Stakeholder Considerations in Remanufacturability Decision-Making: Findings from a Systematic Literature Review

Damola Ikeoluwa Akano[a], Winifred Ijomah[a], James Windmill[b]

[a]Department of Design, Manufacturing and Engineering Management, University of Strathclyde, Glasgow [b]Department of Electrical and Electronics Engineering, University of Strathclyde, Glasgow.

Abstract

Remanufacturing is a sustainable product recovery strategy with environmental, economic and social benefits. Remanufacturability assessment, the process of deciding whether or not to remanufacture an end-of-life or end-of-use product, is complex and has a high level of uncertainty. Several tools and methods have been proposed to reduce this complexity without compromising the effectiveness and inclusiveness of the process. However, there is a lack of comprehensive review of the decision factors and how they fulfil the requirements of different stakeholders that are critical to the success of remanufacturing systems. This study fills the gap by performing a systematic literature review of decision factors with the aim of understanding how the requirements of stakeholders have been accounted for in remanufacturability decision-making. Decision factors that have been used to represent the different stakeholders were identified and discussed. Findings revealed the lack of research on including consumer requirements in remanufacturability decision-making. Future research should focus on bridging the gap between consumers and other stakeholders, especially during the remanufacturability decision-making process. The novelty is that this is the first study that comprehensively reviews decision factors in remanufacturability assessment from the perspectives of the different stakeholders and provide insights on the impact of consumer requirements on remanufacturability decision-making.

Keywords: remanufacturing, remanufacturability, decision-making, consumer

1. Introduction

The paradigm shift from the notion of unlimited resources and regenerative capacity of the environment towards the realisation of limited resources is reshaping every aspect of human life [1]. This, coupled with increasing general awareness of environmental pollution and degradation [2], has championed the drive towards the circular economy, which has resulted in scrutiny of product manufacturing, recovery and disposal. Effort aimed at improving sustainability begin at the product development phase, through its manufacture, use, end of life and recovery. Thus, efficient material usage during initial manufacturing and appropriate end of life recovery strategies have been encouraged.

To encourage sustainable manufacturing (e.g., via product recovery), governments have enacted legislations (e.g., WEEE and ELV) penalising manufacturers based on the amount of waste they produce. The EU Directive on Waste Electrical and Electronic Equipment (WEEE) aimed to encourage reuse, refurbishment, remanufacturing and other end of life recovery options to reduce the amount of waste sent to the landfill [3]. The WEEE directive has been discussed extensively in literature with Zlamparet *et. al.* (2017) focusing on remanufacturing strategies that reduce e-wastes [4]. The end-of-life Vehicle (ELV) Directive focused on the automotive industry to reduce automotive wastes. With the concept of "extended producer responsibility", Gerrard and Kandlikar (2007) argued that the ELV directive has encouraged innovation relating to vehicle design and recovery level of end of life vehicles [5]. Extensive discussions on existing legislations and regulations can be found in [4]–[6].

Product recovery strategies aim to improve sustainability by taking used products (cores) through a new use phase. In the case of remanufacturing, used products are returned to a condition that is equivalent to that of corresponding new products with warranty to match [7] through a less costly (economically and environmentally) industrial process. Remanufacturing is good for the environment, business and consumers, in line with the triple-bottom line of sustainability which has been discussed extensively in literature [8]–[12].

The process of deciding the most appropriate end of life strategy for a product is important to every stakeholder involved in the product lifecycle including the consumers, supply chain practitioners, remanufacturers and original manufacturers. During this process, a decision is made to reuse, remanufacture, recycle or dispose of the product or component. Remanufacturability decision-making is the process of deciding whether or not to remanufacture a product and it has been discussed exhaustively in literature, refer to [13]–[15].

Evidence from existing research reflects the complexity and uncertainty of remanufacturability decision-making which requires a consideration of many different factors including business, resources, legislative, product, technology, market, economic, environmental and social factors. With these factors, researcher have developed different methods, tools and frameworks to assess the remanufacturability of products. However, no studies have critically reviewed the different factors and considerations used in remanufacturability decision-making from the perspective of the stakeholders. Thus, the objective of this study is to explore the state of art in remanufacturability decision-making with the aim of identifying decision factors and the category of stakeholders that they apply to.

A systematic literature search was performed followed by a review of selected articles. The identified decision factors were placed into different groups (or metrics) which relate to the product, sustainability and technology. Each metric was discussed focusing on the importance of using the factors and a description of existing literature. Also, selected articles were assessed in terms of the stakeholder, the decision factors, the industry or products considered, the methodology and the level of decision as appropriate.

