2019d)
[109] Own source modified according to (Deutges 2012), (Niemann 2016b), p. 387
[110] Cf. (Herrmann 2010), p. 131

Figure 27 shows an iceberg as an illustration of the lifecycle costs. At first glance only the acquisition costs of the product can be seen as the follow-up costs are not directly visible, though those costs are significant as they account for the greatest part of the costs.[111]

This is shown by Figure 28. It shows the cost distribution of a machine tool over a lifecycle of 10 years.

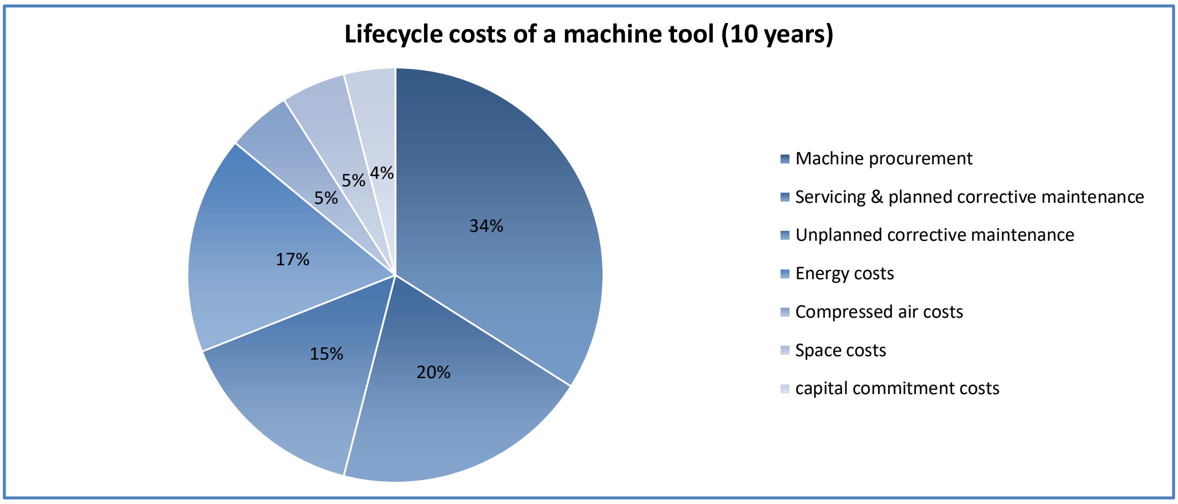

Figure 28: Lifecycle costs of a machine tool (10 years)[112]

In the following a closer look is taken at the VDI 2884 guideline as well as at the VDMA 34160 standard sheet.

5.3.1 VDI 2884

VDI 2884 acquisition, operation and maintenance of production means applying the life cycle costing (LCC). One goal of the guideline is to support operators regarding the choice of different production means. Therefore a methodical framework was made available in order to take a decision regarding the acquisition based on the resulting lifecycle costs. Further the goal of this guideline is to support producers by means of a methodical framework regarding the development of products against the background of a lifecycle cost consideration.[113]

[111] Cf. (Deutges 2012)
[112] (Dressel/Pfeiffer 2011), p. 39
[113] Cf. (VDI 2884 1999), p. 3

5.3.2 VDMA 34160

VDMA 34160 Forecasting model for the lifecycle costs of machines and plants.

In this standard sheet the structured definiton and prognosis of the lifecycle costs for machines, plants and components are described. In the described forecasting model for the determination of lifecycle costs no price effects like financing or capital costs are considered. The model determines cost blocks for every phase as well as calculation rules. Furthermore the VDMA provides an Excel tool for the calculation of lifecycle costs, which is based on the standard sheet VDMA 34160.[114]

6. Lifecycle Information Support

In a holistic product lifecycle management information appear in every phase of the product. The goal is to give an information feedback to the initial lifecycle design phase in order to develop new, better and more innovative products. Like this a continuous improvement process is possible.

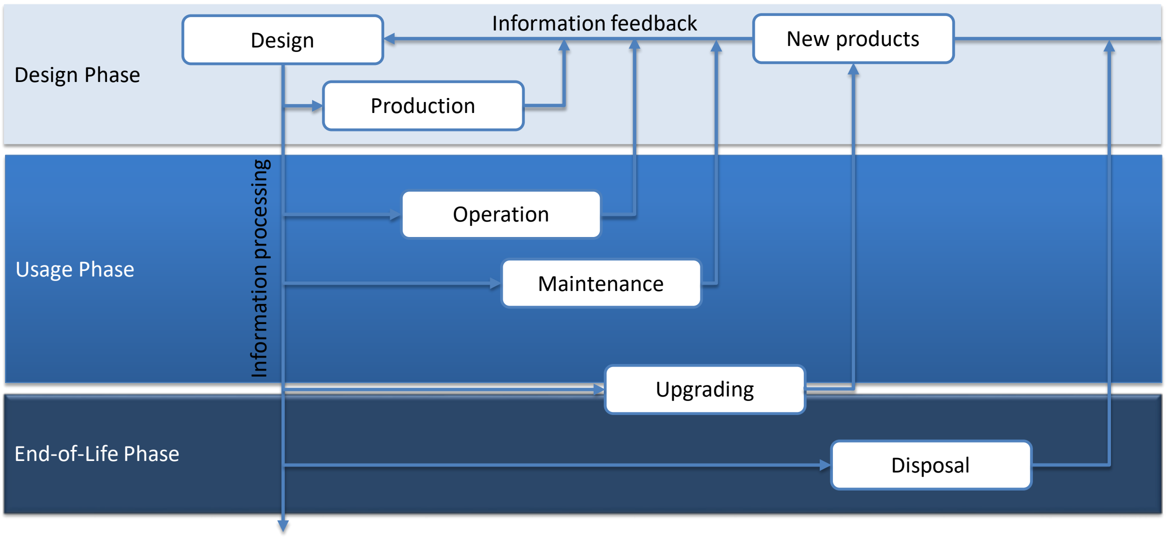

Figure 29: Information flows of the product lifecycle management[115]

Figure 29 shows the information flows that occur in a holistic product lifecycle management. In order to support the collection, processing and administration of information,

[114] Cf. (VDMA 2016), S. 5, (Niemann 2016), S.7
[115] Own source modified according to (Niemann et al. 2009), p.113, (Niemann 2016a), p. 356), (Feldhusen et al. 2013b), p. 300

it makes sense to apply a lifecycle management software (PLM software). Some companies today work with different systems describing data in their different departments. The development for example works with a CAD-Software, which applies specific parts lists. In the production an enterprise resource planning software is applied and in sales special data processing programs are used. The goal of using a PLM software is to standardize and stabilize descriptive information of every department. In all phases of the product lifecycle product-related data result, from the development up to service measures, which are subject to constant changes by different users. That’s why it is no longer sufficient to only grant the development but all responsible departments access to all product-related data.[116]

The application of a PLM software brings various advantages. Decisions can be made faster and more precise due to current and complete information. Changes can be done faster and costs can be lowered. The customer satisfaction can be increased due to an excellent maintenance service, which has access to all relevant data like for example parts lists.

[116] Cf. (Wannenwetsch 2005), p. 398–399

7. Dynamic Life Cycle Controlling

The author finished his Ph.D. about a method fort he dynamic life cyclce controlling of production systems. Within this thesis a new term of „life cycle controling“ has been developed and introduced into the scientific community. The following paragraphs give an summariesed overview about the thesis, the method and the results of the research activities: [117]

Today's manufacturing companies in series productions are open to global competition especially concerning the acquisition of potential customers and orders. These markets are characterized by volatile customer demands. Such companies need to react constantly to change in order to survive under these turbulent market conditions. Shortened product market cycles require adaptable manufacturing systems and method-based planning systems to master dynamic changes in order structures, both from a manufacturing and also a cost point of view. However, the high costs of the manufacturing resources implemented also demand long-term planning horizons in order to safeguard planned investments in a lasting way and to utilize them optimally.

The objective of this thesis was therefore to develop a method for the continuous optimization of manufacturing system costs in dependence upon planned output quantities in the field of series productions. To do this, a controlling concept has been developed which enables the optimum cost operating point to be adjusted using a controlling model based on control cycles. The model permits the user to identify potential improvement measures and to evaluate them in advance with regard to their profitability. To achieve this, the actual system configuration is acquired and depicted in a simulation-based planning environment together with the resources used and all interrelationships. The required data is imported into the planning system via the various operating data acquisition systems.

In contrast with known control concepts used up till now, order planning is not the central issue for a particular system. The role of the controller model is rather to ensure the optimum configuration of a manufacturing system in dependence upon existing orders for a period of planning time. In this way, the structural design of the manufacturing system also forms part of the optimization process.

[117] Cf. (Niemann 2007), p. 1-4

Through the use of simulation tools, the method which has been developed supports the targeted and continuous promotion of learning processes. This makes it possible to evaluate alternative manufacturing scenarios faster and to learn from the “future” by implementing improvement measures.

With the method, all order data and operating information regarding the actual system configuration are first collected from various operational information system sources. Once in-plant production has been determined using PPC, manufacturing orders are not transferred to the fine-planning but are rather divided into their individual machining processes which, added up, then form capacitance packages. A capacitance package comprises one or more machines which can be used to attain technologically-similar process results. In this way, the required busy times per capacitance package can be determined via the planning times from the preparatory work.

