Aligning remanufacturing in comparison to recirculation processes

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Abstract

Remanufacturing is a value retention process (VRP), along with direct reuse, repair, and comprehensive refurbishment, which prepares the used product for new uses by controlling and recapturing its value through several industrial operations. Remanufacturing possesses significant financial, environmental, and societal opportunities, and some manufacturers tend to challenge their business models, production systems, products, logistics, and customer management to comply with a circular economy (CE).

However, remanufacturing is sometimes undervalued and is ranked low, compared to other VRPs, among the recirculation processes (after-use-phase processes that bring and keep used products, their parts or material in a closed material loop through reuse, recycling, downcycling, and upcycling). The main reason for this is the greater number of resources required and fewer benefits provided compared to direct product reuse and repair. This paper studies a remanufacturer using different VRPs to satisfy customer needs and to better balance an incoming core (used product and its part) quality and the demanded product quality.

The aim of this paper is to define remanufacturing value and better align remanufacturing in comparison to other recirculation processes. The data was collected through a literature study and interviews with an EEE remanufacturer to fulfill the aim of this paper.The literature study covered the previous knowledge on remanufacturing, VRPs and recirculation processes. The interviews with an EEE remanufacturer provided valuable input to the scope of the VRPs performed by a single remanufacturer.

Lean approaches the remanufacturing value from a customer perspective shifting the paradigm of VRP, where remanufacturing is ranked low. Remanufacturing tends to demand greater resources to save the product value and implies greater product intervention. However, the output quality assured with a longer warranty, new product identity and prolonged (doubled or tripled) product use phase overcomes the benefits associated with the other VRPs, when customer value is in focus. The analysis of the remanufacturing value in comparison to other recirculation processes elevates remanufacturing in a recirculation taxonomy for technical products. The assessment of social, environmental, and economic benefits with remanufacturing compliments the findings. The result of the study lays the foundation for the development of the “9R taxonomy” – a framework on recirculation processes for technical products, where six VRPs can be handled by a remanufacturer.

Keywords: circular economy; lean improvement strategy; recirculation process; value retention process; 9R taxonomy; customer value.

1. Introduction

A circular economy claims prolonged product use through material and product recirculation, implying controlled and recaptured product value, after the product attains its end-of-use phase (Brennan et al., 2015; Murray et al., 2017) (see also Fig. 1). To comply with the circular innovations in the business model, product design, products, retail, industrial symbiosis, logistics, quality assurance and customer management (for details, see Gelbmann and Hammerl, 2015; Bocken et al., 2016; Stewart and Niero, 2018; Guldmann and Huulgaard, 2020), many manufacturers investigate their opportunity to retain the value of a used product. While some industrial sectors, such as automotive, heavy-duty and off-road (HDOR) equipment, and machinery, tend to adopt remanufacturing better than others (Parker et al., 2015), most used technical products never receive a second life through remanufacturing (Kurilova-Palisaitiene et al., 2020).

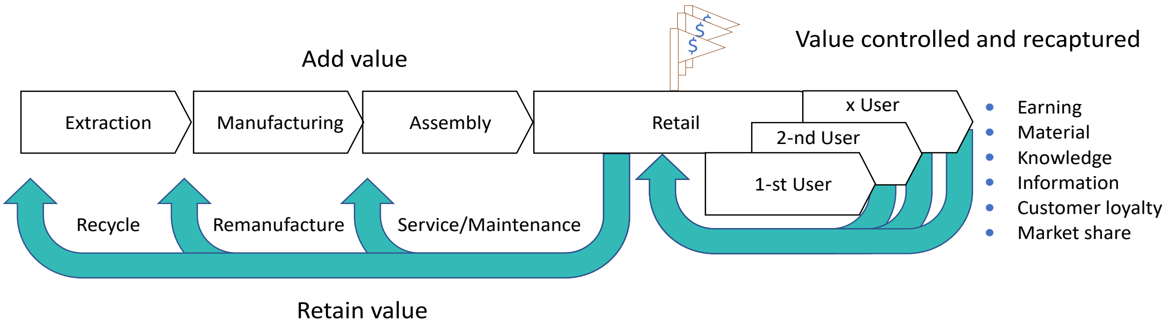

Figure 1: Circular system for technical products with controlled and recaptured product value through recirculation: used product collection, service/maintenance, remanufacturing and recycling (Kurilova-Palisaitiene et al., 2020, inspired by Fischer and Achterberg, 2016).

