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Design of a Methodological Framework for Adaptive Remanufacturing-based Business Models

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Abstract

As manufacturing companies face a globally increasing consumption of resources and the associated environmental impact, sustainable solutions are gaining in importance for manufacturing companies. In this context, the life cycle extension of capital goods offers a promising approach to increase the resource efficiency. On this basis, a proactive, intelligent maintenance strategy is being developed as part of the research project Adaptive Remanufacturing for Life cycle Optimization of Capital Goods (ReLIFE). The associated preservation of a predefined machine performance level enables the realization of new business models. This paper provides a framework for the development of the theoretical and methodological foundations for a business model based on Adaptive Remanufacturing, derived from the current state of the art in the field of remanufacturing- and maintenance-based business models. The development process consists of the four steps - Status Quo, Business Context, Value Architecture and Business Model Characteristics - and is supported via the adoption of the Business Model Canvas as well as the St. Gallen Business Model Navigator. The Value Architecture, in which the focus is on the implementation of a Product Service System (PSS), represents the core of the business model. Instead of selling the product, only its usage is provided. The manufacturer, as PSS provider, retains ownership and is responsible for maintenance, remanufacturing and other services in order to keep control of the product. Moreover, the idea of ownerless consumption and a transparent financing model opens the market for new customers and enables economic potential by extending the use phase of the respective capital good.

Keywords: Adaptive Remanufacturing; Intelligent Maintenance Strategy; Intelligent Life cycle Extension; Resource Efficiency; Product Service System; Business Model

1. Introduction

As consequence of an increasing consumption of natural resources and the associated burden on the environment, sustainable and resource efficient solutions are required in the manufacturing sector. Increased resource efficiency can be achieved by means of a circular economy. Within such a circular economy, an intelligent life cycle extension of capital goods provides an important aspect to improve the resource efficiency. In this context, the term Adaptive Remanufacturing (AdR) implies intelligent decisions for the application of measures in a range from maintenance to remanufacturing to improve resource efficiency of capital goods. The idea of AdR is based on the research project *Adaptive Remanufacturing for Life Cycle Optimization of Capital Goods (ReLIFE)* [1]. As opposed to traditional maintenance strategies, which aim at maintaining availability and functionality, AdR ensures a predefined performance level of a sensor-monitored machine.

The provision of a guarantee for performance levels and the associated long-term productivity enables the development of innovative Business Models (BM) in the field of maintenance and remanufacturing. This paper presents a theoretical and methodological framework to support the translation of an intelligent maintenance strategy into an innovative BM. A

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profitable BM, based on the idea of AdR, should motivate manufacturers to design durable products and contribute to more sustainability.

Nomenclature

AdR	Adaptive Remanufacturing
BM	Business Models
CR	Contracted Remanufacturer
CM	Condition Monitoring
FAST	Function Analysis System Technique
IR	Independent Remanufacturer
LCC	Life Cycle Costing
LCA	Life Cycle Assessment
OEM	Original Equipment Manufacturer
OER	Original Equipment Remanufacturer
PSS	Product Service System
PdM	Predictive Maintenance
PsM	Prescriptive Maintenance
PO	Product-Oriented
RO	Result-Oriented
SV	Sustainable Value
UO	Use-Oriented

2. State of the Art

2.1. Intelligent Life Cycle Optimization

The application of technical systems requires an increasing availability, reliability and assurance. At the same time, industrial companies aspire to reduce maintenance and operating costs. To approach these goals, continuous monitoring and analysis of machine components is essential. Condition Monitoring (CM) is a sensor-based system, which intends to decrease downtimes and performance losses and aims to detect machine failures at an early stage. Moreover, it ensures controlling, planning and managing of production processes earlier and more reliably [2], [3]. CM can be divided into the three steps detection, diagnosis and prognosis [4]. Based on data of a fully functional machine health, the system recognizes deviations in case of failures and predicts further behavior with a certain probability [5].

A continuous monitoring of machine components enables approaches for intelligent maintenance strategies, e.g. Predictive Maintenance (PdM) and Prescriptive Maintenance (PsM). PdM describes a demand-oriented approach, which facilitates a precise planning of maintenance activities. The combination of efficient sensor technologies, high computing capacities and intelligent algorithms leads to a downtime prognosis and an optimal maintenance schedule before the failure occurs. Not only can such benefits be achieved in new products but even with retrofit strategies for goods already commissioned [6]. This has an effect of cost reductions and a higher resource efficiency of maintenance measures and machine availability [5], [7]. The highest complexity and maturity level of intelligent maintenance is known as PsM. Besides the prediction of future machine conditions, PsM comprises the automatic decision making and proposals of optimized maintenance measures. In addition to "What failure occur?", PsM aims to answer, "How should it be prevented?". Properties of this maintenance strategy are lower life cycle cost while upholding maximum availability and safety. Human interventions should be minimized [8]–[10].