Improvement measures are then identified by analyzing sequence types in the capacitance packages over the overall planning time. Here, critical work packages or those associated with potentials are first ascertained. These are characterized either by capacity bottlenecks or free, unused capacities. Conceivable capacity situations and corresponding strategic options for action derived from them are then represented using morphology.

In a first step, on aligning the desired and nominal capacities, an efficient operating point for the manufacturing system is found. In a second step - taking required resource times and costs into account - a manufacturing function is then drawn up for the capacitance package tested. On considering the gradients, it is possible to read off the leverage effects and trade-offs of potential improvement concepts for each factor. This step enables system integration in the direction of the optimum operating point.

The improvement concepts identified in these two steps are depicted in the simulation model as preliminary costing and are then evaluated with regard to their effects on costs and time. Measures fulfilling individual company profitability criteria are then released for implementation in the manufacturing system. These measures result in forecast experience and learning curve effects which are reflected in a degression of piece costs. The cost curve later forms a reference line (benchmark) to continuously control the performance of the given system. To monitor the system, relevant data is specified which has been obtained from the various sources of operating data acquisition (MDA, QDA, PDC) and from PPC to plan, monitor operations and optimize the system. Any deviations regarding planning times and costs which have been ascertained from the final costing process give information about inefficiencies and wastages in the system. The constantly-updated model of the system thus forms a basis for future planning and optimization cycles. By back-coupling planning data with actual data, a life cycle-orientated control cycle is formed which can be used to continuously plan, optimize and monitor manufacturing systems throughout their life cycle.

The method developed has been practically implemented in a project for a series manufacturer producing electrically drive tools as well as to control the life cycle of a manufacturing system for the series production of machinable components. The system view obtained using the method showed not only that time was saved by analyzing alternative rationalization scenarios but also that qualitative improvements could be achieved by implementing the solutions found with regard to the quality and toughness/rating (validity) of the cost optimization ascertained.

As a result of this supporting method, the company was able to achieve considerably greater cost degressions as would have been attained on average using empirical learning curves. The practical application of the controlling model thus enables companies to achieve steeper learning curves in manufacturing. Due to the increased learning speed, comparative cost advantages can be realized which contribute towards safeguarding company competitiveness.

The method which has been developed places the cost-optimized synchronization of manufacturing orders with a specific manufacturing system in a central position. There is a further research requirement to integrate influencing factors concerning the market which are reflected as volatile product prices affecting profits. To do this, the method also needs to be extended by additional target functions and strategies regarding market price formation. Thus, the objective of life cycle-orientated optimization would no longer be to attain optimized production costs but rather to constantly adjust a system in order to ensure optimum manufacturing efficiency. Other research fields are also formed as a result of extending the balance sheet classification in a horizontal or vertical dimension. Here, the method could be extended horizontally to include the optimization of several logistically-interlinked manufacturing systems. This could be achieved by vertically integrating the method into superior system controls. By tapping of these reserves through superior optimization, far-reaching potentials for the future will be ascertained.

8. Conclusion

The literature review and existing research activities show that the holistic and sustainable consideration of the product lifecycle and the corresponding services disciplines is a novel viewpoint.

The impacts of a product in a holistic, lifecycle-oriented product planning and development need to be considered regarding all sustainability dimensions. Thus the knowledge about possible economical, ecological and social impacts in every phase of the lifecycle is important. In order to generate such a knowledge, it is necessary to analyze the lifecycle phases from the sustainability point of view. Through an appropriate lifecycle information support a constant access to all information by every involved department is possible. A continuous lifecycle controlling enables users to constantly monitor acutal and unexpected deviations from planned life cycle objectives. Lifecycle controling helps to keep on track with „moving targets“ and to ensure the lifecycle success.

Referring to this knowledge future products can be developed best in order to meet the increasing challenges and provide excellent services and products.

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III Scientific and academic development plan

From the previous chapters dealing with a general framework regarding the Lifecycle & Services Management a variety of further topics for scientific and industrial research can be derived.

The following figure 30 for this purpose displays some fields of work, which can be developed in the future within further research works and/ or with industrial participation.

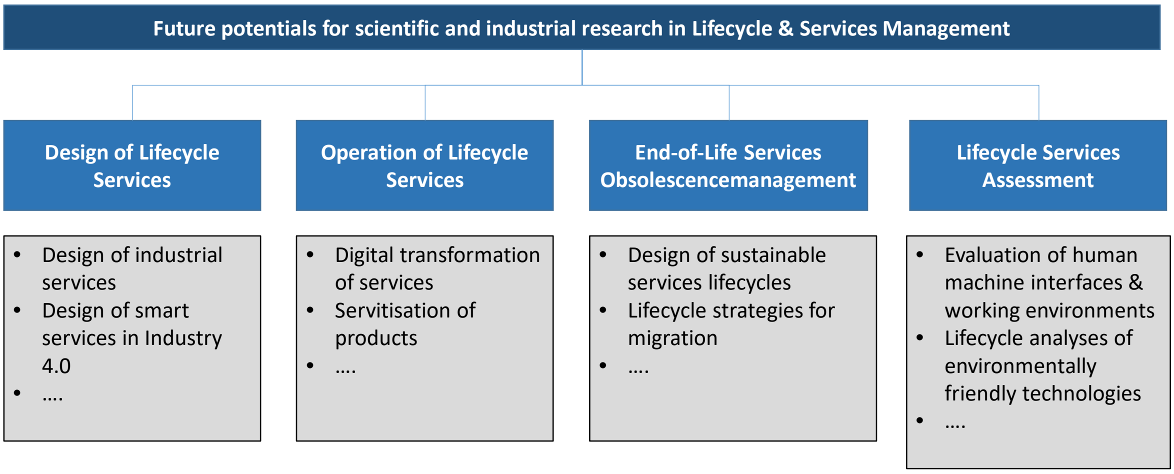

Figure 30: Future potentials for doctoral research

The potentials can then be displayed along a lifecycle oriented perspective. Generally services interfere – as shown in the previous chapters – in all phases of a product. Therefore the design of a service is of great importance: Besides the lifecycle of the product the services themselves have a lifecycle of their own. Services are developed, operated and at one day shut down (removed from the market). This means that also the lifecycle of a service needs to be managed (see obsolescence management). Especially interesting and relatively new are the service approaches, which result out of the technologies in the environment of industry 4.0 and the digital transformation. Here an enormous potential for further innovative services emerges, that at present is not developed at all. The increasing digitization also influences the phase of the assessment, in which increasingly questions of changes regarding the human working world in the field of those technologies are object of research. In the following chapters the identified fields of research shall be described in more detail. In addition exemplary research projects of the author are presented.

1. Scientific development

1.1 Research field 1: Conventional industrial services

Some weeks ago while working with the notebook on an important project: without any prior warning the screen turned black and the computer bowed out; everything was out of service, nothing working any more. One could say it is not a problem and the device is not yet old, so the producer shall immediately help solve the problem. Put briefly, without any valid service contract the issue would be very expensive and it is uncertain in advance if the recovery would work a 100%. But one could gladly send in the device…though a first preliminary examination will last some days…a time span that – if the device is needed – one normally cannot wait for. Not to mention the potential loss of data.

Scenarios like this show how important reliable services are in such a deciding moment. A service is needed that offers a fast and expedient recovery of the system. Be it in the industrial area, if for example a machine breaks down and the production needs to be interrupted or in the public field, if for example the control system of a traffic light is defect or in private, if the dishwasher or the car is defect.

Thereby the damage of a product or a machine interestingly can have quite positive effects on the business relation of customers and suppliers in the long run. Etzel and Silverman discovered this phenomenon during their investigations more than 30 years ago. They found that under specific conditions customers become more satisfied after having had a problem and after having received support and an especially good customer service. It turned out that they were more satisfied than customers who have never had any problem.

After the occurrence of the problem and the successful solution through the service an increase in satisfaction with the producer could be found, which even outperforms the initial satisfaction (Figure 31). An important condition is though that the service was performed in a competent way and at the complete satisfaction of the customer. The service excellence is the deciding factor of success in competing for the customer and a long-term business relation.

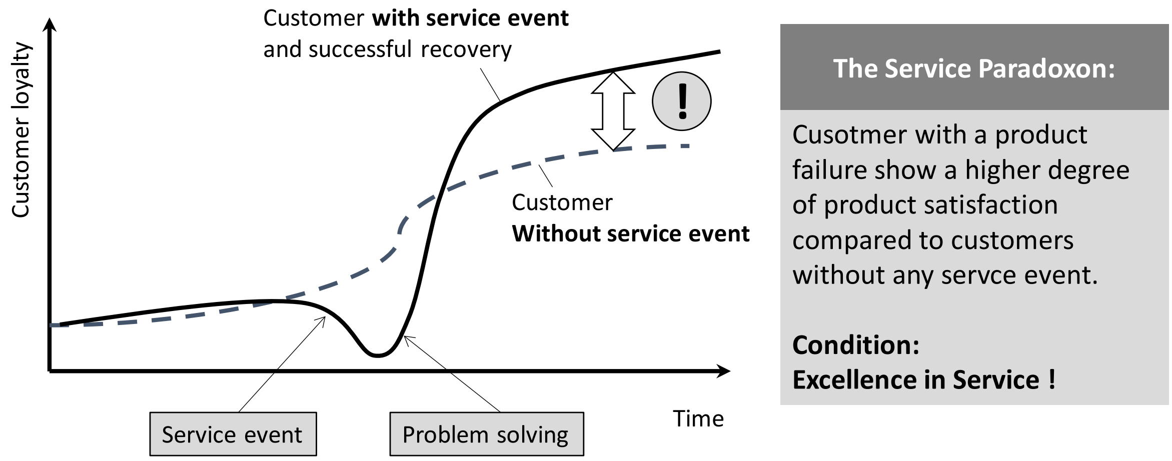

Figure 31: Strengthening customer loyalty[118]

The lifecycle of a customer relation is thereby strongly influenced by the satisfaction regarding the accompanying service. The first machine is sold by the sales team, the second by the service. Better said, the own service excellence is a vital component in order to position oneself as a more competent and trustworthy lifecycle partner for the customer[119].