Remanufacturing is a value retention process (VRP), along with direct reuse, repair, and comprehensive refurbishment, which prepares the used product for new uses by controlling and recapturing its value through several industrial operations (Nasr and Russel 2018; Kurilova-Palisaitiene et al., 2020). Remanufacturing possesses significant financial, environmental, and societal opportunities; it helps to reduce the demand for new materials, compared to a newly manufactured product, up to 98%. Due to resource conservation, up to 90% of energy could be saved compared to new product manufacturing. Further, CO^2 emissions could be reduced by 53% when remanufacturing is chosen instead of new product manufacturing (Nasr and Russel, 2018; APRA Europe and ReMaTec, 2019).

Nevertheless, regarding the opportunities with remanufacturing, the majority of industries maintain linear material and information flows. More support is needed to enhance the remanufacturization (a shift towards remanufacturing) of the manufacturing industry. It is important to investigate the value of remanufacturing from a customer perspective compared to other VRPs.

Lean is an improvement strategy that can boost remanufacturing value and motivate other industries to adopt remanufacturing. By illuminating customer demand, lean can help remanufacturers to define the customer value of a remanufactured product.

The **aim** of this paper is to define remanufacturing value and better align remanufacturing in comparison to other material and product recirculation processes. Lean improvement strategy is utilized to define the remanufacturing value to fulfill the aim of this paper.

2. Lean improvement strategy

Lean production (or simply lean), originating from the Toyota Production System (TPS), is one possible improvement strategy to increase customer satisfaction. According to Pettersen (2009), lean is ruled by a philosophy of continuous improvement towards the creation of value for customers. Value designates what the customer is asking for (Ohno, 1988). Therefore, value generation is a pure aim of lean (Ahlstrom, 1997).

Lean was originally used to boost manufacturers' performance (Womack et al., 2007, Fullerton et al., 2003) but has spread to other industries, including service ones. Lean service and, in particular, lean sales shed light on a careful customer approach towards consumption. Lean in sales follows the philosophy of "less is more" (for details, see Womack and Jones, 2003; Liker, 2004; Morgan and Liker, 2006), appealing for the benefits of a rational choice and avoiding unnecessary impulsive consumption.

The lean improvement strategy, and in particularly its approach to emphasize customer's value of a remanufactured product is used to define the right remanufacturing level. Therefore, in this paper, the level of remanufacturing (the amount and intensity of operations during the remanufacturing process and the need for resources) is dependent on customer demand.

3. Benefits associated with remanufacturing

There are numerous benefits that a company can achieve by applying remanufacturing to its products. In this paper, the benefits associated with remanufacturing originate from the notion of a triple bottom line (TBL), where the economic, environmental, and social benefits are three declared elements of a circular economy (Elkington and Rowlands, 1999).

Economic benefits are one of the most important benefits associated with remanufacturing. Remanufacturing can bring additional profit since it can enlarge a business segment and increase sales volume (Kovach et al., 2018; APRA Europe and ReMaTec, 2019). Apart from the economic, other benefits are environmental (Sundin and Lee, 2011) and social (Sundin et al., 2016). Regarding the environmental benefits, the reduction of CO^2 emissions, material use, water use and energy use are the most typical (Kalverkamp, 2018). In particular, closing the loop for scarce and hazardous materials is environmentally beneficial (Sundin and Lee, 2011). According to a report by Nasr and Russel (2018), remanufacturing can contribute to the reduction of CO^2 emissions and new material requirements by up to 99% in some sectors compared to new product manufacturing and double or even triple the expected product use phase. APRA Europe and ReMaTec (2019) emphasize savings of up to 85% on raw material, 55% on energy and 79% on CO^2 emissions compared with new product manufacturing.

