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Procedia Computer Science 232 (2024) 2240–2248

Procedia Computer Science

www.elsevier.com/locate/procedia

5th International Conference on Industry 4.0 and Smart Manufacturing

Data driven value creation in industrial services including remanufacturing

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Abstract

In the era of twin transition companies face complex challenges. Economical resource usage and efficiency are particularly important in the manufacturing sector. Product-service systems are seen a promising solution that can meet the expectations regarding efficiency in a sustainable way. However, there is a huge potential regarding the evaluation of sustainable value creation. The paper focuses on the value creation process in product-service systems including offers with remanufactured products.

Against this background, the goal of this paper is to describe how data driven industrial services can create sustainable value in the meaning of the triple bottom line. Based on previous work, a quantitative model for the assessment and optimization of this value creation is extended to include additional remanufacturing strategies. The value optimization model integrates the different perspectives of provider, custumer and society. The numerical evaluation of this model for a specific application case shows that economic and ecological value creation can be jointly achieved and optimized, and which service arrangements lead to this optimization.

Keywords: product-service system; remanufacturing; sustainable value creation; data driven decision making

1. Introduction

Achieving the European Commission's ambitious objective of a net-zero carbon Europe by 2050 requires radical changes in the classical business processes. Therefore companies are facing interdisciplinary challenges in the era of twin transition – meaning the green and digital transition in the same time. [1] The digital transition is an ongoing process involving the industry 4.0 originated in 2011 in Germany. Since that time industrial companies all over the world discovered several benefits that might be realised with digital technologies, such as increased efficiency and

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10.1016/j.procs.2024.02.043

quality, reduced lead times and costs. The new and emerging phase of the digital transition is industry 5.0 with a human-centred focus. The European Commission proposed that Industry 5.0 represents a new vision for the industry, redefining the role and functionality of value chains, business models, and digital transformation in the complex business environment dominated by the climate crisis and social tensions. [2] However, average businesses, particularly SMEs, still struggle with Industry 4.0 technologies. [3] The digital transition happens on its own [1], because the advantages for industrial companies are straightforward. Becoming green has to be forced and necessitates the active participation of politics, therefore the terminology green transformation might be more suitable. One of the biggest barriers in the twin transition might be the costs associated with the changes. Collaborative and data driven business models are seen as one of the most important enabling factors for the twin transition [1].

Quantitative models dealing with value creation can be a suitable methodology for supporting the twin transition. Numerical approaches facilitate not just the definition of action plans but might support the execution and tracking of the changes required. The papers is focusing on the value creation with sustainable servitization including remanufacturing. After presenting the relevant state-of-the art and the research question of the paper in section 2, value creation is investigated in section 3 in an industrial use case from the perspectives of remanufacturer and custormer considering the ecological aspects of their business.

2. State of the Art

2.1. Sustainable value

Sustainability is a multifaceted concept that has been extensively researched in various contexts. In academia, the concept of sustainability is often unified by an investigation regarding three dimensions: social, economic, and environmental, and has also been integrated into the context of sustainable value [4]. The social dimension focuses on meeting human needs and includes elements such as trust, shared meaning, diversity, learning capacity, and self-organization [4, 5, 6]. The economic dimension focuses on addressing the rational limits to economic growth through competitive, collaborative, inclusive, and dynamic economic systems [4]. The protection and conservation of natural ecosystem resources characterize the environmental dimension [4, 7].

The most common definition of sustainable value is proposed by Hart and Milstein [8] in the often-quoted "Creating sustainable value". They defined sustainable value as the implementation of strategies and practices that contribute to a more sustainable world while simultaneously generating value for shareholders. Their framework encompasses two key dimensions: temporal and spatial. The combination of these vertical (temporal) and horizontal (spatial) axes establishes a framework comprising four strategic dimensions, each accompanied by its associated sustainability drivers. These dimensions are as follows [8]:

- *Pollution prevention:* This dimension deals with the prevention of the environmental consequences of industrialization.
- *Product stewardship:* It considers the proliferation and interconnectedness of products with civil society and stakeholders.
- *Clean technology:* This dimension focuses on emerging and adopting new environmentally friendly technologies.
- *Sustainability vision:* It involves a strategic orientation to mitigate the negative impacts of population growth, poverty, and inequality.

