Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 98 (2021) 91–96

www.elsevier.com/locate/procedia

28th CIRP Conference on Life Cycle Engineering

On Remanufacturing Readiness Level - An introduction to a Remometer™

Jelena Kurilova-Palisaitiene*

Division of Environmental Engineering and Management, Department of Management and Engineering, Linköping University, 58183, Linköping, Sweden

* Corresponding author. Tel.: +46-7-0089-5862. *E-mail address:* jelena.kurilova@liu.se (J. Kurilova-Palisaitiene)

Abstract

Linear material flows dominate in the Swedish manufacturing industry, and knowledge on remanufacturing as a value-retention process remains limited. Today, only a limited amount of electrical and electronic equipment (EEE) for consumer goods (that are acquired for personal use), such as laptops and mobile phones, are remanufactured in Sweden.

More support is needed to enhance the remanufacturization (a shift towards remanufacturing) of manufacturing industries by targeting manufacturers that have prerequisites and/or show interest in implementing remanufacturing on their products (later called developing remanufacturing industries). One way to support the developing remanufacturing industries could be by providing a tool to assesses manufacturers' potential with remanufacturing. The aim of this paper is to introduce such a tool, called the Remometer™, and to present this approach to measure a company's remanufacturing readiness level (RRL). The data was collected through a literature study and semi-structured interviews to fulfill the aim of this paper. The authors' research on lean remanufacturing, in collaboration with EEE, automotive, heavy equipment and machinery manufacturers, service/maintenance providers and retailers, laid the basis for developing the Remometer™ tool.

By assessing 15 subjects shared between four critical to remanufacturing areas, namely, *business model*, *production system*, *product* and *customer*, manufacturers can measure their remanufacturing readiness level and a gap towards a world-class remanufacturer. However, neither RRL nor a gap is a purpose of the Remometer™ tool, but a useful measure to communicate to top managers on a manufacturer's potential to become more circular through remanufacturing. Remometer™ is developed to support the remanufacturization of a Swedish EEE manufacturer of consumer goods and can be applied at other developing remanufacturing industries.

Keywords: Circular economy; Remanufacturization; Remanufacturing readiness level; Developing remanufacturing industries; EEE; Consumer goods; Lean remanufacturing; Value-retention processes; Product value chain; Remometer ™

1. Introduction

A circular economy aims to prolong a product's use through material recirculation after the product attains its end-of-use phase [1,2]. A closed-loop system suggests a business model where manufacturers carry responsibility for the product and associated services through a total product value chain [3-5]. Consequently, an original product and its retained values, namely, extra earning, saved material, expanded knowledge and information on the product, greater customer loyalty, and market share, are controlled [6].

Remanufacturing is a value-retention process (VRP) [7] that prepares the used technical product for reuse (see reuse in the 3R waste hierarchy (reduce, reuse, and recycle)) [8]. Other VRPs, defined as direct reuse, repair, and comprehensive refurbishment [7], do not necessarily apply a standardized, certified industrial process as in the case of remanufacturing.

The research on remanufacturing originates at the traditional remanufacturing industries, such as automotive, heavy-duty and off-road (HDOR) equipment, and machinery (for details, see [9-11]). Many remanufacturing researchers conclude that remanufacturing possesses significant financial, environmental, and societal opportunities [12-15]. Remanufacturing helps to reduce the demand for new materials, compared to a newly manufactured product, by between 50% and 98% [7,16]. Due to the resource conservation, between 56% and 90% of energy could be saved if compared to new product manufacturing. According to

10.1016/j.procir.2021.01.011

APRA Europe and ReMaTec [16], CO_2 emissions could be reduced by 53% when remanufacturing is chosen instead of new product manufacturing.

However, the opportunities that remanufacturing tends to provide remain underestimated by many developing remanufacturing industries, including electrical and electronic equipment (EEE) for consumer goods. One reason for this could be a lack of remanufacturing cases. Apart from some cases, for example, Fuji FILM single-use cameras [17], EEE remanufacturing of consumer goods is lacking behind successful examples of the traditional remanufacturing industries. The remanufacturization of the EEE industry, along with other developing remanufacturing industries, requires support from local government and international policymakers, customer representative organizations, manufacturer associations, and other stakeholders (see also [6,7,15,18]). There is a lack of tools and methods that support remanufacturization (see also [19]). There is also a need to support EEE and other developing remanufacturing industries to assess their remanufacturing potential and help those industries implement remanufacturing.