The remaining part of this article has 4 sections. First, the literature review methodology is presented, describing how the articles reviewed in this study were selected. Second, three metrics for remanufacturability are presented. The section highlights and discusses the assessment criteria for remanufacturability, including the factors, methods, stakeholders and products of relevant articles. Third, a discussion of the key findings relating to stakeholder considerations in remanufacturability is presented. Finally, conclusions, (including future work) are drawn from the study.

2. Review Method

Remanufacturability assessment is an active area of research in remanufacturing discipline. Thus, there exists a large number of research articles that would be related to the focus of this study. Systematic literature review methodology was selected for this study because it is a rigorous, transparent and robust approach to literature review [16]. The systematic approach to literature review has received wide usage in remanufacturing literature [15], [17]. This study used the guideline to literature review methodology described by Snyder (2019) [18]. This review was conducted in three phases: 1) designing the review, 2) searching literature, 3) analysis of the final selected articles

2.1. Review design

The first step in research is to understand the importance of the study and to identify the best approach. The aim of this review is to identify decision factors used in remanufacturability assessment and evaluate them from a viewpoint of stakeholder consideration in the decision process. The research questions are listed below.

1. What are the decision factors used in remanufacturability assessment?
2. Which stakeholders have been considered in remanufacturability decision-making?
3. What are the knowledge gaps in remanufacturability decision-making?

2.2. Literature search

The effectiveness of systematic literature review is in its strict approach to literature search and article selection. The depth and rigour of systematic review is reflected in a selection of keywords, search databases, inclusion and exclusion criteria [18].

2.2.1. Keyword selection

Keywords selected for this review were *"remanufacturability", "remanufactur* decision factor", "decision making", "decision support",* and *"remanufactur* factor"*. These keywords were selected because they relate directly to the research questions and will help achieve the aim of the review. The wildcard "*" was used to increase the inclusiveness of the search and ensure that words like remanufacture, remanufacturing, remanufacturability and remanufactured are included.

2.2.2. Database search

Search databases selected for this review were Scopus and Web of Science. Asides the fact that these two databases are widely used in remanufacturing literature, Scopus and Web of science rely on robust criteria set by expert editors to select good quality publications from journals and conference proceedings.

2.2.3. Inclusion criteria

Since it is impossible to review all the articles in the results of the initial literature search, inclusion criteria were proposed to systematically select articles [15], [17]:

- Articles written in English language, peer-reviewed for journal publications or high-quality conference papers
- Articles relating to end-of-life recovery strategy planning, remanufacturing decision making of 'whether or not' to remanufacture a product. Articles that also deal with specific issues such as product designs, remanufacturing technology, sustainability and consumers focusing on end-of-life decision-making.
- Articles published between 1990 and January 2021.
- Articles with full text availability

2.2.4. Search results and final selection

The results from the initial search, shown in Table 1, returned 724 publications which were assessed in five stages. First, the search results from the two databases were merged to remove duplicates after which 467 were left. Second, the titles were assessed to eliminate unrelated studies, which left 328. Third, the abstracts were assessed which left 85 publications. Articles with full text available were 58. Fourth, a 'bird-eye' scanning [19] of the full-text was performed, leaving 43 articles. Fifth, the final articles selected were further screened to ensure that they met the inclusion criteria stated in section 2.2.3. The systematic literature search process is shown in figure 1. All the 43 articles selected for this review appeared in high-impact sources.

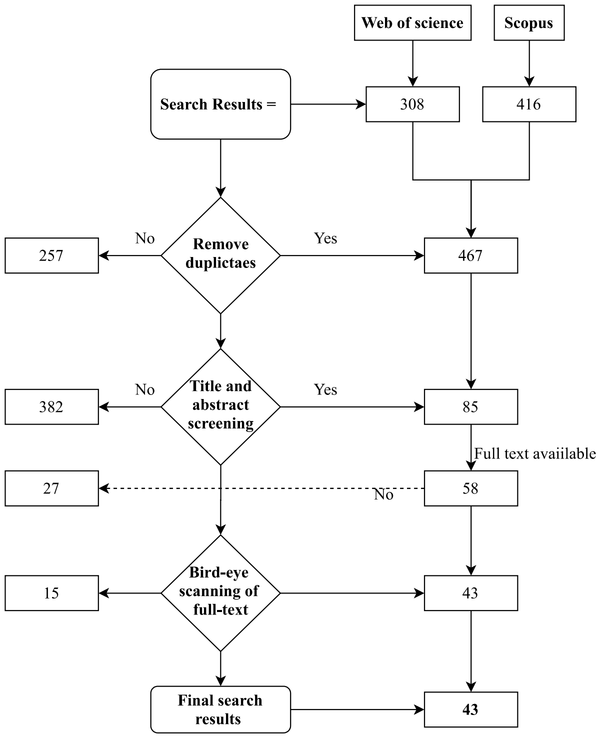

Figure 1: Results of systematic literature search

Table 1: Keyword search results

Keywords	Web of Science	Scopus
remanufacturability	72	110
remanufactur* decision factor	162	201
remanufactur* factor AND "decision making"	69	98
remanufactur* factor AND "decision support"	5	7
Total	308	416