But how can this excellence in service be reached? The service delivery, especially in the field of mechanical and plant engineering, is an important source of income for many companies, for some actually the greatest source of income. In different customer surveys – especially in the B2B sector – again and again the service competence of a producer is mentioned as one of the most important criteria for the purchase decision of a product[120]

For the economic success the type and quantity of the available service features is less relevant, but rather it is important that the service is designed based on targets and needs of the customer. Many service providers face the challenge that especially for the development of complex and professional services adequate procedures and methods are lacking. How can those ideas precisely be transformed into competitive service products? Which concrete activities have to be dealt with within the development phase and which tools are available? Herewith the poductization of services has an essential meaning from an economic viewpoint.

[118] (Niemann 2016), p. 3
[119] Niemann 2007, p. 23, (Niemann 2009), p. 143
[120] (Niemann 2009), p. 167, (Morar et al. 2008), p.597

The author for this purpose in cooperation with students at the Hochschule Dusseldorf developed a practical textbook (Figure 32).

Following the “established practice” the presence book describes in 11 steps, how services in an in-house service manufacture through a continuous and structured approach from the first idea to the final market maturity have to be developed in order to finally be successful in the market .[121]

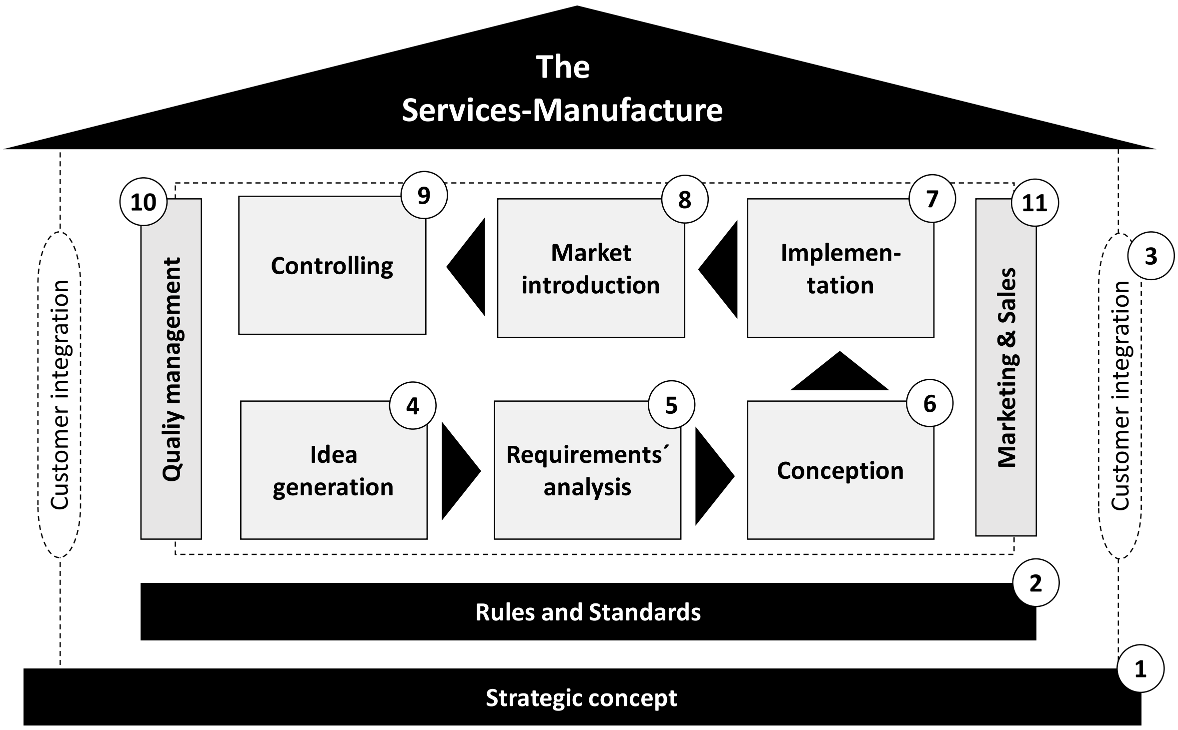

Figure 32: The Services Manufacture[122]

The necessary steps are completed with additional exercises after every chapter, which help the reader practically deepen and rehearse the methods on the basis of tools and approaches. To verify the results, at the end of the book solution approaches for the individual tasks are given.

A special focus here is put on the early connection of customer needs with the service strategies of the provider. Under this primacy the productization takes place in an integrated holistic approach, which besides functional, organizational and employee-related aspects also contains criteria of economic efficiency and service quality.

[121] (Niemann 2016), p. 12
[122] (Niemann 2016), p. 11

Finally a manufacture for productization of services is created, whose components are explained in more detail in the following chapters. For a better orientation each component of the service manufacture that is dealt with is graphically highlighted at the beginning of every chapter.

This book (currently a unique new approach on the market) delivers the basis for further research in the field of academic and industry-oriented research with the goal to develop services of the future in an efficient and methodical way.

Further research potential

The further research potential amongst others is in the development of a methodology and the development of innovative services. The development of services is currently only little supported by methodology. By the development of a marketable methodology industrial companies are put in the position to increase the revenue potential in the future.

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1.2 Research field 2: Smart industrial services

A Smart Service is a digital service that reacts on collected and analyzed data based on networked, intelligent technical systems and platforms. In contrast to the technology of Industry 4.0 which can exist in just one specific sector, Smart Services require cross-functional areas. These areas provide services which respond to analyzed data of other areas. Areas can be different departments in one company or more typically different companies which function as players in a network. The following figure describes the relation of the interaction between the different players and the technological progress and the resulting product of Smart Services. In contrast to normal products, "Smart Products" are products or components with embedded systems, which can collect, communicate and network data[123] (Figure 33).

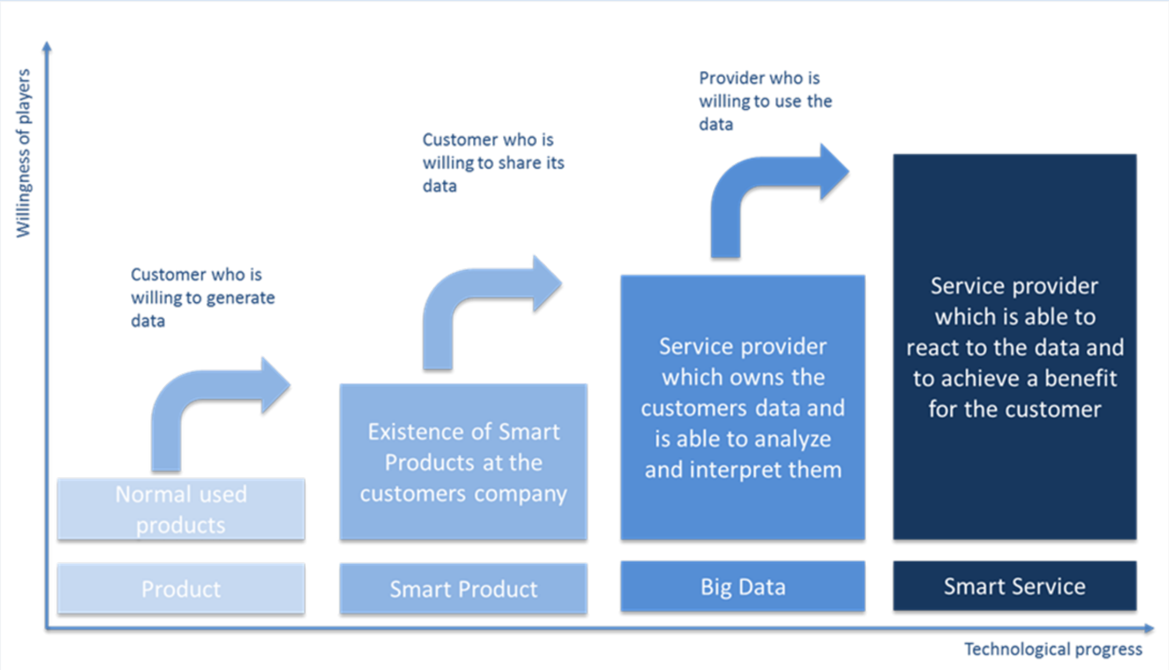

Figure 33: Requirements for Smart Service[124]

In dealing with Smart Services there need to be clearly defined premises. One of them is the usage orientation. The added value needs to be in focus as well as adapted to specific situations and contexts. The average customer activities must not be interrupted but must completely be understood to integrate the value-added activities. A further premise is the availability of Smart Data. In order to generate the

[123] Cf. (Jasperneite 2019), (Pöppelbuß 2017)
[124] Own source, modified and enhanced according to (Jasperneite 2017), (Pöppelbuß 2017)

data, Smart Products are used. Thus, status and usage data can be collected continuously. The data are combined in real-time from various sources.