Extending the idea of PsM, AdR comprises an intelligent and adaptive strategy for the planning and execution of maintenance and remanufacturing measures in an optimal time and scope under technical, economic and ecological aspects. Different to PsM and PdM, which attempt to prevent machine failure, AdR aims to ensure a predefined performance level of production resources under consideration of the technical progress. Through the preservation of a predefined performance level, AdR enables an increasing resource efficiency by extending the product life cycle. On this basis, the development of an innovative BM should motivate manufacturers, owners and operators to integrate this intelligent maintenance strategy into their company.

2.2. Business Model Development

A suitable methodology for the development and characterization of a BM is provided the *St. Gallen Business Model Navigator* by Gassmann et al [11]. The authors divide the BM into the four dimensions "Who?", "What?", "How?" and "Value?". The answers to these questions, in terms of customers, value proposition, value chain and revenue model represent the essential components of a business model. Moreover, the authors assume that 90 % of all new BM are based on 55 existing patterns. To achieve an innovation, existing models must be transferred into other branches, combined with each other or repeated in another sector of the company. The Navigator consists of the four steps Initiation, Ideation, Integration and Implementation.

The Business Model Canvas (BMC) offers a holistic visualization of a BM. The authors use a map to represent the key elements of a BM. Filling out the nine building blocks *Customer Segments, Value Proposition, Channels, Customer Relationship, Revenue Stream, Key Resources, Key Activities, Key Partnerships* and *Cost Structure* provides companies with a process for the development of a new BM [12].

2.3. Product Service System

Several articles in literature take the concept of Product-Service-System (PSS) as BM approach for remanufacturing as well as maintenance into account [13]–[18]. A PSS describes the shift from a pure product sale to a higher service-orientation within a framework of an increasing servitization. The aim is to combine products and services in such a way that an individual value can be created for potential consumers in a sustainable and economic manner. Instead of selling the product, the value creation focuses on product-integrated services. The customers are no longer the buyers of the product. Instead they receive dematerialized services and system solutions [19]–[21]. The most widely accepted categorization of PSS divides these into three types, based on the degree of service delivery and product ownership [18], [20], [22]:

- Product-Oriented (PO): In addition to a traditional product sale, the PSS provider offers services, e.g. take-back agreements, to guarantee product functionality and durability. The customer assumes ownership of the product.

- Use-Oriented (UO): Instead of selling the product, the PSS provider guarantees its usage and availability. Examples for an UO PSS are leasing, sharing, renting or pooling agreements. Thus, the ownership remains with the provider.
- Result-Oriented (RO): A RO PSS defines the highest degree of servitization. The main value is on services to fulfil individual customer needs. The customer receives a functional product result, output or capability instead of the physical product. The ownership remains with the provider, who is completely responsible for the product.

3. Methodological Framework

The aim is to provide a framework for the implementation of the innovative idea of AdR into an innovative BM. Based on the method of Barquet et al. [18] and BM approaches in the remanufacturing sector [13], [15], the BM development process consists of the four steps *Status Quo*, *Business Context*, *Value Architecture* und *Business Model Characteristics*. Especially the detailing of the *Value Architecture* with the pillars *Product Service System*, *Executive Actors* and *System Integration* provides an addition to the framework that support the adoption of an innovative maintenance strategy into service-oriented BMs.

Figure 1 below shows a summary of the proposed framework with tasks assigned to each step mentioned above as well as a proposal for suitable tools to use. The four steps and associated tools will be presented in more detail in the following sections of this paper.

3.1. Status Quo

Besides the technical concept of an innovative maintenance strategy, the Status Quo takes the current BM of the company, based on the respective capital good, into account. This can be compiled in a workshop by application of the Business Model Canvas [12]. A moderator guides the workshop participants through the nine building blocks. For each block, a period of time is defined to fill it with contents of the current BM.

From a technological perspective, it is important to identify and understand the functions that most contribute to customer value creation. One well-established tool to achieve this purpose is Function Analysis System Technique (FAST) [23]. In value engineering processes, FAST clearly maps the top-level functions (so-called *basic* functions) that provide benefits to customers, along with all sub-functions required to fulfil the basic functions. The description of *dependent functions* (DF) helps identifying suitable technical components to perform these functions.