The **aim** of this paper is to introduce a tool to assess a manufacturer's potential with remanufacturing and to present an approach to measure manufacturer's remanufacturing readiness level (RRL).

2. Method

A literature review was used to collect evidence on the studied phenomenon of *remanufacturing* in combination with the words *prerequisites*, *challenges*, *barriers*, *opportunities*, *benefits,* and *lean remanufacturing* in the *Scopus*, *ScienceDirect*, and *Google Scholar* databases. After the initial literature study, the additional papers, found in the references of the selected papers, were included in the analysis due to their relevance to fulfil paper's aim.

Empirical data was collected via semi-structured interviews with representatives from *EEE*, *automotive*, *heavy equipment and machinery manufacturers*, *remanufacturers*, their *service*/*maintenance providers* and *retailers*, and the observations of their *remanufacturing*, *manufacturing*, *maintenance*, and *retail operations*.

3. Developing remanufacturing industries

Stable technology, *high after-use value*, and *replaceable components* are three characteristics that unite products suitable for remanufacturing (see also [7,11,19,20]). These three characteristics, originating in the traditional remanufacturing industries, are broadly accepted by many developing remanufacturing industries, including EEE for consumer goods. Due to a historical demand by industrial customers, traditional remanufacturing industries, represented by heavy products and their lighter components, dominate within a business-to-business (B2B) market. The group of developing remanufacturing industries, including EEE for customer goods and seasonal industries (gardening and building tools, sporting goods) or products that are used intensively for a short period of time (child stroller), tend to have a potential for remanufacturing in a business-to-customer (B2C) market (see also [18]).

3.1. EEE for consumer goods

An electrification trend across many industries prevails in the EEE industry. EEE for consumer goods require power such as electricity to operate power and garden tools, for example. EEE can be small, portable products that occupy less space, such as mobile phones or laptops, or be large electric products like televisions, computer processing units, and robotic lawn mowers (for more details see [21]).

Huisman et al. [22] point out that EEE products' use phase was reduced by 10% between 2000 and 2010, identifying a constantly growing demand for EEE. Many manufacturers and their retailers collect used EEE. An exchange of used EEE among customers (customer-to-customer (C2C)) and businesses (customer-to-business (C2B)) is great evidence of consumers' interest in used or repaired EEE. One of the reasons for used EEE to become waste is a product malfunctioning or underperforming, which required knowledge and resources to bring it to "as good as new" functionality. The costs of spare parts and the limited knowledge of certified repairs or remanufacturing contribute to the growth of waste EEE (see also [22]).

In the European Union (EU), EEE remanufacturers are ranked number one when it comes to the number of established remanufacturing companies and number four in turnover after the aerospace, automotive, and HDOR industries [18]. However, most EEE remanufacturers deal with a narrow scope of EEE: laptops, toner cartridges, and industrial photocopiers. Reasons for why few EEE manufacturers of consumer goods implement remanufacturing are unawareness of remanufacturing, poor circular business model, weak product design suitability for remanufacturing, and poor availability of the remanufacturing process technologies [6,15].

4. The Remometer™ tool

One way to support manufacturers to implement remanufacturing could be by defining their potential with remanufacturing. The following section will introduce a Remometer™ tool and its approach to measure RRL.

4.1. On a remanufacturing readiness level

To define a set of appropriate indicators to assess a manufacturer's potential with remanufacturing, the remanufacturing prerequisites, challenges, barriers, opportunities, and benefits with remanufacturing need to be considered.

The product suitability for remanufacturing (see [7,11,19,20] needs to be included in an assessment of RRL. According to Parker et al. [18], companies with a more circular business strategy (leasing or product-service systems (PSS)) find it easier to implement remanufacturing. Products designed for continuous use (easy to disassemble and reassemble, modular design with interchangeable components) [15] are more suitable for remanufacturing. Experience and knowledge

of the VRP and their technologies, access to raw material and spare parts, and an eagerness to change employees and customers [23-25] contribute to a successful remanufacturing practice.

A study of remanufacturing challenges/barriers reveals that an initial challenge for every potential remanufacturer is to start collecting its cores. A need to collect cores [26,27] implies the development of well-functioning reverse logistics [28,29], a supportive business model, and legislation [11,30].