According to Hart and Milstein [8], equal importance is attributed to all four quadrants, along with the associated strategies and drivers. However, it is crucial to acknowledge that this model was introduced two decades ago, specifically in 2003. Since then, the sustainability agenda has undergone significant transformations [9].

Current research from Cardoni et al. [9] has shown that strategic drivers for sustainability have moved from purely environmental, as in Hart and Milstein's concept. Globalization, economic fluctuations, knowledge innovations, etc., are becoming as important as green technologies and carbon reduction policies. Therefore, Cardoni et al. have evolved Hart and Milstein's concept into an integrated view of Sustainable Value Management, see Fig. 1. As the authors describe, sustainable strategy and innovation determine the future value the company will create and deliver for its stakeholders at the business model level [9].

2.2. Service value creation

By moving from a products to a service business, manufacturing companies can achieve several economic benefits such as additional revenue and increased customer loyalty [10]. This is especially relevant in saturated and commoditized markets with high competitive pressure, because customers get more benefits of improved functionality, performance, and productivity [11]. By various forms of machine- or people-based services, customers get values in personal or business oriented dimension [12]. Against this background, the relative importance of the value created by services is increasing as opposed to the value crated by goods [13], which leads to the concept of the product-service-systems (PSS) [14]. Mutual value is co-created in ecosystems of providers, customers, and other actors in the ecosystem [15]. The transformation from products to services is further enabeld and intensified by the shift to digital services [16]. With smart, connected products, providers can move up a value hierarchy, which typically applies when providing maintenance services [11]: (1) pure monitoring of a process or an equipment, (2) controlling its performance by introducing a feedback loop, (3) optimizing a target function such as, e.g., maximizing the output or minimizing costs or breakdwon durations, (4) autonomous systems that integrate contextual data for full self-control [17]. By utilizing the data from smart, connected products to control and optimize the equipment and processes, providers are enabled to offer output-oriented services (also called smart services [18]), i.e., promise an output performance (e.g., number of units produced per time) at a fixed price [11], which reduces the operational risks of the customer and gives the provider the chance to increase margins by achieving operational excellence. As a downside, output-oriented services represent a major challenge for the providers, as there is a transfer of operational risks from the customer to the provider [11]. Therefore, data and analytics of operational processes become a key resource for managing these risks [16]. A model for quantitatively assessing the economic value creation by data-driven services is developed and described in [19].

2.3. Sustainalbe servitization

According to [20], PSS enable a provider to create higher economic value and to improve its innovation potential by an increased customer intimacy. Alongside with these effects, the application of PSS leads to improved resource and energy efficiency and thus digital servitization has a positive sustainable impact (for background and examples

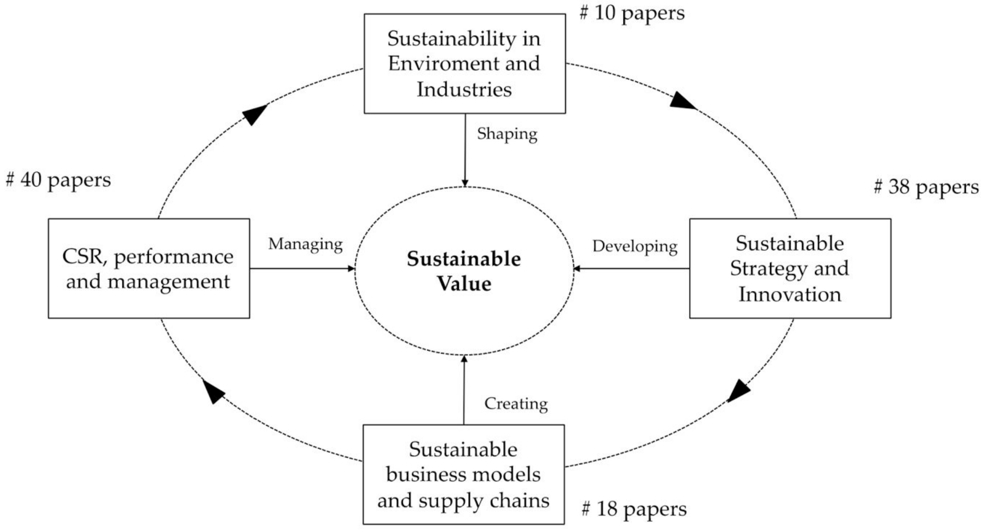

Fig. 1. Integrated view of sustainable value management [9]