3. Metrics for Remanufacturability assessment

This study identified three (3) main approaches to remanufacturability assessment from literature. These are: Sustainability, Product and Technology metrics. The sustainability metric covers the economic, environmental and social impact assessments, whereas the product metric assesses the product design and returned core management. Technology metric covers the assessment of the remanufacturing operation. It is important to note that there is logical overlap and interactions between the remanufacturability decision factors (as shown in figure 2) although this is out of the scope of the present study. Further discussions on these metrics are presented in the following sections, as shown in figure 2.

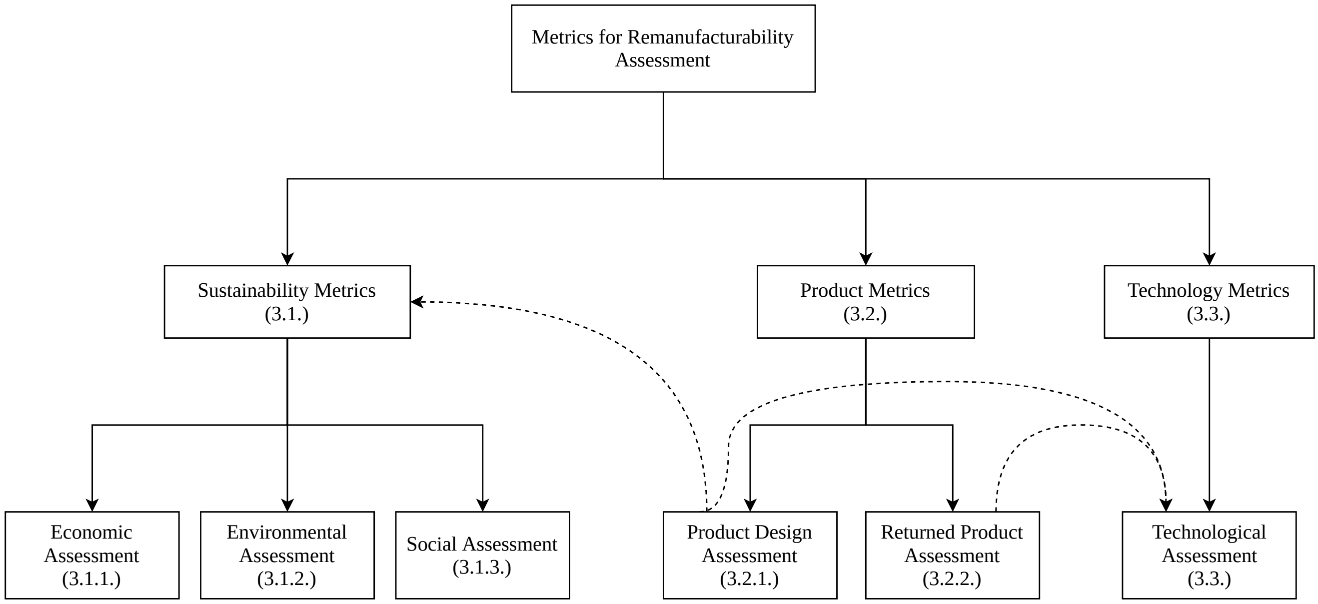

Figure 2: Overview of remanufacturability assessment

3.1. Sustainability Metric

Existing studies have shown the importance of evaluating sustainability factors when assessing the viability of remanufacturing a product. One early work on remanufacturability decision making, Amezquita *et. al.* (1995) identified key decision factors such as economic and environmental [20]. These factors have been further discussed by researchers in remanufacturing discipline as basic requirements for assessing the viability of conducting remanufacturing operation. Goodall *et. al.* (2014) highlighted the importance of sustainability factors when assessing the feasibility of remanufacturing [15]. Golinska *et. al.* (2015) took the discussion further by proposing an holistic remanufacturability decision-making tool based on the three pillars of sustainability factors [12]. Karaulova and Bashkite (2016) used sustainability factors in the integrated remanufacturability assessment method proposed for used industrial equipment [21]. Jiang *et. al.* (2019) performed a data-driven analysis to identify key factors that influence remanufacturing ecological performance [22]. Meng *et. al.* (2020a) proposed a demand-dependent multi-objective decision-making model to take in consideration the economic, environmental and societal factors [23]. Results have shown a higher relative weight for sustainability factors compared to other metric used in remanufacturability assessment such as technological assessment [21].