After the study on remanufacturing prerequisites, challenges, barriers, opportunities, and benefits with remanufacturing, a set of 15 appropriate indicators to assess manufacturers potential with remanufacturing was identified and separated into four critical areas: 1) business model, 2) production system, 3) product, and 4) customer (see Table 1) (for more details, see [6,31,32]).

4.2. Introduction to a Remometer™ tool

The Remometer™ addresses the issue of a lack of methods/tools to assess the manufacturer's potential with remanufacturing by measuring (a) RRL and (b) socio-economic and environmental benefits with remanufacturing. The Remometer™ tool aims to evoke manufacturers' interest in remanufacturing and support their remanufacturization journey. The long-term aim of the Remometer™ is to elevate remanufacturing to manufacturers' strategic level.

The Remometer™ is comprised of four steps that are connected to each other in the following sequence:

Step 1: Define the product suitability for remanufacturing
Step 2: Measure the manufacturer's RRL
Step 3: Estimate the socio-economic and environmental benefits of remanufacturing, and
Step 4: Develop an action plan to implement remanufacturing

The tool is intended to be used by a team of a company's top managers and experts responsible for a company's functions, among others, business management, environmental management, after-use support, manufacturing technologies, product design, marketing, and research and development. The broad spectrum of the company's functions is dictated by the interdisciplinary, cross-border nature of remanufacturing, which is also reflected in the Remometer™ tool. Therefore, the Remometer™ tool entails deep learning on remanufacturing by the one who executes it. While the tool intends to occupy a relatively small portion of time when executed (recommended time is 4 hours), it is developed to generate constructive results that can motivate a company to take the necessary actions to implement remanufacturing. This research paper touches upon Step 2 of the Remometer™ tool.

4.3. RRL Matrix

RRL is derived from the RRL Matrix as an average score in 15 subjects and defines a manufacturer's gap towards remanufacturing (see Table 1 and Fig. 1). The RRL Matrix is a comprehensive set of 15 questions to expound on four critical to remanufacturing areas:

1. Business model
- Experience with value-retention processes (VRPs)
- Experience with product take-back strategies
- Available resources to initiate remanufacturing
- Position in a product value chain

2. Production system
- Availability of used products and proximity to their suppliers
- Availability of new spare parts and proximity to their suppliers

3. Product
- Product suitability for remanufacturing

4. Customer
- Customer demand for the remanufactured product

Four alternative answers to each of 15 questions enable a company to find a better match to its current situation. Each answer gives a score between 1 and 4; however, scores of 0.5, 1.5, 2.5, and 3.5 can be selected if the company's situation is reflected in between two answers. Consequently, there are 8 possible scores to be filled in the RRL Matrix. Each score is plotted in a spider diagram to visualize a gap towards remanufacturing (see Fig. 1).

The higher the scores in the RRL Matrix, the more manufacturer is mature to practice remanufacturing in a successful manner. An RRL of 1, associated with little or no remanufacturing, denotes a low readiness level, while level 3 stands for a good RRL. The outer green ring (see Fig. 1) of the spider diagram, which has a level of 4, denotes a world-class remanufacturer. This is an ideal case that embraces a strive for perfection, driven by the need for continuous improvements, that originates from lean (for more details, see also [33,34]. However, an RRL of 3 is appropriate to strive for if no or little remanufacturing is implemented today.

A low RRL can be observed at the companies that are not aware of or neglect any VRP. Other companies may have some interaction with other product value chain stakeholders regarding some VRP and investigate their opportunity to expand their traditional business functions – those companies receive an RRL of 2 on average. An RRL of 3 can be seen at the companies that practice remanufacturing or deep refurbishment; however, they need support to improve their performance and efficiency. World-class remanufacturers with strong product ownership are prized, with a maximum RRL of 4.

The RRL defines a manufacturer's starting point in a remanufacturization journey and a gap to become a remanufacturer. A gap is represented by a sphere between the joined scores, marked in blue (see an example of RRL of 1.9 in Fig. 1), and the desired level of 3 or 4. The gap denotes the scope (which subject) and direction (of which four critical to remanufacturing areas) of resources required for a manufacturer to become a successful remanufacturer.

The learning outcome from the RRL Matrix is a self-analysis of a current company's situation in four critical to remanufacturing areas. A dialog on RRL between top managers can result in a decision to implement or improve remanufacturing. This dialog may become a starting point of a company's remanufacturization journey.