see [18]). PSS can create sustainable value by services for improving the performance achieved at a given resource input and by improved maintenance schemes leading to improved energy and material utilization. The output-oriented services described above are ideally suited to achieve these goals as the resource costs are incurred on the provider side while the customer pays a price which is independent of these costs. Thus, the provider has an incentive to lower the resource consumption in order to increase its margin [21, 22]. This leads to various forms of circular economy (CE) practices leading to regenerative and restorative industrial systems [23], which in their entirety support the triple bottom line goals (economic, environmental, and social performance, with the latter not being in the focus of this paper) [24]. Services for end-of-life practices, such as reduce, resuse, or recycle [25] or long-term upgradeability [26] support the concept of circular economy. In [27], the quantitative economic model given in [19] is extended to incorporate the ecological benefit coming along the economic ones. For instance, if the economic value of remote service consists in cost savings by an extended customer lifetime with an industrial equipment, its ecological benefit is given by the higher utilization of the material resources for producing the desired output.

2.4. Remanufacturing

In the circular economy literature, options for extending product life are discussed under several terms such as reprocessing, reuse, refurbishment and remanufacturing. The definitions of these terms are often not clearly separable, which means that they often overlap in meaning. In the specific case of production planning, however, it is the terms refurbishment and remanufacturing that are most frequently mentioned [28]. In refurbishment, waste is collected, inspected, repaired, cleaned and resold as used, functional products without being dismantled. Meanwhile, remanufacturing is usually defined as the recovery of used products, which involves the collection, repair, disassembly and replacement of worn-out components to bring the products back to the quality level of newly manufactured products. The main feature of remanufacturing is the disassembly of the entire product, which is the first and most important step in the markets for spare parts or remanufacturing operations in production [28].

To illustrate how CE enhances the linear production approach, it is important to understand how the interaction between backward and forward flows affects the production planning process. This interference includes i) the planning of the recovery and procurement of raw materials; ii) the planning of the production activities necessary to convert the input materials into finished products to meet customer demand, considering both remanufactured and new products; and iii) the reverse flows, which affect the decision-making levels of the production systems to varying degrees [28].

In the following, the individual process steps of the remanufacturing process, in which the old parts are regenerated, are represented:

- *Disassembly:* In disassembly, the uncleaned old part is disassembled into individual parts or components and presorted according to reusability, whereby wearing parts such as seals and bearings are sorted out and later replaced by new parts in reconditioning or reassembly [29].
- *Cleaning:* All components are cleaned chemically and/or mechanically, and this manufacturing step is most often a bottleneck because machines with fixed cycle times and limited capacity are used [29].
- *Testing and sorting:* During inspection, components are non-destructively checked for damage and for reusability. If a component is worn or damaged, it is either sent to the component remanufacturing step or disposed of [30].
- *Component reconditioning:* In component reconditioning (in short ”reconditioning”), mainly machining processes are used to bring the components back to a quality level equal to the new part [29].
- *Reassembly:* In reassembly, the replacement products or regenerates are produced using new parts. This manufacturing step deviates the least from new production, but tends to have a higher manual share [31].

2.5. Research question

Given this review of the state of the art, it becomes apparent that there is a broad scope of existing models considering the diverse impacts of economic and ecological value creation by smart services. A limitation of the work discussed in [19] is that it discusses the ecological value creation on a quite rough level and specifically does not consider in detail the remanufacturing strategies at the end of the lifecycle, which have particularly high potential for ecological value.