More discussions of the sustainability decision factors are presented in three subsections: economic, environmental and social impact assessment. Table 2 shows a summary of the sustainability decision factors that have been used in literature to assess remanufacturability, including an analysis of the methods, product or industry, and the stakeholder considered.

3.1.1. Economic Impact Assessment

Economic assessment of remanufacturability has been the leading consideration in remanufacturability assessment. Lund (1984) described how economic motivation in terms of costs and profits were the first points of call when deciding whether, or not to venture into the remanufacturing business [24]. Over the past 3 decades, economic gains have been described as one of the key benefits of remanufacturing, alongside environmental conservation [7], [25]–[28]. Existing studies have shown that remanufacturing serves as a profitable operation for the remanufacturer, and as a low-priced alternative to the consumer. Therefore, assessing if a product can be remanufactured such that the remanufacturers make profit and consumers are offered a cheaper product with a quality similar to that of a new product has become a common practice. This process is referred to as economic remanufacturability assessment, and it has been used exhaustively in literature.

Amezquita *et. al.* (1995) identified two factors of economic assessment: costs and price [20]. Costs refers to the financial implication of conducting remanufacturing while price is described as the monetary value for which the remanufactured product is offered to the consumer. When assessing economic impact as a tool for remanufacturability, the aim is to analyse the financial burden of conducting remanufacturing depending on who is performing the operation. Therefore, Goodall *et. al*. (2014) suggested that the cost of remanufacturing is attributed to the steps and processes involved in remanufacturing [15], such as the cost of core acquisition, disassembly, cleaning, inspection and sorting, part remanufacturing, reassembly and testing [12], [21]. These costs were modelled as a quadratic mixed integer programming (QMIP) problem in the decision support tool by Farahani *et. al.* (2019) as operational cost, purchasing and under-stocking cost, setup or idle cost and revenue [29]. Goodall *et. al.* (2014) noted that these costs include labour cost, material cost and other overheads [15], [21]. It has been suggested that remanufacturing costs are affected by the quality of returned core items, original design of product, skill of the technician, available tools, machines, and remanufacturing technology [12], [15], [30]. Jiang *et. al.*, (2020) proposed a high-precision data-driven decomposition integration remanufacturing cost prediction model to evaluate remanufacturability quantitatively and overcome obstacles to cost estimation which include cost instability and limited available information [31].

Subramoniam *et. al.* (2009) identified key factors in remanufacturing decision-making whereas Subramoniam *et. al*. (2013) ranked these decision factors using the analytical hierarchical process (AHP) methodology [26]. Subramoniam *et. al*. (2013) further proposed a remanufacturing decision-making framework (RDMF) based on the decision factors ranked using the AHP methodology. Financial impact factor, which was used to represent economic assessment, was ranked as the most significant factor in the decision-making system. This finding further affirmed the importance of economic assessment in remanufacturability decision-making, in line with Lund (1984).

Researchers in remanufacturing have proposed different methods, frameworks and models to assess remanufacturability of products using economic factors. Zhang *et. al.* (2004) proposed a web-based tool for product end of life decision support which use cost and profit function as the economic assessment of the product [8]. The remanufacturability decision support tool developed by Yang *et. al.* (2016) incorporated economic index by assessing the added-value and the overall cost of remanufacturing the product [13]. Yang *et. al.* (2015) deployed economic assessment at the component-level [32]. The component-level economic index was quantitatively measured from the costs of disposal or the cost of returning the individual product components to like-new condition. Jiang *et.al.* (2011) also focused on component remanufacturability and developed a multi-criteria decision-making (MCDM) model based on AHP methodology for selecting appropriate technology for part remanufacturing [11].

Economic remanufacturability factors covered in literature focused mostly on the economic expectations of the original manufacturer and/or the external remanufacturer i.e., costs and profits. Consumer expectations, in terms of pricing acceptability, have not been duly included in remanufacturability assessment.

3.1.2. Environmental Impact Assessment

Researchers have evaluated the environmental impacts [24] of end of life product and the remanufacturing process when assessing the viability of remanufacturing. Considerable research efforts have been focused on prioritising environmental impact assessment for remanufacturability decision-making. Subramoniam *et. al.* (2009) and Jiang *et. al.* (2019) identified environmental performance as a critical factor in assessing remanufacturability [9], [22]. Subramoniam *et. al.* (2013) proposed a remanufacturing decision-making framework (RDMF) that prioritise environmental consciousness for businesses in manufacturing and remanufacturing sectors [26].