Social benefits of remanufacturing are the creation of new jobs in the local community (observed by a majority of remanufacturers at www.remanufacturing.eu) and greater access to the product through reduced product price for the customers with a lower income (Wang et al., 2015; Sundin et al., 2016).

Another approach to estimating the potential benefits of remanufacturing is studied by Östlin. et al. (2008). Besides remanufacturing driving profit and helping the environment, Östlin et al. (2008) identified a policy domain where the after-market segment can gain additional benefits from preempting regulations, brand protection, and feedback to design.

4. Material and product recirculation processes

Material and product recirculation covers the processes at the end-of-use phase, starting with material recovery and then product part or whole product preparation for reuse. Remanufacturing is one of the VRPs, together with reuse (direct reuse), repair, and refurbish (comprehensive refurbishment) (Potting et al., 2017; Nasr and Russel, 2018; Henry et al., 2020). However, these four VRPs are often seen as separate processes, valid for specific industries or products (see Nasr and Russel, 2018). In some cases, remanufacturing is ranked lowest of four, close to linear economy and next to recycling (see Nasr and Russel, 2018). The reason for such a low ranking is based on the greater resources needed to remanufacture a product and a lower level of benefits, such as savings in energy and material compared to providing direct product reuse, repair or comprehensive refurbishment (Potting et al., 2017; Nasr and Russel, 2018). However, this approach neglects the fact that remanufacturing is the process that considerably prolongs the product use phase (by double or triple for some products) compared to other VRPs (see Nasr and Russel, 2018), and in the long-term remanufacturing can become a leader in socio-economic and environmental benefits.

While some researchers indicate that repair and refurbishment can save even more resources and energy than remanufacturing (Potting et al., 2017), this research paper takes a position that both repair and refurbishment are the value retain operations under recirculation processes and can be performed by a remanufacturer, considering that the level of VRP is defined by customer demand (see Section 2).

The material and product recirculation taxonomy (later called the 9R taxonomy) is developed and shown in Figure 2 to reflect a broad scope of operations under the remanufacturing process.The 9R taxonomy unites nine material recovery, product part or whole product preparation for reuse processes: (1) recover, (2) recycle, (3) reuse, (4) refresh, (5) repair, (6) recondition, (7) refurbish, (8) remanufacture and (9) repurpose, where six VRPs (nr. 3-8) can take place during a remanufacturing process. The 9R taxonomy takes a broader perspective and includes operations that border VRP (nr. 1 and 2, and 9 in Fig. 2) and have a more detailed approach to VRP, elevating refresh and recondition as a part of the VRPs. This is to better define the level and intensity of the operations required during the remanufacturing process (see Section 2).

The material recovery (see Fig. 2) processes bring the used product to the material and energy level, losing the product identity. "Product or its part recirculation", or extended VRPs, denote that the product purpose is the same as an original one, while "repurposing" implies a different product application area. By investing the resources and increasing the level of intervention regarding the core, the value of the original product is saved. The product warranty is typically provided after VRPs; however, the conditions vary dramatically. The more intervention to the product and the greater the resources invested in saving the value, the longer the warranty. While material recovery does not maintain product identity, the product keeps its identity, marking after VRPs nr. 3-5, and gains a neutral identity after reconditioning, refurbishing, and remanufacturing, with some exceptions. The remanufactured product's physical outlook and performance correspond to as "good as new" or better (with upgrade), implying a new product identity and product number in many cases. The output quality is higher in VRPs of refurbishment and remanufacturing, while it remains the same or less in the other