Table 1. The Remometer™ RRL Matrix with 15 subjects within four critical to remanufacturing areas, where S = Subject and Q = Question (encompasses the findings of [6,9,11,15,18-20,23-26,28,30-32,35]).

Area	Subject / Question	Score 1	Score 2	Score 3	Score 4
Business model	S1: Value-retention processes (VRPs) (operations) Q1: What is your current experience with the value-retention processes (operations)?	No experience in product retention, minor after-sales support, such as warranty service. Strong focus on key business of Manufacturing/Retail/Service.	Perform maintenance, partial proactive maintenance, and performance monitoring. Used products come to facility from time to time. Provide direct product reuse or reuse after minor repair or only repair operations.	Perform proactive maintenance, performance monitoring. Reverse logistics of used products is fully established. Provide product reuse after remanufacturing operations or deep refurbishment. Approved and certified remanufacturer. Leasing (PSS) or other schemes of product ownership are negotiable.	World-class remanufacturer. Strong ownership of the product. Adequate remanufacturing technologies are in place. Successfully practicing lean remanufacturing in combination with leasing through PSS or other schemes. KPIs are linked to socio-economic and environmental measures.
	S2: Product take-back strategies Q2: What is your current experience with product take-back strategies? What element of reverse logistics do you possess?	No practice of product take-back, no return logistics is established, no return flow of used products. After-sales activities are limited to warranty-related ones. After product has left the facility, no further communication nor feedback is provided or asked for.	Irregular returns of used products. No strategy is set for managing those returns; however, some return product activities are encouraged.	Stable flow of returns through product take-back strategies, such as buy-back, volunteer-based, deposit-based, and others.	Predictable return flow of cores through a mix of product take-back strategies, which is incorporated into the core company's strategy, led by continuous improvements.
	S3: Available resources to develop remanufacturing Q3: What is a current situation regarding your time, effort, human resources, investment in the development of remanufacturing?	No resource allocation on developing remanufacturing. Only proceeding with business as usual. Human resources are fully utilized in everyday activities. No capacity to add additional activities to the current workforce.	Minor projects in the development of some VRPs (operations), no long-term strategy to develop remanufacturing. Human resources are partly involved in some VRPs (operations). There is a workforce capacity to expand the current everyday activities above.	Long-term strategy with the dedicated resources together with the motivated workforce to establish remanufacturing operations, proactive or reactive approach depending on industrial settings. Workforce is involved in remanufacturing operations.	Multiple large projects and substantial resources dedicated to the development of new sustainable venues of business, continuous improvements, and upgrades. Workforce has the needed capacity for efficient remanufacturing operations.
	S4: Profit margin on the remanufactured product Q4: What is your profit margin on the remanufactured product?	No margin. No remanufacturing gives no opportunity for additional profits.	Minor margin. Irregular VRPs (operations) give some opportunity for additional profits.	Good margin. Growing profit from remanufacturing activities.	Higher margins than on an original product, remanufacturing is fully integrated into the core business.
	S5: Relations with other stakeholders in a product value chain Q5: What is your relationship with other stakeholders in a product value chain? Can you identify and influence them?	No knowledge on other stakeholders of a product value chain. No relations with them. Other stakeholders are competitors. No sharing of material and information. No feedback is given or provided. No opportunity to influence other stakeholders in a product value chain.	Minor knowledge about other stakeholders of a product value chain. Irregular relations. Minor operation on material and information flows. Minor opportunity to influence other stakeholders in a product value chain.	Good knowledge about other stakeholders of a product value chain. Stable relations. Good operation on material and information flows. Good opportunity to influence other stakeholders in a product value chain.	Dynamic sharing of knowledge about material and information flows among all stakeholders of a product value chain. Close relations. Very good opportunity to influence other stakeholders in a product value chain.
Production system	S6: Workforce qualification in remanufacturing Q6: To what extent does your workforce have the knowledge and skills in value-retaining and remanufacturing operations?	Workforce has no or very limited knowledge and skills of remanufacturing operations, and no education is provided.	Workforce has varying degrees of knowledge and skills on remanufacturing operations, some courses/training on VRP (operations) are provided. However, no or few mentee/mentor relationships are established within the company or with the other stakeholders of a product value chain.	There is enough qualified workforce. Workforce has good knowledge and skills of remanufacturing operations; education is a part of everyday activities. Good mentee/mentor relationships within the company or with the other stakeholders of a product value chain.	Workforce has the required knowledge and skills of the remanufacturing operations. Continues learning to improve workforce qualification is in the company's strategy. Knowledge is retained through mentee/mentor relationships and shared among all stakeholders of a product value chain, and there is good documentation of practice. Resources invested in workers ensure improvements in efficiency.
	S7: Facility for remanufacturing operations Q7: What facilities do you have for remanufacturing? What is your remanufacturing volume?	No available facility/part of facility for remanufacturing operations. No resources available to obtain new facility. No remanufacturing volume.	VRP (operations) are performed at the current facility, or facilities required for those operations are available for procurement. Grow in product VRP (operations).	Remanufacturing operations are performed at the current facility. The facility layout and material and information flows could be more efficient. Low to moderate remanufacturing volume with stable growth.	Effective and efficient use of facility by remanufacturing operations. State-of-the-art facilities available for remanufacturing development and expansion. Remanufacturing facilities aim for high-volume remanufacturing.
	S8: Technology and equipment for remanufacturing Q8: To what extent do you have the technology, equipment, and tools required for remanufacturing operations?	Basic equipment and tools used for everyday activities. No additional equipment for remanufacturing.	Some equipment and tools used for VRPs (operations) or new product manufacturing could be used for remanufacturing.	All equipment and tools required for remanufacturing operations are available for procurement. Advanced technology could be practiced.	Flexible technology, equipment, and tools could be used for an efficient remanufacturing process when required. Advanced remanufacturing technology, such as 3D scanning and additive manufacturing, and equipment available for remanufacturing development and expansion.
	S9: Availability of used product (core) and proximity to suppliers Q9: To what extent are the used products available?	No knowledge on the availability of used products. Company is in the international distance to used product suppliers and/or market. Transport distance and distribution costs are very high.	Used products are hard to come by or of poor but retrievable condition if attained. Company is in multi-regional distance to used product suppliers and/or market. Transport distance and distribution costs are high.	Used products are common and in a retrievable state. Company is in regional distance to used product suppliers and/or market. Transport distance and distribution costs are moderate.	Large amounts of used products in circulation or use. Company is in direct contact with used product suppliers and/or market. Transport distance and distribution costs are low.