Therefore, the research question addressed by this paper is: *How can remanufacturing strategies be integrated in existing quantitative models for economic and ecological value creation and how do they impact the value creation.*

3. Use Case

3.1. Description

In a remanufacturing plant, cylinderheads extracted from exhausted castings are retrieved once they've reached the end of their operational lifespan. Following the steps of disassembly, precision machining, thorough cleaning, and meticulous reassembly, these cylinder heads are then sent back to the customer. It's worth noting that this describED OEM has the opportunity to remanufacture these cylinder heads up to three times before they are ultimately discarded. Uncertainty about the timing, quality and reusability of the returned components and assemblies creates scheduling problems for the remanufacturer. The trade-offs for the OEM are increased inventory, increased production capacity available at short notice. These uncertainties result in financial losses and production waste, as well as bottlenecks in the supply of materials for gas engine assembly. Being able to offer competitive and customized services for their customers makes it necessary to investigate the value creation within remanufacturing. One possible solution for handling the typical uncertainties might be the digital product passport initiated by the European Commission [32]. In the plant itself, cylinder heads can pass through three different lines, depending on size and series, with a total of eleven different variants in constant circulation.

3.2. Model description

[27] introduce a model for quantitatively modelling the value creation along four lifecycle phases, as shown in Fig. 2.

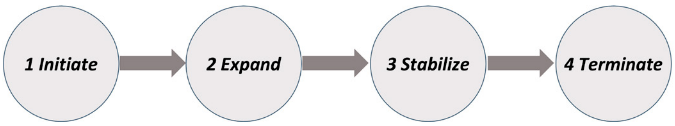

Fig. 2. Phases of the customer lifecycle (based on [19])

The four phases represent: (1) "Initiate": the pre-sales including services for finding the optimal solution for a customer, e.g., convincing the customer of a remanufactured cylinder head, (2) "Expand": the customer familiarizing with the new product or service and improving the performance over time, supported by services, e.g., the customer starting to apply the cylinder head (less relevant in this study) (3) "Stabilize": the cylinder head is operated over a longer duration (typically many years in industrial contexts), i.e., mutual value is created supported by services such as consulting or maintenance, (4) "Terminate & win-back": the customer gives up or replaces the cylinder head, whereby the usage time (i.e., the lifecycle) can be extended or the product, components or material can be re-used (or remanufactured or refurbished or recycled).

Alongside these phases, economic values for the provider and the customer are calculated by

$$V_P = \sum_{i=1}^{4} V_{P,i} \quad \text{and} \quad V_C = \frac{1}{CLT} \sum_{i=1}^{4} V_{C,i} \tag{1}$$

with V_P the value for the provider and $V_{P,i}$ the value created in phase i of the lifecycle. The same way, V_C and $V_{C,i}$ for the customer. V_C is normalized by the customer lifetime for a perspective of operational costs per time period (explanation see [19]).

As introduced in [27], the ecological value creation is calculated by the impact of the services on the "CO2 equivalent", CO_2e [33].

$$V_{Eco} = \frac{1}{CLT} \sum V_{Eco,i} \tag{2}$$

[27] suggest that the benefits and impacts of the smart services are described by different intensity levels of smart services in the different phases of the lifecycle. These levels for the particular use case are described in Table 1 in the second column. Against the background of the research question addressed in this paper and in extension to [27], special consideration is given to the additional impact of the remanufacturing strategies, which is described in the third column of Table 1.

Table 1. Service levels and their impact in the four phases of lifecycle. Note: service levels build cumulatively on each other.

Lifecycle phase	Smart service level impacting $V_{P,i}$, $V_{C,i}$, $V_{Eco,i}$	Additional impact of remanufacturing
Initiate	3. use remanufactured product, 2. targeted offerings, 1. no targeted offerings (reducing material use, costs of customer acquisition, and travelling)	saving costs and material usage for remanufacturer, reducing price for customer
Expand	2. targeted training, 1. no targeted training (higher performance for the customer, less material waste)	no additional impact
Stabilize	5. performance optimization, 4. condition based maintenance, 3. remote service, 2. monitoring, 1. standard (higher performance for the customer, less material waste, less travelling)	no additional impact
Terminate	4. retention, remanufacturing, 3. retention, no remanufacturing, 2. no retention, remanufacturing, 1. no retention, no remanufacturing (higher customer lifetime value, lower costs for customer, more output per material)	less material waste with remanufacturing, higher costs for remanufacturing than for disposal

3.3. Results

The model described in section 3.2 is implemented in a numerical model programmed in Python. The parameter values are chosen as described in [19] and [27] and coming from [32]. The parameters for the additional impact of remanufacturing introduced in this paper are shown in Table 2.