Many studies in remanufacturing literature have assessed the environmental impact of remanufacturing a product based on a number of factors. Amezquita *et. al.* (1995) assessed the environmental feasibility of remanufacturing using factors such as amount of wastes generated and energy consumption during material extraction and original manufacturing process [20]. Environmental considerations in the multi-criteria decision-making (MCDM) model based on AHP developed by Jiang *et. al.* (2011) were measured by process waste emission, energy efficiency, and material consumption [11]. Yang *et. al.* (2015) assessed environmental index of component remanufacturability based on material usage, energy consumption, amount of wastes and toxic substances discharged [32]. Golinska *et. al.* (2015) proposed a novel remanufacturability decision-making tool which measured environmental performance using energy consumption level, amount of wastes generated, material recovery rate, and amount of generated emissions per remanufactured item [12]. Karaulova and Bashkite (2016) developed a remanufacturability assessment method for used industrial equipment which considered material saving, energy saving and pollution reduction benefits of remanufacturing a product [21]. Yang *et. al.* (2016) assessed the environmental viability of remanufacturing a product and/or its component by measuring the energy consumption of the process [13].

Another dimension to environmental assessment is the impact of existing regulations on end-of-life product treatment. Gehin *et. al.* (2008) reviewed the concept of extended producer responsibility (EPR) regulations in Europe, which include the End of life Vehicle (ELV) and the Waste of Electrical and Electronic Equipment (WEEE) [33]. The presence of these regulations has resulted in original manufacturers improving their product designs to reduce environmental impact. Subramoniam *et. al.* (2009) described how these regulations can be a major determinant for remanufacturing decision-making [9] and ranked the impact of government regulations on remanufacturing decision-making as 6th (out of 9 factors) in Subramoniam *et. al.* (2013) [26]. Yang *et. al.* (2016) included compliance with local legislation as an important consideration when assessing remanufacturability of a product [13].

Discussions on environmental assessment is lacking consumers' perception of the environmental benefits of the remanufactured product or the green image of the remanufacturing organisation. Consumers' environmental involvement, which plays a role in consumer acceptance of remanufactured products, has not been adequately catered for in remanufacturability assessment.

3.1.3. Social Impact Assessment

Social remanufacturability assessment considers the impact of remanufacturing a product on the people and community. Goodall *et. al.* (2014) identified two dimensions of social impact assessment, which are the human factor and societal factor [15]. The human factor relates to the individuals within the remanufacturing business. These include employees, consumers, and business partners etc. Societal factors focus on the immediate community where the remanufacturing operation is conducted.

Social factors haven't received much attention, with Goodall *et. al.* (2014) referring to it as the least explored factor in sustainability considerations. Social remanufacturability factors that have been discussed in literature are: low cost alternatives, additional job creation, safety of remanufacturing process, and consumer satisfaction [15], [34], [35]. Social performance assessment framework proposed by Golinska *et. al.* (2015) used factors such as employment, hazards related to the remanufacturing process, and level of innovation [12].

Table 2: Summary of the sustainability metrics used for remanufacturability assessment

References	**Sustainability factor considered in study**			**Description**				**Stakeholder considered in study**		
	Economic	**Environmental**	**Social**	**Aim of study**	**Method**	**Level of decision**	**Product/ Industry**	**OEM**	**TPR**	**Consumer**
Amezquita *et al.*, (1995) [20]	Costs Price	Waste generated, Energy consumption	N/A	Assess remanufacturability	Quant	Product	Automobile door	X	X	O
Zhang *et al.*, (2004) [8]	Costs, Profit	Considered but unclear	N/A	Assess remanufacturability	Quant	Product	Desktop computer	X	O	O
Gonzalez and Adenso-Diaz, (2005) [36]	Profit	Resource consumption, Waste generation	N/A	End of life strategy selection	Quant	Product	Mobile phone	X	O	O
Gehin *et. al. (*2008) [33]	N/A	Regulations, Material consumption, Pollution from process	N/A	Improve design for remanufacturing (DfRem)	Qual	Products	Cement Mixer	X	O	O
Subramoniam *et. al.* (2009) [9]	Cost, Price	Regulations, Firm's green image	N/A	Improve remanufacturability decision-making process	Qual (Review)	Product	Automotive industry	X	O	X
Jiang *et. al.* (2011) [11]	Costs	process waste emission, energy efficiency, material consumption	N/A	Remanufacturing technology selection	Quant	Company	Valve stem	X	O	O
Subramoniam *et al.* (2013) [26]	Financial impact, Disposal costs Product value	Regulations, Green perception	N/A	Assess remanufacturability	Quant	Product	Automotive aftermarket	X	X	X
Ng *et. al.* (2013) [37]	Recovery costs	GHG emissions	No of workers, Skill, Salary	Assess remanufacturability	Quant	Product	Hair dryer	O	X	X
Goodall *et. al*. (2014) [15]	Costs, Value	Waste generation, Energy consumption, Legislations	Human factors Societal factors	Assess remanufacturability	Qual (Review)	Unspecified	1. Wind turbine gearbox 2. Automotive parts 3. Industrial machine parts 4. Automotive lighting 5. Gearboxes	X	X	O
Yang *et. al.* (2015) [32]	Costs	Material consumption, Energy consumption, Waste generation Toxic substance discharge	N/A	Assess remanufacturability	Mixed	Component	1. Alternators 2. Hedge trimmer	O	X	O
Golinska *et. al.*, (2015) [12]	Costs	energy consumption, amount of wastes generated, material recovery rate, and amount of generated emissions	Employment Hazards on workers Level of innovation	Measuring company's sustainability level	Quant	Company	Automotive remanufacturi ng sector	O	X	O