Production system	S10: Availability of original spare parts and proximity to suppliers Q10: To what extent are the original spare parts available?	Difficult to obtain an original spare part. Poor connection / long distance to spare part supplier. Company is in the international distance to original spare parts suppliers and/or market. Transport distance and distribution costs are very high.	Time-to time difficult to obtain an original spare part. Spare parts are retrieved semi-regularly with some safety stock for operations. Company is in multi-regional distance to original spare parts suppliers and/or market. Transport distance and distribution costs are high.	Easy to obtain an original spare part from the supplier or used spare part stock. Company is in regional distance to original spare parts suppliers and/or market. Transport distance and distribution costs are moderate.	Spare parts either in stock or arriving just in time for remanufacturing operation, remanufacturing near spare parts warehouse or supply on demand. Company is in direct contact with original spare parts suppliers and/or market. Transport distance and distribution costs are low.
Product	S11: Product design for remanufacturing Q11: To what extent is the product designed for remanufacturing? To what extent do the critical components can or need to be replaced?	Product cannot or is difficult to be disassembled and then assembled again. Service or maintenance costs are very high, serviceability of product is challenging. Salvage rate of products/components is very high. Majority of components need to be replaced if/when doing VRP (operations).	Product can be disassembled and then assembled again, without damaging the product, however, requires many efforts, specialized tools, and very good skills. Salvage rate of products/components is high. Large number of critical components need to be replaced if/when doing VRPs (operations). Product technology is under development.	Product can be disassembled and then assembled again, however the issues of product design suitability for remanufacturing are typical. Several critical components need to be replaced, during remanufacturing /deep refurbishment operations. Stable product technology.	Design for remanufacturing. Product designed for smooth and repeatable disassembly and reassembly. Product is designed for remanufacturing with an effective technological upgrade and high product re-constructability through modular design and smart fixturing elements. Standard number of critical components need to be replaced during remanufacturing operations. Stable and predictable product technology.
	S12: Remaining value of used product Q12: What are the remaining value and quality of the used product? To what extent are the product and its critical components durable?	Very poor or unusable condition of used product intended for retrieval operations. No remaining value of a product. Recycling is the only option. The product is fully worn after the first use-cycle. Critical components wear or break after several uses.	Variable quality of used product intended for retrieval operations, high amounts of wear, few components can be reused. Product has short expected lifespan, moderate technical durability. Few components have long lifespan and can be remanufactured. Service or maintenance costs are moderate.	Good quality of used product intended for remanufacturing, low amounts of wear, many components can be reused. High value is kept after remanufacturing operations. Product has moderate expected lifespan, product is durable. Many components have long lifespan and can be remanufactured. Service or maintenance costs are low. Serviceability of product is encouraged.	Good or as good as new quality of used product intended for remanufacturing with very low amounts of wear, most components can be reused. The returned used product (core) value almost equates to new product value. Product has long expected lifespan, highly durable. Critical components have long lifespan and can be remanufactured. Product is provided through a service contract, low costs for product service.
Customer	S13: Customer awareness and demand for remanufactured products Q13: To what extent are your customers aware of remanufactured products? What is the customers' demand for a remanufactured product?	No knowledge on demand, since no remanufactured is provided. Customer is not aware of remanufactured products. Customers have no interest in remanufactured products.	Growing demand for used products. Products are repaired and sold on a second-hand market for a substantial amount, about half the price of the original product.	The product is remanufactured/deeply refurbished to be sold for three-quarters of original product price or leasing. Growing customer interest for remanufactured products with warranty.	The product is in a constant circular flow, customer demand is high. Same price as original product or higher due to technological upgrade or environment positivity with at least a one-year warranty, alternatively by providing leasing. Remanufactured products are perceived to have the same quality or better than new manufactured products, moreover, they are environmentally friendly.
	S14: Customer's access to and acceptance of remanufactured products Q14: What are the customer's access points for a remanufactured product? To what extent do your customers accept remanufactured products?	No sales/lease of remanufactured products, therefore no access points for customers. Customers have a negative attitude towards remanufactured products.	Sporadic, irregular sales of used products after some repair, very limited access points for customers. No long warranty is provided. Customers have a neutral attitude towards remanufactured products. Possible concern regarding life expectancy, physical appearance, or performance. Remanufactured products are perceived as inferior compared to new products.	Regular sales/lease of remanufactured products through different channels: e-channels, direct sales in the shops, via telephone and email. Customers have a positive attitude towards remanufactured products. Remanufactured products are perceived to have as good as new product quality, physical appearance, and performance.	Lease /sharing of remanufactured products through different channels: e-channels, direct sales in the shops, via telephone and email. Flexible alternatives for product exchange, lease and sharing between industry and community. Remanufactured products are prioritized by the customers. Remanufactured products are perceived to have as good as new or better product quality, physical appearance, and performance.
	S15: Customer loyalty to original brand Q15: To what extent are the customers loyal to the original brand?	No loyalty: after purchase, does not utilize service offers or make any future commitments. May prefer other brand's products.	Neutral customer, use service offerings for a VRP (operations), but purchase different brands.	Loyal customers, brand first choice of customers, purchase other brands if necessary.	Customers devoted to brand, only purchase these products.