This allows to make forecasts for future situations. Smart Services are marketed and accessed through digital platforms. They are available to the customer at any place and time. The digital access offers fast release cycles and is well scalable for providers.[125]

Germany has set itself the goal of becoming the number one country in Europe in digital growth. Throughout the first future project "Industry 4.0", Germany has already taken a major step towards this direction in order to tap the potential of this new form of industrialization as the first country. The second future project "Smart Service Welt" is now focusing on the value chains that emerge from Smart Products in Industry 4.0 after they left the factory. Intelligent products combine physical and digital services to Smart Services. They are provided flexibly and as required. The single vendor with its classic products and services is no longer in focus. The focus will be on the consumer and their expectation always receiving the right combination of products and services. In the future, companies must increase their cooperation beyond industry and sectoral boundaries. Furthermore, the product and service portfolio must be expanded and/or adapted consistently and continuously.[126]

The development of Smart Services depends on the fact in which industry its applied to. In the communication media or trade industry an advanced stage of maturity level in new digital business models can be found because these industries are close to the digital world. The maturity level of industries like energy and the industrial production is very low. These industries have a high potential in developing new digital business models and Smart Services. The maturity level of the various industries is illustrated in Figure 34.[127] What is needed to develop Smart Services and to create new digital business models?

The basis of Smart Services is an abundance of data. These data are information concerning the area of life or the area of work. The goal is to supply a digital service to the customer that is attuned to the customer benefit. This new way of creating new business models and additional services to the physical product should be

[125] Cf. (Pöppelbuß 2017)
[126] Cf. (Smart Service 2019)
[127] Cf. (Smart Service 2019)

minted by a digitalization and a development which is organized in an intelligent network.

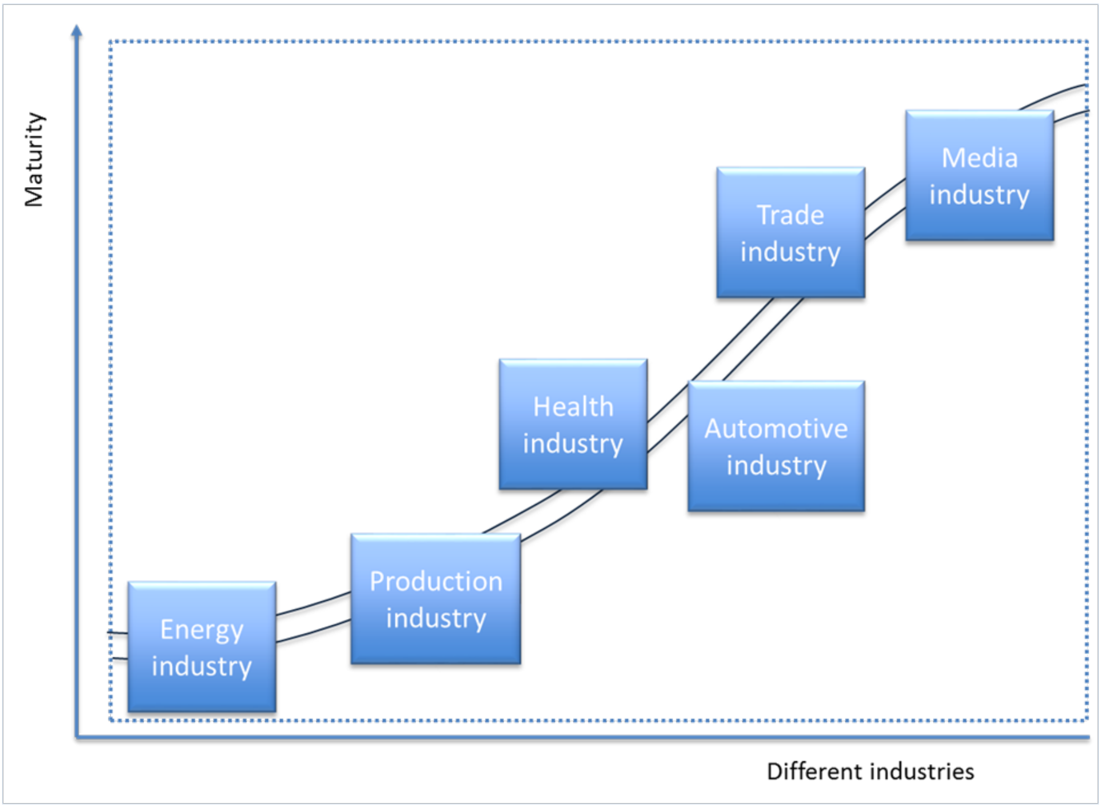

Figure 34: Maturity in the different industries[128]

The Internet of Things (IoT) takes a main role and connects the data and services of the physical products with the digital network.[129] This creates a new digital infrastructure.[130] The infrastructure can be shown in a four-layer-model. This model is shown in Figure 35.

The lowest stage of this model is the technical infrastructure. Two requirements are existing in this stage. The first one is the internal infrastructure. Nowadays the information and communication technology (ICT) makes it easy to connect the physical products and services with the digital world. The second one is the external infrastructure. It is necessary to have a high-speed connection to deal with the abundance of data.

[128] (Smart Service 2019)
[129] Cf. (Fleisch/Mattern 2005), p. 27
[130] Cf. (Smart Service 2019)

The following stage is the connected physical platform. This platform is created by all intelligent products which are related to the internet (Smart Products). Every single connected device can be understood as a hub in the internet that generates new data. These single hubs build a new connected network with an abundance of data. These connected devices can be a mobile, car or a machine that is used in the production process.

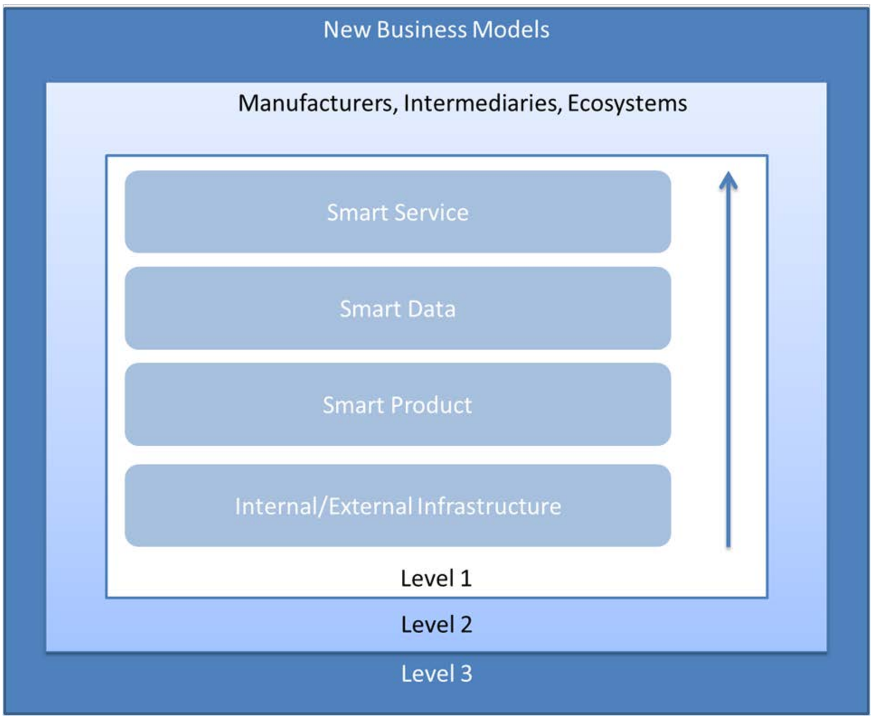

Figure 35: Four-layer model[131]

The software defined platform is the second stage of the model. At this level, the available data should be extracted and analysed to connect the basic information to new knowledge (Smart Data). This can be done by a traditional hosting or by using a cloud.

The last stage is the service platform. With these platform, the digital and physical services can be connected for every single customer. This can be a connection of cars with the gas stations, to lead the driver immediately to the next gas station if the car transmits the information that the fuel tank runs dry. However, to make this work all the information should be connected within a digital ecosystem, where the companies combine and transfer their knowledge.

[131] Cf. (Smart Service 2019), (Stöhr et al. 2017), p. 3

This infrastructure shall be the basis to reveal a strategy for building Smart Services. For the development of Smart Services, it is essential – like for every new business idea – to analyse which benefit can be created for the customer when using the product or service.[132]

Step 1:

The first step represents stage four and three of the four-layer-model. Intelligent products (Smart Products) are needed to generate information and create Smart Services that fulfil the customers value. Therefore, sensors and cyber-physical-systems are necessary (CPS).[133] The CPS is a network of informatics and software technical components with mechanical and electronical parts which communicate by a data infrastructure like the internet. The sensors and actuators make it possible to detect and handle the environment and incorporated data. With this, the digital and physical object fuse together. The goal must be to sell the use of the product instead of just selling the product itself.[134]

Example: A supplier which produces assemblies for the automotive industry can equip the needed materials with

tracking technologies and an infrastructure at the production which allows to handle the tracked information and make it accessible. Thereby, the materials can be tracked through every single production step, makingit possible to record the quality information and store it directly at the production part. A more broadly application area can be found in the gapless tracking of internal commodity flow in order to optimize the supplier and production network. The company can monitor the delivered parts in detail. It allows to track the quantity and kind of the product without manual labour and mostly in an accurate way. If the company has installed an information reading device in the goods receiving area, they are able to control the next production step by giving information on the incoming goods.