Yang *et. al.* (2016) [13]	Reman process cost, Added value	Regulation, Energy consumption	N/A	Assess remanufacturability	Mixed	Product	Desktop phones	O	X	X
Karaulova and Bashkite (2016) [21]	Costs	Material consumption, Energy consumption, Pollution	N/A	Assess remanufacturability	Quant	Product	Used Industrial equipment	O	X	O
Gao *et. al.* (2018) [38]	Costs, Profit	Material environmental impact	N/A	Assess remanufacturability	Quant	Product	Electric Motor	O	X	O
Farahani *et. al.* (2019) [29]	Costs, Revenue	N/A	N/A	Assess remanufacturability	Quant	Product	Personal Computer	O	X	O
Jiang *et. al.* (2020) [31]	Reman Costs	N/A	N/A	Assess remanufacturability	Quant	Product	Excavator	O	X	O
Meng *et. al.* (2020a) [23]	Costs	Energy savings, Energy consumptions, CO_2 Emissions	Job creation	Assess remanufacturability	Quant	Product	Automobile Engine	X	X	O
Jiang *et. al.* (2019) [22]	Cost Income	Environmental benefits Exhaust fumes emissions Waste discharge Energy and water consumption	Service level Social responsibility	Assessed ecological performance	Quant	Product	Hydraulic cylinder and boom cylinder	X	X	X

X – Factor considered, O – Factor not considered

3.2. Product Assessment Metrics

Product assessment approach to assessing product remanufacturability measures the feasibility of remanufacturing a product based on the characteristics of the product. It covers an assessment of the product structure or design and the condition of the returned products (cores). Researchers in remanufacturing literature have used this approach in many different ways. Several tools and methods have been proposed to aid the decision of "whether or not" to remanufacture a product. This section highlights what has been discussed in literature on assessing a product for remanufacturability, including factors such as the product design, core availability, core quality and quantity.

3.2.1. Product Design Assessment

A literature review by Subramoniam *et. al.* (2009) on the strategic decision factors suggested the impact of product design on its end-of-life decision-making [9]. Subramoniam *et. al.* (2013) proposed a remanufacturing decision-making framework (RDMF) which ranked the importance of product design when assessing the remanufacturability of a product [26]. Duberg *et. al.*, (2020) also identified product design for remanufacturing and information exchange as a supporting factor in remanufacturability decision-making [39]. Also, using fuzzy DEMATEL, Singhal *et al.*, (2020) identified design for remanufacturing as a major factor that influence remanufacturing [40]. The finding from these studies shows the importance of product design on the ease of remanufacturing. This means that products designed with end-of-life considerations are more likely to be feasible for remanufacturing. Wahab *et. al.* (2018) reviewed design for remanufacturing in the marine industry with a focus on how design for remanufacturing can improve the reliability and safety of marine equipment [41].

Since product design significantly affects the feasibility and efficiency of remanufacturing operations, researchers have developed models, frameworks and methods to assess the remanufacturability of product designs. Among such work is Amezquita *et. al.* (1995) which identified key design factors that affects product remanufacturability. The proposed design for remanufacturing guideline by Amezquita *et. al.* (1995) focused on specific stages in the remanufacturing processes such as disassembly, cleaning, inspection, part replacement and reassembly [20]. Bras and Hammond (1996) described metrics for assessing remanufacturability of products based on specific design characteristics [25]. The proposed assessment metrics formed the early basis of design for remanufacturing (DfRem) concept which consider the impact of product design on the ease of remanufacturing process. Yang *et. al.* (2016) proposed a four-step decision model for assessing the viability of remanufacturing a product and its components. The component-level feasibility analysis in the proposed decision model evaluates the impact of product design on remanufacturing feasibility [13].