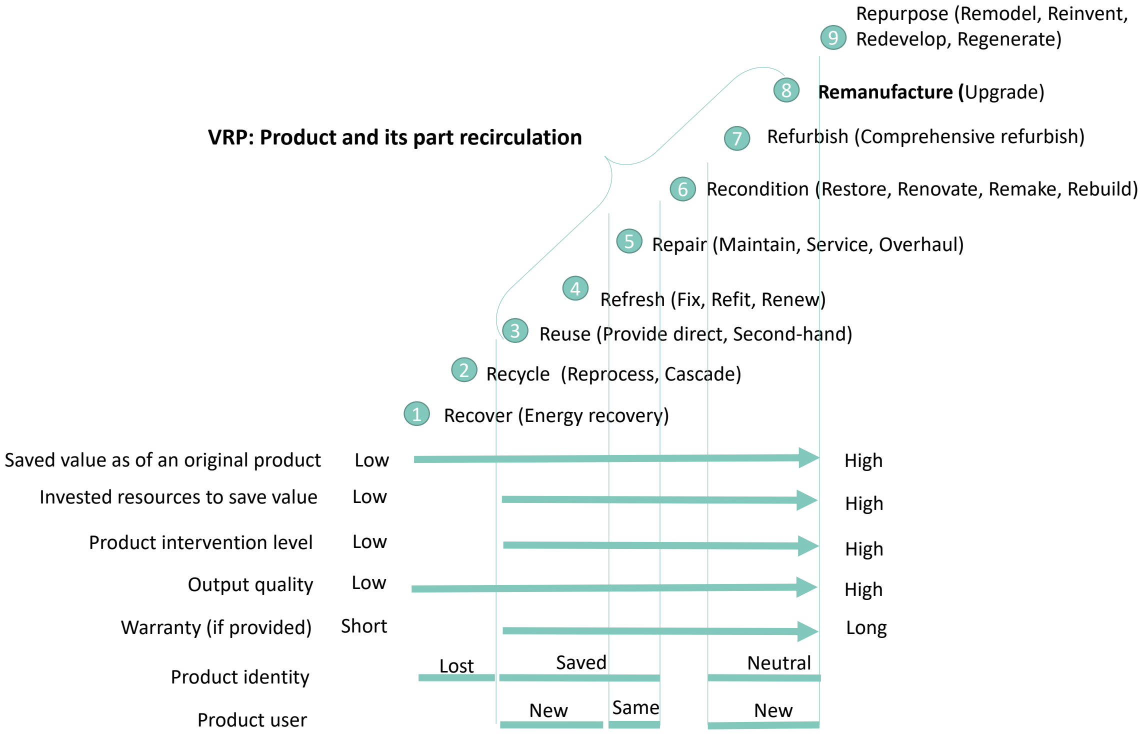

Figure 2: 9R taxonomy, aligning material and product recirculation processes according to the invested resources to save value, product intervention level, output quality, warranty length, product identity, and product user.

cases. While a new user is typical for the majority of VRPs, the same user tends to remain after product repair (but also some other VRPs in certain cases).

Definitions of the 9R taxonomy are partly adapted from Brennan et al. (2015), Ghisellini et al. (2016), King et al. (2006), Kirchherr et al. (2017), Potting et al. (2017), Nasr and Russel (2018), and Henry et al. (2020):

1. **Recovery** of the product takes the used product for energy generation.
2. **Recycling** brings the product to the material level. The material is reprocessed to generate new materials or cascaded further to other industries that can utilize the used product or its parts, like an industrial symbiosis.
3. By providing direct **reuse**, a remanufacturer takes no action to intervene regarding the core. A remanufacturing process includes inspection but excludes any following process step to provide a product to a second-hand market.
4. **Refresh** operations denote no intervention regarding the core but impose some action required to bring a product to "as new" condition. Minor deviations from product performance are fixed by refitting the component or renewing the product's appearance or cleaning it.
5. **Repair** stands for the process step that requires a deeper intervention regarding the core and implies disassembly and reassembly to some extent. Product maintenance, service or overhaul are interchangeable concepts used in different industries that can be united under the repair. Typically, repair is a consequence of a product malfunctioning when a fault or error is detected in the product use phase. The steps during the repair operations are defined by customer demand. Maintenance can be perceived as the opposite of a repair, seeking to prevent malfunctioning. However, the actions required to inspect and

assess the functionality of the product-in-use often ask for a considerable interaction and replacement of some components or reprogramming.