In the initiate phase, remanufacturing has an impact of three different parameters. The probability that an offering will be accepted is increased because the customer already knows and trusts the provider and makes a conscious decision in favor of a remanufactured product, on one hand because of the advantage of the price, but on the other hand also thanks to the experience that remanufactured products have an equivalent quality to new ones. There is also an advantage for the provider as a remanufactured product generates lower costs than a new one.

Table 2. The table shows which parameters are improved by remanufacturing in the initiate and terminate phases.

Phase	Improvement with remanufacturing	Value no remanufacutring	Value remanufacturing
Initiate	Higher acceptance rate for offerings	0.2 (probability)	0.3 (probability)
	Base fee reduction	7000 (fee)	5000 (fee)
	Manufacturing price product	10000 (price)	2000 (price)
Terminate	Winback probability	0.2 (probability)	0.25 (probability)

The advantage which is generated in the terminate phase is the increased probability that the customer extends the lifetime. The reason for this is that the customer has had good experiences with the remanufactured product and recognizes its advantages of longer usage period, which is also more sustainable. Remanufacturing of the product after the terminate phase also saves new material, which has a positive effect on V_{Eco} and reduces the cost of disposal for V_P.

The economic value creation per lifecycle phase is reflected by applying the schemes and the numerical example described in [19], [27] and enhanced by the detailed model for the remanufacturing as explained above. In order to assess all possible combinations of the service levels described in Table 1, the numerical model evaluates all combinatorial arrangements of the different combinations of services along the lifecycle, which results in 120 (= $3 \cdot 2 \cdot 5 \cdot 4$) different value creation schemes. The resulting values V_P, V_C, and V_{Eco} are shown in the three-dimensional scatter plot in Fig. 3.

As discussed in [19] and [27], optimum service arrangements are on the so-called Pareto front. These points are indicated by red bullets in the scatter plot. On the Pareto front, improving one value component (e.g., V_C) can only be achieved by worsening the other value dimensions. Therefore, the Pareto front represents the optimal sub-set of possible service combinations. All together 28 Pareto points were identified in the use case – a few of them are shown in Table 3.