Ijomah (2009) proposed a design for remanufacturing (DfRem) guideline using case studies and workshop to assist designers in improving the feasibility of remanufacturing. Specific design characteristics considered in the design guideline are the impact of material selection, assembly and joining technique, and product structure on the ease of remanufacturing processes [10]. Chakraborty *et. al.* (2017) developed a hierarchical model using Fuzzy AHP methodology to assess the remanufacturability based on specific design criteria [42]. The study focused on design characteristics that affect each step in the remanufacturing process. For example, design characteristics for ease of disassembly may include fastener design, part accessibility, design modularity and number of parts. Gehin *et. al.* (2008) developed a remanufacturable product profile (RePro^{2}) tool to be used early in the design process to ensure that products are designed for sustainability [33], thereby improving remanufacturability. Hatcher *et. al.* (2013) used case study research to highlight the operational factors that affect design for the ease of remanufacturing. The factors identified were related to the consumers, designer knowledge of remanufacturing process, suppliers, and OEM business requirements [43].

Comprehensive discussion on design for remanufacturing can be found in literature which are outside the scope of this review. Studies reviewed in this section have highlighted design-related considerations such as materials selection, fastener design, product structure and accessibility of components as the common design factors assessed during remanufacturability assessment. A summary is presented in table 3.

Table 3: Summary of product design assessment tools

References	Description	Method	Approach	Design criteria for remanufacturability assessment	Product/Industry considered
Subramoniam *et al*., 2013 [26]	proposed a remanufacturing decision-making framework based on strategic factors	Quantitative	Analytical Hierarchical process	Design for remanufacturing	Automotive aftermarket
Wahab *et al.*, 2018 [41]	reviewed design for remanufacturing issues in the marine industry	Qualitative	Literature review	1. durability of the materials, 2. product geometry, 3. design architecture, 4. design complexity and, 5. reliability of components and assemblies.	Marine or offshore components and structures
Amezquita *et al.*, 1995 [20]	proposed design for remanufacturing guideline to improve the ease of remanufacturing	Qualitative	Interview	1. Materials selection 2. Assembly methods 3. Fastener and Jointing technique 4. Design modularity 5. Part quality	Automobile door
Bras and Hammond 1996 [25]	proposed design for remanufacturing metrics to measure remanufacturability of product designs	Quantitative	Case study	1. Part interfacing 2. Quality assurance 3. Damage correction 4. Testing	1. Kodak Funsaver camera 2. Clutch disk and cover 3. Automobile alternator 4. Jeep Grand Cherokee four-wheel drive transfer
Gehin *et. al.* (2008) [33]	proposed a RePro2 approach that can be used early in the design phase to improve product remanufacturability at its end of life.	Quantitative		Design for remanufacturing	Cement mixer
Ijomah 2009 [10]	proposed a design guideline to improve remanufacturability of product designs	Qualitative	Case study Workshop	1. Material selection 2. Assembly technique 3. Product structure	Mechanical and electronic products
Yang *et al.*, 2016 [13]	developed a decision support tool for planning product end of life recovery strategy	Mixed methods	Multi-stage approach using Case studies	Design viability	Desktop phones
Chakraborty *et. al.* (2017) [42]	proposed hierarchical model to evaluate remanufacturability based on design criteria	Quantitative Fuzzy AHP Fuzzy AD	Expert survey	1. Fastener design 2. Design modularity 3. Part accessibility 4. Product geometry 5. Material selection 6. Surface finishing 7. Part durability 8. Part restorability 9. Part identification 10. Standardised parts 11. redundant parts	Automotive diesel engine remanufacturing plant
Hatcher *et. al.* (2013) [43]	developed a method to help OEMs assess their design for remanufacturing maturity	Qualitative	Case study Semi-structured interviews	1. designer motivation 2. Designer knowledge and understanding 3. Management commitment 4. Design priorities 5. Product design specifications 6. design reviews 7. design tools	1. Diesel engines 2. Oil pump 3. Off-road equipment
Duberg *et. al.* (2020) [39]	identified decision factors which should be considered when assessing remanufacturing capability of OEMs	Qualitative	Case Study	Design for remanufacturing Information feedback	Electrical and electronics equipment manufacturer
Singhal *et. al.*, (2020) [40]	assessed the interaction between critical factors that influence remanufacturing	Quantitative	*Fuzzy* DEMATEL	Design for remanufacturing	Unspecified

3.2.2. Returned Product Assessment

Returned products (or cores) assessment evaluates the feasibility of remanufacturing a product based on the condition, quantity and timing of the returned end of life product. Research has identified uncertainty issues associated with returned cores. A number of studies have assessed the remanufacturability of a product using the conditions of returned cores. Subramoniam *et. al.* (2009) and Singhal *et. al.*, (2020) suggested that core management, represented by core availability [9] and core collection strategy [40], is a backbone for successful remanufacturing activity and should be considered during remanufacturability assessment. Subramoniam *et. al.* (2013) ranked core management as second most critical factor considered during remanufacturability assessment [26]. Recently, Duberg *et. al.* (2020) identified the availability and supply of cores, expressed in terms of core acquisition and reverse logistics, as a critical factor for remanufacturability [39]. Also, a review article by Meng et. al., (2020b) identified quality and quantity of returns as important considerations during smart recovery decision-making [44]. This further shows the criticality of core management in the remanufacturability assessment process.