The technology that can be used for tracking is e.g. a barcode or a radio frequency identification (RFID). However, the RFID (smart labels) is compared to the barcode the more advantageous technology. The smart labels operate without an own energy supply, are designed in a small size and can read or write up to hundreds of

[132] Cf. (Smart Service 2019)
[133] Cf. (Bruhn/Hadwich 2016), S.27
[134] Cf. (Smart Service 2019), (Suh et al. 2014), p. 57

bits in a range of thirty meters. The reading process can be done without any visual contact between the transmitter and the receiver. In addition, the smart labels are weatherproofed and insensitive to dirt so that they can be placed on mostly every material. The information that can be stored on this chip contains data about the size and weight of the product, but also production data like the cutting speed.[135]

Step 2:

The mass of data (Big Data) that is collected by Smart Products must be analysed in real time with information extracting methods and intelligent algorithms to generate new knowledge. The real-time data collection here is very important, otherwise the reality is not shown and customer needs cannot be satisfied. This new knowledge is called Smart Data. A very relevant and important source in analysing the information is the cloud respectively the cloud-computing[136]

The cloud-computing is a further development of the traditional hosting. It is characterized by a high failure safety as well as a high flexibility and therefore it is the most advantageous technology. An additional advantage is that the data can be multiply stored at different locations to reduce the risk of data loss. The flexibility is given because the user can match the needed service with the changed requirements. In the cloud, the user can easily add more data memory or more computing performance. In the traditional hosting, the user must change the hardware manually on his own, which costs a lot of time and money. Another advantage compared to the traditional hosting, is the payment model “pay per use”. The user of the cloud only has to pay for the actual used service e.g. internal memory, computing power or data volume. The cloud-computing building is a tool with different services for data collection and handling over the internet. These services are classified by the Institute of Standards and Technology (NIST) into three different service models. These are “Infrastructure as a Service (IaaS)”, “Software as a Service (SaaS)” and “Platform as a Service (Paas)”. With this, the customer can use this service which

[135] Cf. (Jones/Chung 2008), p.23, (Clampitt 2007), p. 34
[136] Cf. (Furht 2010), p. 13, (Iafrate 2015), p.34, (Niemann et al. 2017), p. 2

generate the most benefit and fulfils the requirements. Examples for different services can be a data memory, software, server system, hardware or computing power.[137]

Example: The supplier who equipped the assemblies with the RFID chips can use the information about the consumed materials (the RFID infrastructure must be installed by the Original Equipment Manufacturer (OEM) as well) by the OEM to analyse the consumer behaviour. With this, the supplier can create a new service for the material supply. This Smart Service reduces the effort needed for the order process by the OEM, so that the supplier or who? can only focus on the consumption of the materials. Another service that the supplier can add and offer is a quality analysis of the used materials. By analysing the cutting speed better material selection or a better setting for the process in order to optimize the production can be reached. To sum up, there are many possibilities of creating Smart Services by using Smart Products.

Step 3:

The information can be stored in a common platform (service platform). With this the information of different Smart Products can be used to generate new digital service and business models leading to an optimization e.g of the whole supply chain.[138][139]

Example: The service platform consists of all stakeholder of this business. This includes the supplier company, who produces the assemblies for the automotive industry, the OEM themselves and the producer of the machine tool for the production. If they publish all the necessary information and it is tracked by the Smart Product of this platform, a high-performance increase over the whole supply chain can be realized. With the tracked data of the RFID chip and the tracked data of the machine they can optimize the production. They can also analyse if the machine has to be maintained or if the setting for the machine, to handle the materials of the supplier

[137] Cf. (El-Osery/Prevost 2015), p. 83
[138] Cf. (Smart Service 2019)
[139] (Niemann/Dehmer 2017), p.2

needs to be adopted. With this the supplier and the machine tool producer can create a Smart Service for maintenance and additionally an optimization of the production by setting up e.g. the cutting speed can be reached.

Exploding data volumes in cloud computing costs a lot of money. The solution shall be an innovative approach, the so-called fog computing. By 2020, 50 billion devices will be connected to the Internet of Things. This produces an enormous amount of data, raising the question: Where to go with all the data? In general, performance capacity costs money. Fog computing counteracts the enormous amounts of data on an intermediate level. Data will not be as previously unprocessed loaded into the cloud, but processed loaded into the cloud. Metaphorically speaking, the chaff is separated from the wheat at fog computing. By reducing the amount of data, a faster data exchange becomes possible. This allows real-time data to be generated and processed. In today's fast-moving times, Smart Services need to be able to respond immediately to changing situations. The response to real-time data plays a significant role for Smart Services. Smart Services should be linked to the fog computing technology in the future in order to avoid too high latent times of cloud computing.[140]

Further research potential

Further research potential lies in the integration of data from modern industry 4.0 application to develop and design new smart life cycle oriented services in various industrial fields.

[140] (Deutsche Messe 2017)

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1.3 Research field 3: Digital transformation of services

Shorter product life cycles, continuous changes and further development of business processes lead to changes in business models and the everyday work life. Customers expect faster business transactions, one- stop- shop solutions and transparency in the value chain. This is only possible, if companies are able to digitalise information and data concerning products, customers, processes and services and thereby transform their business procedures digitally. With this new working method, a high amount of data is collected about all processes, as well as data about internal and external communication, requiring a high amount of management and data analysis. In addition, the quality of the data is very important to ensure consistency and correctness.[141]

Digitalization of production processes, administration procedures and communication usually results in faster transactions and more reliability in means of quality and security. This leads to higher customer satisfaction.

In order to digitally transform one's business, it is essential to have a strategic plan and a clear goal set. Before implementing the new business model or making company modifications, it is recommended to have a change management plan in place.[142] The reason for this is, that often the culture and employees of a company can be large obstacles when exposed to major changes. Companies, who's culture is driven by entrepreneurship, creativity and innovation are more likely to successfully digitally transform their business model, rather than companies with a traditional and closed-minded mentality. A study of McKinsey form 2008 with top managers and executives showed that a company's culture can be the biggest obstacle and at the same time the main driver of innovation and change. [143] The digital transformation can be achieved in 5 steps:

1. As-Is Analysis
2. To-Be Definition and goal setting
3. Best Practises and potentails
4. Digital Fit
5. Execution

[141] Cf. (Baumeier 2016), p. 26
[142] Cf. (Barsh et al. 2017), p.38
[143] Cf. (Kohne 2016), p.7, (Mervelskemper/Paul 2016), p. 746

Step 1 includes an analysis of the current state of the company and its value proposition. The value chain should be analysed as well as the stakeholders. Through this analysis a first indication is given, on what processes, products or services can be digitalized and which can't.

Step 2 is the goal setting process. The company should ask its self where it would like to be positioned in the market, what their priorities are and where it should stand in 5 years. In this manor, the framework for the business development direction is set.

Step 3, Best Practises, involves the potentials of a company. The best practises are analysed, on how these could be integrated in the new digitalized business model. In this phase, the business model is further defined and different alternatives and scenarios of it can be examined.

Step 4 assesses and evaluates the various business model alternatives regarding goals, customer and market demand, investment and the digital feasibility.

Step 5, the final phase, is the implementation phase. This is where the selected business model is implemented. However, this step is recommended to be fulfilled with suitable partners like IT service companies and also change management experts.[144]

The digitalization of processes, products, transactions and machines leads to a high amount of data and information. A network of customers, service provider and O-EMs is laid out that needs to be managed. The amount of data and all communication processes require a high amount of management and analysis to ensure correct interpretation of the data. A solution to the high maintenance of data quality and the management of all digitalized processes, services, machines, products and the network of partners and customers is a cloud platform. This would allow a constant exchange of process data and its automated analysis throughout the whole supply chain as well as full value chain management through the platform provider.

Cloud and IT- service provider can help with the setup of a suitable platform. Typical functions of a cloud platform are multiclient capability, scalability, availability and

[144] Cf. (Kreutzer 2017), p.11, (Schallmo 2017), p.14, (Niemann 2016), p. 23, (Niemann/Dehmer 2017), p. 4

integration possibilities of external databases with and integrated development environment that supports different programming languages (e.g. Python, Java). A core aspect during the development of a platform, is to make sure that the data that is collected is done in a correct and exact manor to ensure high data quality. All automated decisions and analysis are based on this raw data. Furthermore, new value adding services can be created and offered, like for example automated transaction procedures, invoice creation and download, monitoring services of products, machines and processes and even external services, offered by service provider integrated into the platform. [145]

To digitalise the whole value chain, not only must the products and machines be digitalized, but also the logistics, so that the digital image of all objects and their relevant data can be cross-linked to the physical world and thereby communicate with the environment. Relevant information that can be collected is for example status, condition, position, location and weight. This can be achieved through RFID chips (Radio-Frequency Identification chips) and scanning systems that can be placed into the products, the transport boxes and trucks.[146]

Looking at an entire value chain, we have certain stakeholders: the supplier, the producer, the logistics companies and the customer. By integrating all players, products and services into a cloud-based platform and by digitalizing the value chain (products, machines, trucks etc.) A transparent and fully automated manor of communication between the stakeholder but also between all objects in the value chain can be achieved. For example, a machine of the producer can alert the supplier automatically if more resources are needed. The product can alert the truck driver when it will be ready for pick up. The customer can provide the truck driver with a delivery section by making a status request to find out about the location of the truck and the remaining distance to the delivery site. All this data can be collected through chips and sensors and sent to a cloud platform to which all stakeholders of the value chain have access to, to receive their necessary information. A benefit of the platform is not only the automated communication, but also the integration of customers into one’s digital infrastructure. A network of services can be provided, efficient and standardized processes and a transparency in the value chain are in place so that

[145] Cf. (Hahn 2016), p. 595
[146] Cf. (Bousonville 2017), p. 7

a customer "lock- in" can be achieved through a strategic integration into the platform systems. The key is to transform a straight-lined value chain into an ecosystem that encourages innovation and efficiency.[147] Figure 36 shows a depiction of a cloud-platform.