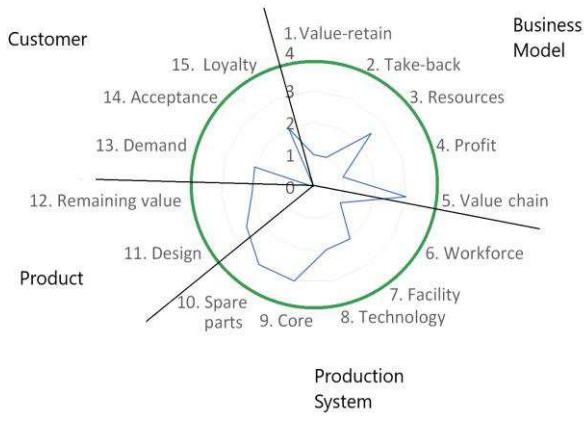

Fig. 1. An example of an RRL of 1.9 and a gap towards remanufacturing across 15 subjects shared between four critical to remanufacturing areas.

5. Discussion and conclusion

Remanufacturing is an enabler of a circular economy that possesses a company's socio-economic and environmental sustainability. Today, it is more important than ever to emphasize the enablers of the circular economy for technical products.

The Remometer™ tool was developed to facilitate the remanufacturization of developing remanufacturing industries, including EEE for consumer goods. The remanufacturing readiness level (RRL) can become a key part of assessing a manufacturer's potential with remanufacturing. The Remometer™ approaches the RRL by measuring a company's average score in 15 subjects spread between four areas critical to remanufacturing: 1) business model, 2) production system, 3) product, and 4) customer. The RRL defines a manufacturer's starting point in its remanufacturization journey. A gap denotes the scope (within

15 subjects) and direction (within four areas critical to remanufacturing) of a manufacturer's resources needed to become a successful remanufacturer.

However, the purpose of the Remometer™ is neither to measure an exact RRL nor to quantify the socio-economic and environmental benefits of remanufacturing. Rather, it is to encourage manufacturers to challenge their current strategies and become more circular through remanufacturing.

Acknowledgements

The author would like to thank the Swedish Energy Agency for financing the research for this paper through the Remometer project, dnr 2019-021532, within the strategic innovation program RE:Source. The author thanks Gustav Johansson, a research assistant at Linköping University, who helped to conduct a literature study that contributed to the development of the RRL Matrix.