This being said, employing FAST helps to trace the path for an AdR measure back to the customer function typically addressed in the value proposition block in the BMC. Thus, the uptake of the current BM as well as the analysis of production functionality of the respective capital good helps to understand the current situation in the company. The current BMC and FAST serve as input for subsequent steps.

3.2. Business Context

The Business Context concerns the initial situation of the company. Through the innovative approach of AdR, or rather the preservation of a predefined performance level of production resources, both the development of new BM or to evolve the current one are suitable options.

Therefore, an analysis of the current BM is necessary to examine if the current one can be adapted or a new one is needed [18]. For the classification and a better understanding of the Status Quo, existing BMs in form of the 55 patterns of the St. Gallen Business Model Navigator [11] are assigned to the current BM. For example, online distribution and trading can be assigned to the pattern E-commerce. As well as the sale of goods, this concerns the exchange of information and support services [11]. Afterwards, it must be examined which problems the current BM solves, whether the market situation has changed and if reinvention is worth the effort. Different circumstances can indicate that a change is necessary, e.g. a shift in the competition, low-end-disrupters, new findings regarding to customer needs [24] or an innovative maintenance strategy.

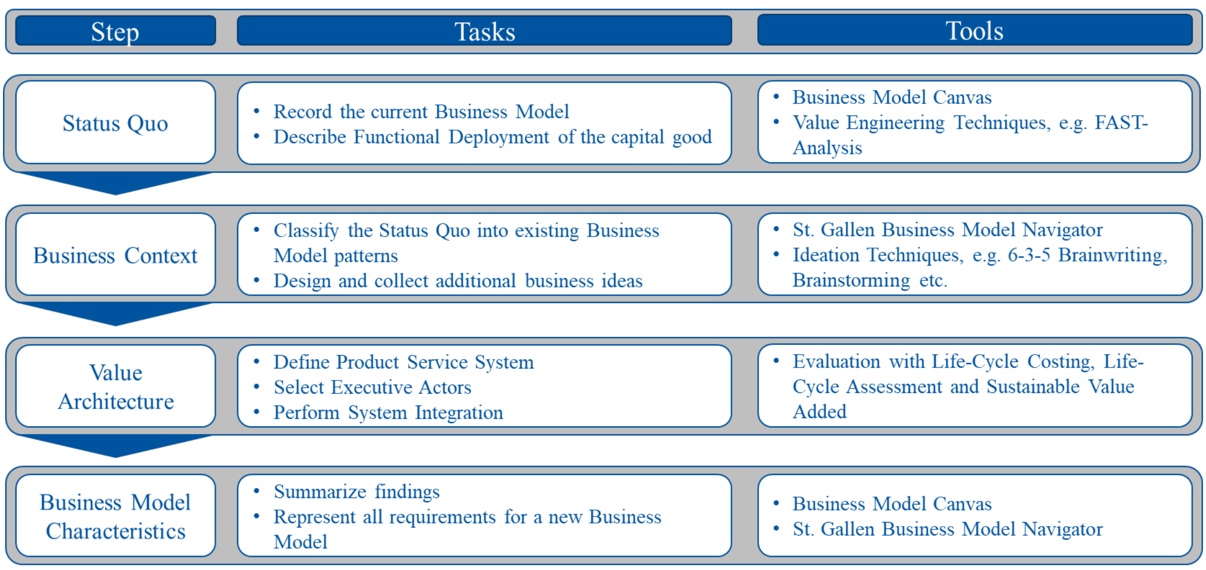

Figure 1: Graphical summary of the proposed methodological framework

To identify potential improvements of the current BM and to find ideas for new BM, ideation techniques, like 6-3-5 Brainwriting, can be used. This method is an alternative to brainstorming in form of a group session. It involves 6 participants, each of whom has to generate three ideas in 5 minutes. These ideas are written down on a worksheet and are further developed by the next participant. After 6 rounds, up to 118 ideas have been created [25]. These ideas are specified in the following Value Architecture.

3.3. Value Architecture

Based on approaches of BM in the remanufacturing sector following [13], [15], the Value Architecture comprises the three pillars *Product Service System*, *Executive Actors* and *System Integration*. This step represents the core of the BM. Especially the integration of a respective PSS type specifies the main character of the value creation.

In *Product Service Systems*, adding value can be achieved through providing extra services without being limited by availability or capability of physical products [26]. The most important question is whether the PSS provider, in this case the OEM, or the customer assumes the ownership of the capital good. To validate different PSS BM, a definition of the respective PSS type, with respect to AdR, is necessary. The identified functions from the Status Quo represent a specific benefit for potential customers. These functions are illustrated in a matrix in dependence of the PSS types to define different scenarios.