6. **Recondition** is a typical remanufacturing operation that is performed on a used product after its use phase is about to end. There is no need for a product malfunctioning, but the overall product performance no longer satisfies the customer. To restore, renovate, remake, or rebuild a core to "as good as new" condition and functionality is a goal for this value retention process.
7. Comprehensive **refurbishment** requires all the steps of a remanufacturing process but with some limitations for the level of disassembly and part replacement or repair. This is also the case in several industries that struggle to define if/how to state a remanufactured product identity (for example, coding that defines a used or remanufactured product (Debnath et al., 2016). Comprehensive refurbishment tends to provide a neutral product identity, new product user and longer product warranty than the other 9R taxonomy processes in Fig. 2.
8. **Remanufacturing** is an industrial value retention process that prepares the used product for continuous reuse. This is the process step with most product intervention that brings the used product to "as good as new" or better product (of the same model) performance. Remanufacturing enables the product to be upgraded to the performance that is desired by the customer. Remanufacturing overcomes the most of 9R taxonomy processes by the number of resources and the level of product intervention.
9. **Repurpose** completes the 9R Taxonomy to emphasize the other options for the used products. By changing the product purpose, a new application area can be explored. Some solutions include taking the used product (or their parts) to remodel, reinvent, redevelop, or regenerate a completely different product.

5. Industrial case: Value retention processes operated by a remanufacturer

A Swedish IT remanufacturer that is buying, repairing, and selling IT equipment is studied to develop the 9R taxonomy. This electronic and electric equipment (EEE) remanufacturer is an independent remanufacturer with over 20 years of experience in Scandinavia. It is a medium-size company that is expanding every year and is now establishing its division in another Scandinavian country. The great demand for used and repaired IT equipment has raised an interest to study the company's approach to satisfying its customers' needs.

The company is continuously adapting its remanufacturing facilities to improve the flow of cores and spare parts. Upon a core's arrival, it is inspected and classified according to the quality and functionality between Class A, "as good as new", Class B, acceptable quality with minor defects, Class C, sufficient defected, and Class D, not suitable for repair:

- Class A – denotes "as new" quality/product performance – a fully functional product with zero or insignificant cosmetic faults
- Class B – indicates high-quality/product performance – a product that has some minor functional problems and minor cosmetic faults
- Class C – designates moderate-quality/product performance – a product that has significant functional problems and substantial cosmetic faults
- Class D – designates scrap

Typically, when the customer places an order for the remanufactured product type and needed quality/performance, the corresponding core that matches the required product quality is withdrawn from the remanufactured product warehouse. However, sometimes, the demanded product quality does not match the available core quality. In this case, during the remanufacturing process, a range of operations is undertaken. Those operations can vary across the 9R taxonomy (see Fig. 2), from providing direct reuse (in the case of a Class A product) (see Fig. 2 and VRP nr. 3) to remanufacturing with upgrade (see Fig. 2 andVRP nr. 8), where several spare parts are replaced, and the used parts are repaired to deliver the desired the customer remanufactured product quality (see Kurilova-Palisaitiene et. al., 2018). This remanufacturer employs an approach to satisfy its customer by matching the incoming core value to the demanded product value by going along 9R taxonomy between reuse and remanufacture. The need for increased flexibility in resource allocation and product intervention is dictated by the need to balance the available core to the demanded product quality. Lean remanufacturing suggests the solutions to adjust the supply and demand by focusing on the customer value in remanufacturing (see Section 2).