References

[1] Brennan D, Tennant M, Blomsma F. Business and production solutions - closing loops and the circular economy; 2015.
[2] Murray A, Skene K, Haynes K. The circular economy: An interdisciplinary exploration of the concept and application in a global context. Journal of Business Ethics; 2017. 140:3, p. 369-380.
[3] Ellen MacArthur Foundation. Intelligent Assets: Unlocking the circular economy potential; 2016.
[4] Ellen MacArthur Foundation. What is a Circular Economy?; 2017. Available at: https://www.ellenmacarthurfoundation.org/circular-economy/concept [Accessed 12 December 2019].
[5] Fischer A, Achterberg E. Create a Financeable Circular Business in 10 Steps, Amsterdam: Circle Economy, Sustainable Finance Lab; 2016.
[6] Kurilova-Palisaitiene J, Vogt Duberg J, Johansson G, Sundin E. How an OEM can become circular with remanufacturing: the case of robotic lawn mowers, In Proceedisnf of Swedish Production Symposium (SPS) 2020, Jönköping; 2020.
[7] Nasr NZ, Russel JD, UN Environment and International Resource Panel. Redefining value - The Manufacturing Revolution. Remanufacturing, Refurbishment, Repair and Direct Reuse in a Circular Economy, UNESCO; 2018. Available at: https://www.resourcepanel.org/reports/re-defining-value-manufacturing-revolution [Accessed 3 March 2020].
[8] Wilson DC. Development drivers for waste management. Waste Management & Research 25; 2007. p. 198-207.
[9] Guide JrVDR, Van Wassenhove LN. Managing product returns for remanufacturing. Production and operations management, 10:2; 2001. p. 142-155.
[10] Ferrer G. On the widget remanufacturing operation. European Journal of Operational Research, 135:2; 2001. p. 373-393.
[11] Seitz MA. A critical assessment of motives for product recovery: the case of engine remanufacturing. Journal of Cleaner Production, 15:11-12; 2007. p. 1147-1157.
[12] All-Party Parliamentary Sustainable Resource Group (APSRG). Remanufacturing: Towards a Resource Efficient Economy; 2014. p. 1–12. Available: https://www.policyconnect.org.uk/apsrg/research/report-remanufacturing-towards-resource-efficient-economy-0 [Accessed 22 January 2020].
[13] Spelman C, Sheerman B, All-Party Parliamentary Sustainable Resource Group and Manufacturing Group. Triple Win: The Social, Economic and Environmental Case for Remanufacturing; 2014. Available at www. policyconnect.org.uk/apsrg [Accessed 2 December 2019].
[14] Abbey JD, Meloy MG, Guide VD, Atalay S. Remanufactured Products in Closed Loop Supply Chains for Consumer Goods. Production and operation management, 24:3; 2015. p. 488-503.
[15] Sundin E, Sakao T, Lindahl M, Kao C, Joungerious B, Ijomah W. Map of Remanufacturing Business Model Landscape, Report from the Horizon 2020 project called ERN - European Remanufacturing Network; 2016. Accessible from www.remanufacturing.eu [Accessed 13 March 2020].
[16] APRA Europe and ReMaTec (RAI Amsterdam). Three key aftermarket trends that challenge warehouse distributors and wholesalers; 2019. Acceasible from: https://apra.org/page/europe. [Accessed 13 March 2020].
[17] Sundin E, Lindahl M. Rethinking Product Design for Remanufacturing to Facilitate Integrated Product Service Offerings, Proceedings of IEEE International Symposium on Electronics and the Environment (IEEE-08), San Francisco, USA; 2008.