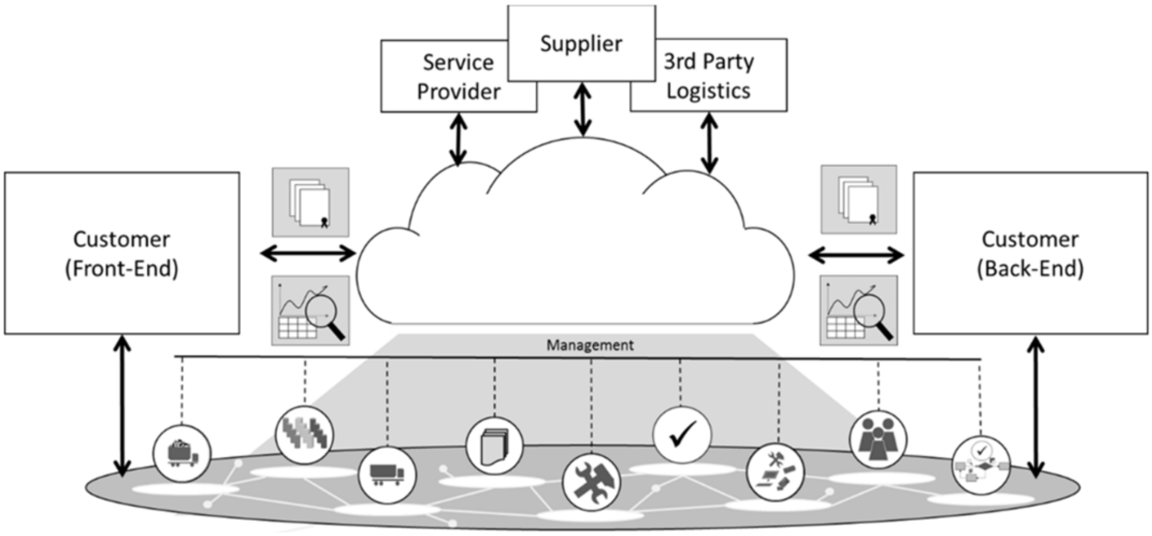

Figure 36: Four-layer model[148]

The following case study of an industrial project shows a digital transformation of a traditional business. Electrical waste (e-waste) recyclers collect e-waste, like for example printers, laptops, mobiles and telephones, from various channels. These can be, public collection points, other recycling companies, OEMs and even retailers. Batteries and other hazardous waste is removed beforehand by specialized companies, as this step requires certain security measures and regulations. The waste is then sorted into different categories and then shredded into a granulate. The granulate is then processed through a material sorting machine to form categories of the same materials. These are then melted and restored to their original raw state. Metals that are extracted are gold, silver, copper, platinum and iron, which can be sold at market prices. Even plastics and other materials can be reclaimed from the used product and resold. The e-waste business is very fragmented and is losing profitability. On the one hand, it is a globally competitive environment and on the other hand the electrical products are becoming smaller and need less precious metals than 20 years ago. The recycling quotas and the amount of waste that is

[147] Cf. Hahn 2016), p. 596, (Bousonville 2017), p. 8
[148] (Niemann/Dehmer 2017), p. 4

provided by the consumers is not sufficient any more for the recyclers to stay profitable. Also, recyclers are reliant on many players in the e-waste value chain and have highly fluctuant revenues, due to the market price changes and the unknown content and quantity of waste they will receive.[149]

The solution is to digitally transform the recycling business. Problems to be solved are the number of tons collected per month and the unpredictable material content of the end of life products, as some people remove the valuable parts beforehand along the value chain. Also, OEMs and retailer are now obliged to provide recycling quotas to an e-waste institution and if they are not met, they will be fined. The key, to solve all stakeholders' issues, is to start at the source of the e-waste: the consumers. The consumers need an incentive to bring back their waste, especially if they know about its value. This can be achieved through an e-waste platform. The platform can provide an interface between the consumers, the producers, the retailer, and the recycling companies. A consumer can register his product through the platform and bring it to a suitable return station. This could be any retailer or OEM as they are obliged to take back e-waste within the EU. The end of life product can be identified by an employee and a barcode can be stuck onto it. This code will have all relevant information about the product type, its weight and material content. The retailer can then scan, weigh and check the product and put it in a box ready to be picked up from a logistics company. The information about the product and material content is sent to the recycler who can pay the retailer an adequate price for the box of collected e-waste and then further process it. This is how the recycler can calculate the exact revenues he can expect at the end of the month as well as the volumes to adapt his capacities accordingly. In addition to this, new services can be provided through the platform, for example repair and refurbishment. From the platform, the processed and raw material can be sold back to the producers. Over capacity, can be distributed to other recyclers over the platform, if they are integrated into the system. Thereby, the entire value chain of e-waste of a certain region, country or continent can be managed by one single company providing a platform. This is how long-term contracts with the frontend channels and customer "lock in" as well as a

[149] (Magalini et al. 2014), p. 7

consistent and plannable material flow can be achieved. In other words, full value chain management.[150]

The transformation of traditional value chain processes towards a digital value chain management enables companies to sustainably establish and retain a competitive market position. The paper has shown the steps on the practical example of electrical waste management. Digitisation offers the opportunity to design and operate expansive process chains with efficient process operations via co-operative platforms. Increased customer loyalty („lock-in“) via integrated measures at the front-end raises utilization and planning certainty for the technological recovery systems.

Further research potential

Further research potential lies in the development of a generic methodology to transform existing services into digital applications with rising customer benefit at lower operating cost. This includes also the servitisation of future products (products as a service) to minimize resoures´consumption and maximise economic efficiency.

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[150] (Bousonville 2017), p. 8

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1.4 Research field 4: Lifecycle Strategies for Services

Production systems nowadays can easily have a lifespan of more than 20 years – provided that they are looked after and maintained correctly.[151]

When it comes to investment calcualtions, plant operators are increasingly assessing new installations or upgrades on the basis of the “contribution they make towards achieving long-term productivity targets”. [152] Life cycle management means here “… not talking about forecasting the future, but shaping it…”. [153] There are two basic strategies here: In some cases, the focus of an increase in productivity lies on maximum output whilst inputting the same amount of materials and energy. However, more often, plant operators try to achieve the planned sales volume with minimal outlay. The more efficient use of resources is therefore an important motivating force for companies looking to achieve lasting competitive advantages.

As far as the “minimal use of resources” is concerned, operators want to know what follow-up costs will be incurred following installation and how the new investments into equipment will help to ensure that processes are managed efficiently. Increasingly, they look at the entire life cycle of the production facility, which can often mean a period of more than 30 years. This poses major challenges system manufacturers, as the lifespan of the individual components which make up a system can vary considerably. Only the cabling roughly matches the lifespan of the entire production facility. Technical obsolescence and innovation cycles mean that computers and software remain economically viable for only five and three years respectively. Successful life cycle management for production systems must address this problem from the point of view of the compatibility of hardware and software components. Only in this way can companies protect their investments in automation technology in the long term and operate a user’s individual applications in a future-proof manner.[154]

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[151] (Bode et al. 2011), p. 3
[152] (NAMUR), p. 2
[153] (NAMUR), p. 2
[154] (Niemann 2009), (Niemann 2011), p. 182, (Niemann/Gerullat 2011), p.4, (Niemann 2012), p.385, (Schrieber et al. 2011), p. 37

With this in mind, the manufacturer has put in place active life cycle management for its systems. This is based upon a group-wide, standardized life cycle model which applies to all parts of a system.

Modern systems have to be designed to allow continuous further development (evolution) but the useful life of the individual components differs, although they run through identical life cycles. Especially when a component is nearing the end of its life cycle this principle has to allow migration to what is then the current product generation. By synchronizing the various lifespans, the manufacturer is able to ensure that the entire process control system is technically up to date over its whole life cycle.

The modular structure offers two benefits: the life of the system can be supported on a long-term basis and technological progress can be integrated into subsystems on an ongoing basis. Moreover the unequivocal allocation of the components to product life phases provides reliable information about the availability of spare parts and the product support the supplier can offer. This planning certainty not only increases overall system reliability but also improves the performance and availability of the plant.[155]

The use of life cycle management for investment goods provides an important opportunity to optimize the benefits of such systems over their entire lifespan. In order to maintain or even increase the productivity of a plant on a sustained basis, it must be possible to assess its performance over its entire life cycle.