The *Executive Actors* refer mainly to the responsibility of maintenance and remanufacturing as well as recycling and disposal measures to implement the adaptive proposals. Besides the OEM as PSS provider, the customer and third-party providers are optional actors for the execution of the measures.

For example, the remanufacturing process can be performed by three different actors, namely the OEM or rather the Original Equipment Remanufacturer (OER), Contracted Remanufacturer (CR) and Independent Remanufacturer (IR). As OER, the company remanufactures their own products, which they receive e.g. by repurchase, end-of-lease contracts or through service centres. The remanufactured components are reused for new products or as spare parts. A CR works for other companies. The OEM is still owner of the component, but the remanufacturing process is in the responsibility of contracted partners. An IR has no or only little contact to the OEM and needs to buy or collect the cores for the process [13], [27].

Whether the customer is involved depends on the service degree of the BM and the kind of ownership of the capital good. Furthermore, measures to maintain functions or rather machine components can be excluded for the customer or third parties, as these should only be maintained by the OEM to protect intellectual property. Similarly, standard components, e.g. bearings or motors, can be defined, which should only be maintained by third parties or the customer.

The *System Integration* aims at integrating all components designed thus far to submit them to an evaluation process: The idea generation phase in 3.1 can yield a significant number of BM ideas, depending on the number of components or functions that are identified as highly relevant for remanufacturing (the number of functions is here denoted as N). These distinct BM proposals can be mapped to both the technical functions as identified in the FAST analysis as well as the three PSS types, thus spanning a $N x 3$ matrix. Results of the Executive Actor definition step are used to reduce the complexity of the system integration search space by X unfavourable options. For instance, for machine components critical to intellectual property, one might refrain from handing these over to the customer or an external re-manufacturer which excludes BMs pertinent to product-oriented PSS in favour of those where the OEM remains the proprietary.

These initial system integration steps reduce the grand total of 118 potential ideas down to $N x 3 - X$, provided that there are no more than 40 dependent functions. Nonetheless, this can amount to a substantial number of possible BM alternatives to inspect. In consequence, valuation tools are needed for the Value Architecture phase. To provide truly sustainable solutions via this methodological framework, the optimal BM should reflect both economic (revenue generation via extended life cycle and digital services) as well as ecological value added (via reduction or avoidance of environmental costs through AdR). Although it has been argued that achieving both economic and ecological goals may prove to be complex [28], we incorporate suitable valuation tools for both of these decision dimensions.

To tackle the economic perspective, we propose to use life cycle costing (LCC). LCC focuses on assessing all costs incurred during the life cycle of a product, i.e., from conceptualisation, manufacturing and operation to the end of its useful life [29]. LCC has been proven to be a useful tool in the context of PSS evaluation [30]. Furthermore, in an attempt to tackle the low proliferation of LCC in PSS research, [31] propose a method to support improvement of offerings by employing LCC. The key component of their revised method is to incorporate a function breakdown in a tree structure. This is in line with the FAST method presented above. However, concerning LCC stages, there is a lack of focus on the end-of-life stage and it is not clear how to approach the costing of refurbished or remanufactured products that get a prolonged life [32]. With AdR specifically focusing on life cycle prolongation, highlighting later-end-of-life functions and components can help in overcoming this downside.

For the ecological perspective, the tool Life Cycle Assessment (LCA) can be used. LCA is a popular tool to assess environmental impacts associated with a product's life cycle [33]. LCA has been the method of choice for PSS evaluation before. For instance, [34] propose to combine LCA and LCC to support the development of PSS, especially for high-energy consuming equipment. They establish LCA and LCC models through recognising the differences between PSS and traditional BM and mapping them to the six known PSS modes. Their approach clearly highlights the efficacy spread between environmental and economic performance, i.e. satisfying economic goals while jeopardizing the environmental dimension. Here, the importance bestowed upon each dimension lies in the hands of the Executive Actor as specified by the servitization degree and this the PSS mode.

In order to realize sustainable BM creation for PSS, we address this decision-making conundrum by including a third valuation method. [35] have proposed to adopt a product life cycle perspective in projects and to use the Sustainable Value (SV) concept in [36] to evaluate projects' sustainability performance. In its essence, the SV method relates a system's eco-efficiency (difference in measurable environmental indicators, such as CO2 emissions) to its economic performance. SV thus calculates the opportunity cost of performing better or worse in terms of sustainable performance compared to a suitable benchmark.