[18] Parker D, Riley K, Robinson S, Symington H, Tewson J, Jansson K, Ramkumar S, Peck D, ERN–European Remanufacturing Network, Remanufacturing Market Study, European Remanufacturing Council, Delft, The Netherlands; 2015. Available: http://www.remanufacturing.eu/assets/pdfs/remanufacturing-market-study.pdf [Accessed 29 November 2019].
[19] Goodall P, Rosamond E, Harding J. A review of state of the art in tools and techniques used to evaluate remanufacturing feasibility. Journal of Clearer Production 81; 2014. p. 1-15.
[20] Falconi V, Sundin E, Colledani M. Key success factors for implementing Upgrading Remanufacturing, Proceedings of International Conference on Remanufacturing (ICoR-17); 2017.p. 33-46.
[21] Debnath B, Roychowdhury P, Kundu R. Electronic Components (EC) Reuse and Recycling-A New Approach towards WEEE Management, International Conference on Solid Waste Management, 5IconSWM: Procedia Environmental Sciences 35; 2016. p. 656-668.
[22] Huisman J, Van der Maesen M, Eijsbouts RJJ, Wang F, Balde CP, Wielenga CA. The Dutch WEEE Flows; 2012.
[23] Lekurwale RR, Akarte MM, Raut DN, Framework to evaluate manufacturing capability using analytical hierarchy process, International Journal of Advanced Manufacturing Technology 76; 2015. p. 565-576.
[24] Govindan K, Shankar KM, Kannan D. Application of fuzzy analytic network process for barrier evaluation in automotive parts remanufacturing towards cleaner production – a study in an Indian scenario. Journal of Cleaner Production 114, 2016. p. 199-213.
[25] Hazen BT, Mollenkoph DA, Wang Y. Remanufacturing for the Circular Economy: An examination of Consumer Switching Behavior, Business Strategy and the Environment 26; 2017. p. 451-464.
[26] Lundmark P, Sundin E, Björkman M. Industrial Challenges within the Remanufacturing System. Stockholm, Sweden, Proceedings of the 3rd Swedish Production Symposium (SPS); 2009.
[27] Wei S, Tang O, Sundin E. Core (product) Acquisition Management for remanfuacturing: a review. Journal of Remanufacturing, 5:4; 2015. p. 1-27.
[28] Guidat T, Uoti M, Tonteri H, Määttä T. A classification of remanufacturing networks in Europe and their influence on new entrants, In: Procedia CIRP 26; 2015. p. 683-688.
[29] Bhatia MS, Srivastava RK. Analysis of external barriers to remanufacturing using grey-DEMATEL approach: An Indian perspective. Resources, Conservation and Recycling 136; 2018. p. 79-87.
[30] Karvonen I, Jansson K, Tonteri H, Vatanen S, Uoti M. Enhancing remanufacturing – studying networks and sustainability to support Finnish industry. Journal of Remanufacturing, 5:1; 2015. p. 5-21.
[31] Vogt Duberg J, Johansson G, Sundin E, Kurilova-Palisaitiene J. Prerequisites facts for Original Equipment Manufacturer Remanufacturing, Journal of Cleaner Production 270; 2020. p. 122309.
[32] Kurilova-Palisaitiene J, Sundin E, Poksinska B. Remanufacturing challenges and possible lean improvements, Journal of Cleaner Production 172; 2018. p. 3225-3236.
[33] Womack JP, Jones DT. Lean Thinking: Banish waste and create wealth in your corporation, Free press business, Great Britain; 2003.
[34] Morgan JM, Liker JK. The Toyota production development system, Productivity Press, USA; 2006.
[35] Graham, I. Goodall P, Peng Y, Palmer C, West A, Conway P, Mascolo JE, Dettmer FU. Performance measurement and KPIs for remanufacturing. Journal of Remanufacturing, 5:1; 2015. , p. 10.