However, experience shows that efficient system management is the most important factor when it comes to maintaining and increasing plant productivity. For this purpose, a measuring system is needed to examine the effectiveness of the processes defined by the plant operator and records e.g. the quality and response time the plant operator needs to provide the know-how for fault location, to identify the required spare parts and organize their delivery if problems arise in the plant. The index depicts not only these technical and logistical processes but also the quality of the processes relevant to company management and strategy. The assessment

[155] (Schrieber et al. 2011), p. 38

includes aspects such as the company management's planning and budgetary horizon or the effectiveness of the continuous improvement processes in place. There is often considerable hidden potential for increasing productivity in this area too.[156]

There is also the option of concluding life cycle agreements, which may have a duration of three to approx. ten years depending on the customer's requirements. They contain predefined packages of measures comprising software and hardware upgrades and other specific services with fixed prices and implementation schedules. Time, activity and cost plans like these ensure clarity as regards the follow-up costs of an investment. Planning the entire life cycle of all components also ensures that they remain future-proof and protects the customer's investment in its system. Guaranteed costs prevent any unpleasant surprises for the duration of the contract and allow operators to draw up budgetary plans for the entire life cycle of their plant.

This foresighted planning approach allows the control systems to be kept up to date at all times and maximizes the benefit which the operator gains from the plant by coordinating all necessary measures in the long term.[157] Planning with Life Cycle Budgets reduces costs by 10 to 30 % over the agreed contractual term compared to classic care schemes.

Experience shows that life cycle planning is essential where users have ambitious plans to achieve constant increases in productivity. Previous indexing has revealed that such dynamic companies invariably use life cycle management in order to realize their full productivity potential.[158] These plant operators have long-term approaches when it comes automation planning and make particular use of modern IT systems and tools in order to develop further improvements based on the production data collected. In most cases, this is done by setting up effective control loops within the company organization. Faults and potential for improvement are analyzed and processed and implemented thoroughly in ongoing improvement measures.[159]

By a continuous monitoring of the systmes over the lifecycle manufacturer and operator commonly take responsibility for the productivity of the plant. By this the man-

[156] (ZVEI 2010), p.4
[157] (Bode et al. 2011), p.56, (Lanza et al. 2009), p.5, (Morar et al. 2008), p. 398
[158] (NAMUR), p.3
[159] (Niemann 2009), (Niemann 2011), p. 182, (Niemann/Gerullat 2011), p.4, (Niemann 2012), p.385, (Schrieber et al. 2011), p. 37

ufacturer becomes a strategic production resource for the operator. A proactive service in return will ensure to meet long-term plant goals. This creates a long-lasting, value-driven partnership which is driven by life cycle service excellence.

Further research potentials:

Further research potentials are located in the design of sustainable lifecycle services under the constraints of environmentally friendly etechnologies. This also includes lifecycle strategies and approaches to master the techonolgical progress and the investment protection under the constraints of environmental and economic efficiency including an obsolescence management at the end-of life stage for the services offered.

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1.5 Reseach field 5: Services in Industry 4.0 environments

Modern production systems under Industry 4.0 will generate permanent data about the current production status. This will allow to design new services applications to optimise production efficiency. The services are not only limited to machine optimisation but also to the human-machine interaction. One possible field in this connection is the application of eye tracking and virtual reality.

Eye tracking is the process of recording a person's eye movement for the better understanding of a person's visual perception. Due to low costs and highly accurate systems, the process of eye tracking is used in many devices and applications to increase computer interaction and to study human behavior.

The device used to record the movement of the eye is called eye tracker. It uses projection patterns and optical sensors to determine the eye's position, viewing direction and eye movements with very high accuracy. There are two possible eye tracking systems. One system is directly linked to a screen, whereas the eye tracking glasses are a mobile system, which does work with a battery and therefore can be used in different environments.[160]

A great majority of eye trackers are based on the principle of corneal reflection tracking. The following measures can be tracked:

- Gaze direction and gaze points, used for the interaction with user interfaces and in behavioral research to determine what attracts a person's attention and for how long. Gaze direction, which last between 200-300ms are cold fixations whereas saccades describe gaze movements until 30-80ms.[161]
- Eye presence detection, in this case the eye tracker must find the presence of eyes vital to the tracking operation and it can also be used to trigger devices.
- Eye position is the ability to calculate the position of the eyes in real time, such features improve the performance of the eye tracker and are also used in gaming and auto stereoscopic 3D display systems.
- User identification, in this case the eye tracker is used as a biometric sensor for PC logging or door operations.

[160] (Blake 2013), p. 368
[161] (Holmqvist 2011), p 4, (Niemann/Fussenecker 2014), p. 7

- Eyelid closure is used for monitoring a person's attention span and can be applied for driver assistance or user safety solutions.
- Eye movement and patterns are used to understand human behavior and diagnose diseases. It is possible to run a hearing test on infants. The study of micro saccades is also central in neurological research.
- Pupil size and pupil dilation is used to determine the user's excitement level or the influence of drugs and alcohol.

Eye tracking has become a powerful tool for understanding human behavior. The eye is directly connected to the information processed by the brain, which provides a simple method to study what a person is thinking.[162]

There are many areas, where eye tracking is used. Leading consumer goods companies use eye tracking to optimize product packaging and retail shelf design; market research companies and major advertisers use eye tracking to optimize print and TV ads; product companies use it to optimize interaction design; web companies use it to optimize online user experiences and the usability of their websites; universities use it for research in psychology, neurology and medicine. New types of medical diagnostics have also been made possible by eye tracking, as well as safety applications that monitor user attention in critical situations.[163] Studies using eye tracking can be categorized in four groups:[164]

- Marketing and advertising – in this field eye tracking is used to observe the customer's perception of a product with the purpose of improving the products design so it will be more appealing to the targeted customer group or to verify if a product's label information is noticed correctly.
- In neuroscience and psychology fields eye tracking is used to study the effects of various diseases and the behavior and decision making process of individuals in various health related cases.
- Computer science and usability – in this case eye tracking is used as an input method for various devices and software.

[162] (Niemann/Fussenecker 2014), p. 4, (Geise 2011), p. 150
[163] (Thomsen/Fulton 2007), p. 28
[164] (Duchowski 2007), p.2ff

• In industrial engineering present and future work environments and processes are analyzed.

As shown in the examples above eye tracking is used in a wide range of applications but is almost absent in the engineering environment. One reason could be that engineering is an exact science and product development and design is based on a rigorous set of physical, functional and legal constraints and only after this requirements are met, the visual aspect is taken into consideration.

Examples of where eye tracking can be used in the software environment was given in “Evaluating an eye tracking interface for a two-dimensional sketch editor” where it could be used as another input method for a CAD software to improve the usability.[165]

Another possible use is to record the customer’s visual analysis of a prototype and see where the points of interest are. This is useful because it can lead to improvements in the product design beyond the requirements and needs expressed verbally.

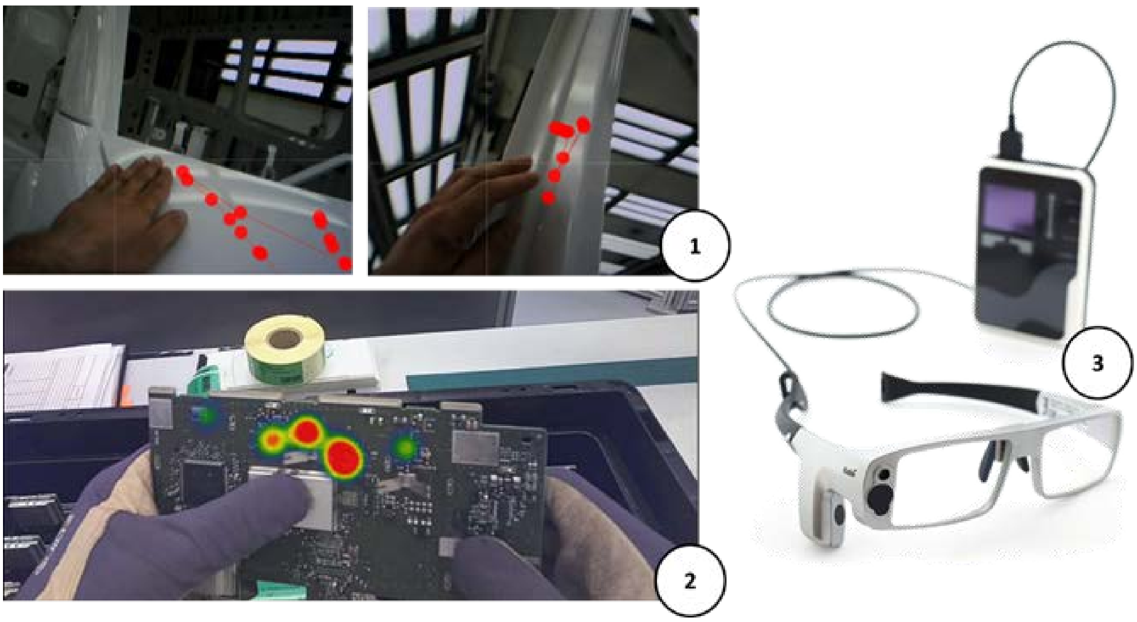

Figure 37: Example of current research activities with eye tracking[166]

Figure 37 illustrates as an example Study objects paint control (1) and circuit breaker (2) and the eye tracking equipment (3). It can be used to analyze how an

[165] (Velasquez 2013), p. 1469
[166] Source: Own representation from projects

assembly line worker perceives the working station and if there are any difficulties in locating the tools or mating points of the parts. It also can give a non-conscious feedback regarding the work activity.