[35] argue that SV, although originally intended to compare company performance to the national economy benchmark, can be scaled to lower-level scopes of reference, too. In the context of AdR, we will use the SV method to estimate the impact of remanufacturing measures to enrichen the purely economic dimension of decision-making.

LCC, LCA and SV thus are in a tightly reciprocal relationship: LCC and LCA results for specific functions both feed into the SV computation. The SV result, in turn, allows for the valuated business model alternatives to be mapped to a portfolio of both economic efficiency and environmental efficiency. In consequence, this methodological trifecta provides indicators for standard revenue engineering as well as a method to monetize the decreased environmental damage associated with the AdR measures.

For the best rated BM, using the BM patterns from step 3.2, a new AdR-based Business Model Canvas is designed in the final step. Fig. 2 below graphically summarizes the flows of information and results between the various methodological components.

3.4. Business Model Characteristics

The last step of the methodological framework summarizes the findings with a new Business Model Canvas. The Canvas Map is used as a clearly arranged way to illustrate the findings of the development process. All requirements for the BM are represented within the nine building blocks.

The identified BM ensures an economic attractiveness of the AdR approach and thus offers companies an incentive to implement the resource-efficient maintenance strategy.

Moreover, the current application of the AdR concept in a German manufacturing company ensures the transfer of the methodological approach into the economic practice.

4. Conclusion and Outlook

The advent of intelligent sensorics in manufacturing paves the way for sophisticated maintenance strategies, such as AdR. Adopting such strategies is expected to have a significant positive effect on resource efficiency in the design, use and disposal of resource-intensive capital goods. The use of intelligent decisions for life cycle optimization further enables new AdR-based BMs. As literature specific to this type of BM is scarce, this paper provides a framework for the development of the theoretical and methodological foundations.

It consists of the four steps Status Quo, Business Context, Value Architecture and Business Model Characteristics, for which we have described relevant contents and defined a suitable methodological toolbox. Building upon functional decomposition via FAST, Product Service System considerations, Executive Actors selection, ideation techniques, LCC, LCA and SV added computations, the proposed framework can help to design a customer-centered AdR business model which is optimized for both economic and ecological performance.

Future research within the project *ReLIFE* will focus on a case-based validation of the proposed model using the example of air purification equipment in non-ferrous metal rolling plants. To validate the sensor-concept and the selection of maintenance and remanufacturing measures as part of the AdR concept, a physical demonstrator will be implemented in an air purification plant. In this context, the developed BM are used for a company-specific recommendation of the AdR measures.

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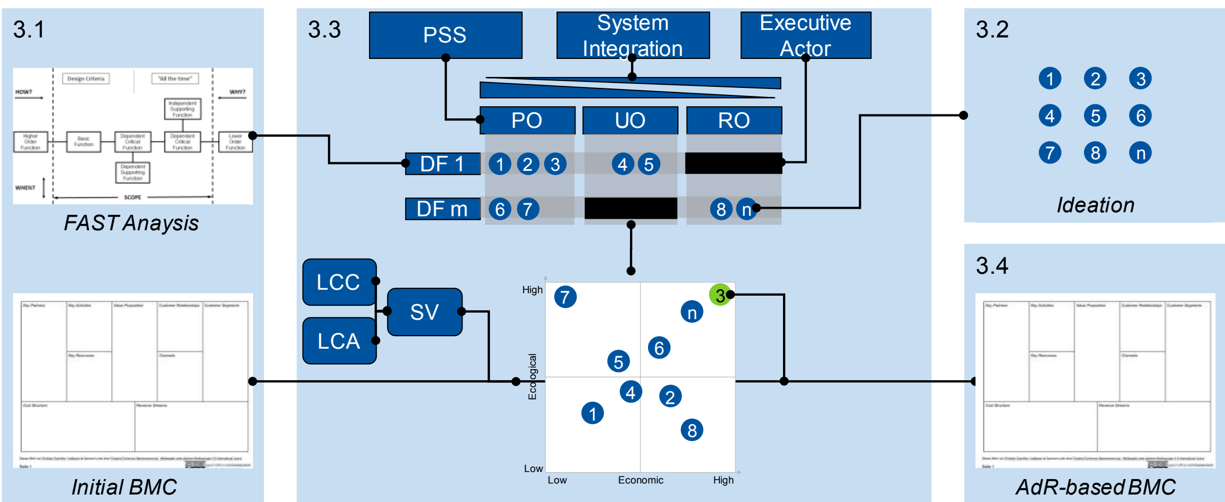

Figure 2: Schematics of the information flow inside the proposed methodology

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