6. Values of remanufacturing compared to other VRPs

The values of remanufacturing, when a used product undergoes any of six VRP processes from 3) reuse to 8) remanufacturing (see Section 5), are associated with product warranty, product life extension, reduced product price (compared to a new product) and costs associated with the use phase (since the product is “as good as new” or better), maintained product performance and output quality (same or slightly better than an original one), and improved availability of a remanufactured product to new customers, especially for the ones with a lower level of income (see Fig. 2). The greater the nr. of VRPs, the greater the need for resources and the intervention level, however the greater the product quality, expected product life after VRP, and warranty, as shown in Fig. 2.

The assessment of the quality versus work content and warranty after the three VRPs, namely, repair, reconditioning and remanufacturing, was also accomplished by Lundmark et al. (2009). Their study showed that an increase in the output quality requires a greater work content and a longer warranty, pointing out remanufacturing winning over reconditioning and repair. In 2018, Pozo Arcos et al. (2018) studied the quality output of several value retention processes, including maintenance, repair, refurbish and reconditioning, reuse, and remanufacturing. The greater quality output was found in the cases where part reuse and remanufacturing took place. Allwood et al. (2011) also provide evidence for the greater material efficiency in the case of product remanufacturing, emphasizing the impact of product design for remanufacturing. While other VRPs, such as repair and reuse, would require less material production, according to Allwood et al. (2011), remanufacturing would deliver greater savings in resources in the long-term.

7. Conclusions

This paper contributes to the previous findings on remanufacturing benefits in comparison to other VRPs, taking a customer demand for the remanufactured product as a starting point to determine the level of intervention into the product and the number of resources required to provide the right remanufactured product quality. Lean improvement strategy brings the focus on the customer and shifts the paradigm of VRPs, ranking remanufacturing high compared to other VRPs. An analysis of the remanufacturing value in comparison to other VRPs elevates remanufacturing as the leading recirculation strategy for technical products with the saved product value.

This paper showed that a remanufacturer can operate a broad spectrum of VRPs (reuse, refresh, repair, recondition, refurbish, and remanufacture) along the 9R taxonomy (see Fig. 2) to satisfy customer needs. In this case, remanufacturing is perceived as a flexible process, where direct product reuse, refresh, repair, recondition, refurbish, and remanufacture with upgrade can take place. The nature of remanufacturing process is dictated by a specific remanufacturing characteristics of unpredictable incoming core quality and the demanded output quality by a customer. While some researchers indicate that repair and refurbishment can save even more resources and energy than remanufacturing, this research paper takes a position that both repair and refurbishment are the value retain processes under the 9R taxonomy (see Fig. 2) defined by the customer value (see Section 2) and can be performed by a remanufacturer (see Section 5).

This paper expands the knowledge on remanufacturing from a separate VRP to a range of recirculation processes united under the 9R taxonomy, namely, (1) recover, (2) recycle, (3) reuse, (4) refresh, (5) repair, (6) recondition, (7) refurbish, (8) remanufacture, and (9) repurpose. To better align remanufacturing and define the scope of the 9R taxonomy, the material recycling, energy recovery, and repurposing processes are added. The 9R taxonomy is developed to expand the four VRPs (Nasr and Russel, 2018) to show the broad spectrum of processes that can be performed by a remanufacturer. The 9R Taxonomy demonstrates to companies of the developing and potential remanufacturing industries that remanufacturing can be adopted based on their customer needs.

8. Methods

The data was collected through a literature study and interviews with a remanufacturer. The literature on remanufacturing values, the benefits of remanufacturing, and lean remanufacturing was studied. The EEE remanufacturer shared its experience to satisfy customers' needs through study visits and interviews. The previous author's knowledge on remanufacturing and VRPs is used to develop the paper.

The report of Nasr and Russel (2018) inspired the development of the 9R taxonomy, placing remanufacturing high compared to the original report.

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