Another application for eye tracking is in the quality control faze of a product. If a more complex product is made and the control needs to be done by an employee, his gaze can be recorded and then checked by a computer to see if all key zones of the product were analyzed.[167]

Future research potentials

Potential lies e.g. in the application of eye tracking in the engineering environment. It is somehow still a pioneer work, using the eye tracking technology in this area. Already reached results show that there is a great potential, which needs to be built on to set up further standards using this technique. The merger of such technologies with virtual reality could generate a loop with integrated “spotting” and “feedback”. The technology could be used for training and optimisation of workers in production environments in the interaction with machines.

[167] (Niemann/ Fussenecker 2014), p.3.7, (N.N. 2012), p. 141ff

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2. Academic development

2.1 Concept for doctoral tutelage

The doctoral studies of a doctoral student are planned for a period of 3 academic years (each composed of 2 academic semesters) and comprise:

1. A training program based on advanced academic studies, carried out in the doctoral school of TU Cluj-Napoca. The training contents and subjects will be defined between the doctoral student and the supervisor.

2. An individual program of scientific research/artistic creation.

The doctoral studies end with the public defense of an original paper which is the result of the research activity carried out by the doctoral student during his/her doctoral studies. The title of doctor is granted or not granted on the basis of the doctoral thesis and its public defense.

The doctoral studies can be executed on both as an internal or external student status. This allows to consider job restrictions and or personal private family issues.

An „ideal“ blueprint of the procedure is shown in the following Figure 38. The doctoral studies are scheduled for a time period of three years. Further restrictions may apply according to the rules of the doctoral school at TU Cluj-Napoca.

Timeline	Activity	Involved persons
Before entering the doctoral programme	• General admission clearance of candidates • Matching of research interest and possible supervisor	• Candidate • University Administration • Doctoral school´s council
1st year	• Elaboration of a scientific draft concerning the research topic • Definition of the title of the doctoral project • Definition of the research method • Elaboration of the accompanying training schedule (courses, industrial trainings etc.)	• Doctoral student • Doctoral supervisor • Doctoral school council

	• Definition of the doctoral supervisor(s) and defintion of time schedule	
2nd year	• Participation on scheduled trainings • Elaboration of thesis • Regular meetings with supervisor to monitor thesis progress	• Doctoral student • Doctoral supervisor • Training institutions
3rd year	• Participation on scheduled trainings • Elaboration of thesis • Regular meetings with supervisor to monitor thesis progress	• Doctoral student • Doctoral supervisor • Training institutions
Public defense of thesis	• Presentation of the content of the doctorate thesis • The doctoral supervisor and the official reviewers read their evaluation reports • The president of the doctoral committee presents the opinions submitted in writing to him/her by specialists who read the thesis or its summary, prior to the public defense • Public debate of the doctoral thesis	• Doctoral student • Doctoral supervisor Doctoral comittee

Figure 38: Ideal schema of the doctoral studies

To ensure a regular and effective supervision of the candidate the author will be available for face-to-face meetings during his lectures or other projects at the TU Cluj-Napoca. Another channel will electronic communication via medias like skype or email.

The author prefers and considers personal meeting as a very important part of the thesis supervision. Therefore personal meetings on a regualr base at least once in a year will be necessary. The meetings can also happen at Duesseldorf, which is very good conneted to Cluj with various flight options (for quite reasonable prices).

The doctoral student is responsible for triggering such meetings according to his individual progresss. This allows to match to the individual learning speed of the students and to consider his/her personal situation (job restrictions, private life etc.)

Optional as part of the doctoral studies candidates may spend a part of their research activities abroad in other research or even indsutrial institutions. The large network of industrial and academic partners will help to support candidates serving a stay abroad as part of their studies. A research stay abroad will also leverage inter-cultural competencies of the participants and support buildign up their personal scientific and industrial network.

2.2 International Network of collaborative life cycle research

The author´s vision of the doctoral school is to crate an international network of partners in research and project work. The doctroal students are an integral part of this network to perform their research and to develop their personal intercultural competencies. Thanks to his research activities the author has already established the basic fundamentum of partners for this network. Figure 39 shows the network and it´s current partners.

Figure 39: International network of research

All partners are already performing research activities in Life Cycle Managemt. The network is open to be extended to more interested partners in similar or related field of research. The network has the ability to participate in various European project calls to acquire funding for international research activities. E.g. the Horizon 2020 RISE programme offers the opportunity to especially fund partners from outside of the EU. The programm especially supports travel and reaearch activites outside from the home institution. As a future member of the doctoral school in the domain of Engineering & Management at the TU Cluj-Napoca the author will offer courses in english language in the field of lifecycle and services managment in Cluj on a regular basis. On the other hand lecures from the TU Cluj will be integrated into the education at Duesseldorf University of Applied Sciences. This will even deeper interlink the current exchange, lecuring and research activities of TUC-N and HSD.

The embedding of the doctoral programme into an international network of research will leverage the qualification of the students and lectures up to a new level of expertise.

IV Appendix

I List of Publications

Monographies

Niemann, Jörg: Die Services-Manufaktur, Industrielle Services planen –entwickeln – einführen. Ein Praxishandbuch Schritt für Schritt mit Übungen und Lösungen. Aachen, Shaker Verlag, 2016

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In planning:

Niemann, Jörg, Pisla, Adrian: Life Cycle Management of Machines and Mechanisms. Springer Verlag, Berlin Heidelberg, (Springer, Publishing Agreement signed, ca. 700 pages, to be published in 2019)

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2019

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<u>2004</u>

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II Curriculum Vitae

Personal Data

Date of birth :	July 6, 1970 in Münster/ Westf., single

Education

1990-1996	School leaving examination, A-levels (Abitur), Studies of business and mechanical engineering at the University of Paderborn/ Germany.
09/1993 – 03/1994	Studies abroad with an ERASMUS scholarship at the University of Economics and Business at Athens/ Greece

Military Service

05/1997 – 02/1998	Serving as a first-aid man in a dental group, Münster

Professional Experience

05/1998 – 12/2002

Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) and Institut of Industrial Manufacturing and Management (IFF), Stuttgart

Personal assistant to the managing director Prof. Westkämper

- Co-ordination of special project of the directors´ board
- Strategy and development for the new research team of Life Cycle Management

01/2003 – 03/208

Institute of Industrial Manufacturing and Management (IFF), University of Stuttgart

Project manager and spokesman of the research team Life Cycle Management

- Leadership in personell and budget to conduct projects in industry and academic research (see register of projects)
- Acquisition of third-party funds from industry and public bodies (state, country, EC)

04/2008 – 12/2009

ABB Automation GmbH, Düsseldorf

Product Manager Life Cycle Service

- Development of services for process control systems
- Development of an innovative service for life cycle oriented consultancy („Life Cycle Index®“)
- Execution of life cycle indexes at customer sites

01/2010 – 06/2012

ABB Automation GmbH, Düsseldorf

Head of Life Cycle Management Group Service Process Control

- Leadership in personell and budget for Service Life Cycle Management (group size: 6, turnover 5 Mio.€ p.a.)
- Development of innovative business models for services

06/2011 – 06/2012

Member of the Supervisory Board of ABB Automation GmbH, Mannheim

07/2012 – today

Düsseldorf University of Applied Sciences, Düsseldorf

Full Professor Chair for Business Administration and Mechanical Engineering

- Programme director studies of Business Administration and Mechanical Engineering (Bachelor and Master level)
- Since 02/2016 Managing director Institute FMDauto – Institut for Product Developement and Innovation (15 scientific staff members, ca. 650k€ p.a.)
- Director of FLiX – Research Centre for Life Cycle Excellence (2 scientific staff members, ca. 100 k€ p.a.)

Ph.D.

06/2007	Industrial validated Ph.D. in production planning and optimisation: „A method for life cycle controlling of production systems“ Content: A closed loop model for long-term investment optimisation in production systems

Trainings

07/1990 – 9/1990	Technical internship in a metalwork shop Fa. Kunst und Bauschlosserei D. Bauer, Münster
03/1992 – 04/1992	Commercial internship in marketing research Fa. Markforschung Krämer GmbH, Münster
09/1995 – 11/1995	Development of a tool for automated conversion of financial statements for the German headquarter Fa. Frontier-Kemper Constructors, Inc., Evansville/ Indiana, USA
01/1996 – 12/1996	Student assistant at the institute of synthetics technology University of Paderborn
02/1997 – 04/1997	Development of a standardised cost calculation sheet for the installation of telecommunication towers Fa. Frontier-Kemper Constructors, Inc., Evansville/ Indiana, USA

Honours and Awards

07/1993	Scholarship for a study abroad awarded by the the faculty of business administration awarded by the University of Paderborn (rector´s list)
08/1995	Scholarship for a overseas training awarded by the German Academic Exchange Service (DAAD)
02/1998	Award of the German army for the implementation of a standard procedure for the phone-based anamnesis of patients
02/2002	Appointment of Honorary Professor awarded by the TU Klausenburg (Romania)
12/2009	Innovation award ABB Europe for the development and successful introduction of the Life Cycle Index®
06/2012	Innovation award Service ABB Global fort he development and successful market introduction of the IT Cyber Security Fingerprints
12/2014	High-Tech-Service Know how Transfer special award fort he developement of an academic studies programme in the area of service engineering & management
01/2019	Fellowship for innovations in digital academic teaching awarded by the state of Northrhine Westfalia

Special skills

Languages	German; Mother tongue English: Business fluent
Six Sigma	Six Sigma Green Belt Trainer for Six Sigma Yellow Belt
VDI	Board Member in the Germany Engineering Association (VDI), Region NIederrhein