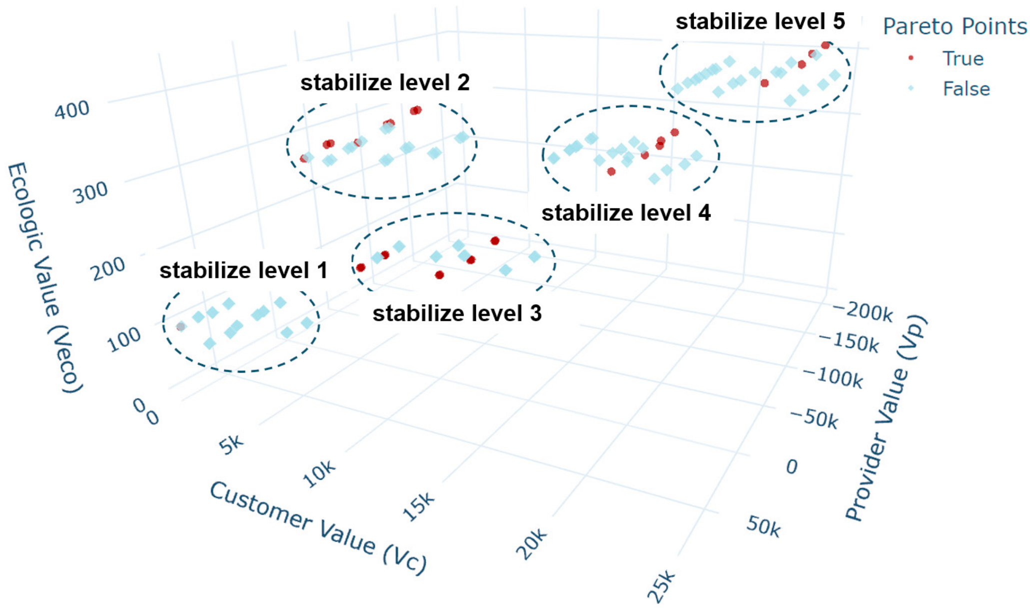

Fig. 3. The figure shows the result from the simulation of the different service combinations from Table 1 with the pareto front in red and the rest of the results in blue. The clusters indicated by dotted lines are described by their common service leveln in phase 3 ”Stabilize”.

Interestingly, there are clusters of points with similar value creation which are defined by the service level in phase 3 ”Stabilize”, as indicated in Fig. 3. It becomes obvious that value creation for the customer V_C is increased when the service level in phase 3 ”Stabilize” gets higher. This is not surprising, as this phase lasts potentially many years for industrial equipment and the customer largely benefits from the additionally services provided. As already discussed in [19], this goes along with a reduction of the value captured by the provider V_P, which reflects that the provider is not able to recover the higher efforts for providing the advanced services by sufficiently higher service fees in the given specific example. However, as discussed in [27], higher value for the customer is highly correlated with higher ecological value. This is explained by the fact that creating more output per resource (time, material, money) for the customer implicitly also reduces the ecological impact.

Considering the clusters in Fig. 3, the two clusters ”stabilize level 2” and ”stabilize level 3” can be considered the most relevant ones. They create reasonably high value for the customer and capture positive value for the provider

Table 3. Points of the Pareto front – examples for the clusters "stabilize level 2" and "stabilize level 3". The quadruple denotes the service arrangement in the four phases according to Table 1.

ID	Cluster	Quadrupel
1	Stabilize 2	2-2-2-4
2	Stabilize 3	2-1-3-4
3	Stabilize 3	2-2-3-4

while simultaneously generating a good ecological impact. Focusing on the Pareto optimal points in these two clusters shows that they are characterized by a higher service level in phase "4 Terminate". In particular, points in the cluster "stabilize level 2" have the highest service level in phase 4, i.e., remanufacturing and retention activated, which creates higher customer lifetime value and substantially reduces material waste at the same time (see also Table 3). This analysis makes apparent that in the given setting of the use case, the service constellation in the lifecycle phase "stabilize" with its long duration have the highest impact on the ecological value creation (see the increasing order of clusters in Fig. 3). These services can outperform the service selection of phase "terminate". Nevertheless, inside each cluster, the service optimum ecological value is achieved when remanufacturing is applied in "terminate". Therefore, we can conclude that the remanufacturing services are relevant, but have second priority compared to services for ecological value creation in phase "stabilize".

4. Discussion and Future Research Agenda

The study discussed in this paper made clear that data driven and sustainable value creation, which is primarily intended to create economic value for the diverse actors of a business ecosystem, has a high and yet untapped potential for creating ecological value. This potential is well known but underutilized because it is not sufficiently clear to companies how it can be measured and whether it could compromise economic potential. The modelling approach shown in this paper and its evaluation at the numerical example show that there is a way for the joint optimization of economic and ecological value creation. If the setting of circular services is adequately chosen, ecological value creation can be achieved while keeping up the economic one, as it was shown at the sample cluster "stabilize level 2" in Fig. 3. Referring to the research question, we can conclude that remanufacturing strategies could be integrated in the quantitative model and the paper showed how this was achieved. The evaluation of the model at the given example showed, however, that for equipment with long use phases (long phase "Stabilize"), the ecological value creation by the maintenance services in phase "Stabilize" can outperform the value creation by remanufacturing services in the phase "terminate". However, this statement cannot be generalized and requires further research.

The model discussed here, however, does not yet include social value creation in a quantitative way. Against the perspective of the triple bottom line, smart, industrial services can potentially create social value, too. Future work will include this component and extend the optimization scope accordingly. Moreover, the ecological and social value components might be extended and might consider several additional sustainability aspects such as circularity rate, fair working conditions.

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