The supply and quantity of core available to feed the remanufacturing process plays an important role in remanufacturability decisions. Therefore, research have highlighted the importance of core availability in the remanufacturing decision system. Ostlin *et. al.* (2009) contributed to remanufacturability assessment by incorporating difficulties involved in obtaining used cores into the end of life decision-making [45]. The study assessed the impact of timing and quantity of returned items on balancing the supply and demand sides of remanufacturing operation. Guide (2000) highlighted uncertainty in timing and quantity of returned core items as a complicating characteristic of remanufacturing [27]. The product-level feasibility analysis of the remanufacturability assessment model proposed by Yang *et. al.* (2016) evaluated the supply of cores needed to drive the remanufacturing process [13]. The study assessed core supply using return potential of used products, which deals with the timing, quantity and quality of returned items.

Some other studies have focused on the physical conditions and quality of returned cores. Sherwood *et. al.* (2000) discussed the impact of failure and scrap modes of returned cores on remanufacturability assessment [46]. Yang *et. al.* (2015) proposed a tool to assist decision-makers in assessing the remanufacturability of components [32]. The first step in the decision tool involved a physical assessment of the returned cores to identify defects, failures and damages of the part. Kin *et. al.* (2014) measured product remanufacturability by assessing the condition of returned cores using the FMEA approach [30]. Farahani *et. al.* (2019) proposed a quality grading approach for returned core items using a case study of computer remanufacturing [29]. The decision support tool proposed in the study begins with an evaluation of the quality and quantity of retuned core items. Gao *et. al.* (2018) focused on component-level remanufacturability assessment by evaluating the quality condition of returned items [38]. Gao *et. al.* (2018) also assessed the uncertainty criteria associated with the quality condition of components of returned cores. Evaluation of the quality criterion forms a strong basis in the proposed model. A summary of the discussions in this section is presented in table 4.

Table 4: Summary of Returned Product assessment discussions in literature

References	**Description**	**Method**	**Approach**	**Returned core remanufacturability considerations**	**Products/Industry considered**
Subramoniam et. al. (2009) [9]	reviewed literature to identify gaps in automotive remanufacturing	Qualitative	Case study Semi-structured interview	Unclear	Automotive aftermarket
Singhal *et. al.*, (2020) [40]	assessed the interaction between critical factors that influence remanufacturing	Quantitative	Fuzzy DEMATEL	Collection strategy Inventory control	Unspecified
Subramoniam et al., (2013) [26]	proposed a remanufacturing decision-making framework based on strategic factors	Quantitative Analytical Hierarchical process		Core Management	Automotive aftermarket
Ostlin et. al. (2009) [45]	addressed the impact of balancing supply of cores and demand for remanufactured products on remanufacturing operations and firms	Qualitative	Case study Semi-structured interview	Timing of returned core Quantity of returns Mean product lifetime, Rate of technical innovation Failure rate of components	1. Forklift trucks 2. Toner cartridges 3. Soil compactors 4. Filling machines 5. Engines 6. Automotive components
Guide (2000) [27]	identified and discussed certain characteristics that complicate end of life strategy planning for remanufacturing firms.	Quantitative	Expert Survey	Uncertainty in timing of return Quantity of returned cores	1. automotive. 2. aerospace, 3. machinery, 4. office equipment, 5. bearings, 6. gears, 7. pumps
Yang et. al. (2016) [13]	developed a decision support tool for planning product end of life recovery strategy	Mixed methods	Multi-stage approach using Case studies	Return potential Remaining useful life	Desktop phones

Sherwood et. al. (2000) [46]	analysed the waste stream of remanufacturing firms to understand the impact of failure modes on remanufacturability	Quantitative FMEA	Numerical example	Failure modes	Automotive
Yang et. al. (2015) [32]	proposed a decision support tool to assess component remanufacturability after the product is disassembled to different components	Mixed Methods	Case study	Quality of returned core	1. Alternators 2. Hedge trimmer
Kin et. al. (2014) [30]	assessed condition of returned cores for optimal remanufacturing operation planning	Quantitative FMEA	Numerical examples	Quality of returned core	Camshafts
Farahani et. al. (2019) [29]	presented a framework to assist decision makers decide whether to remanufacture or replace parts during product remanufacturing	Quantitative	Case study (Numerical illustration)	Quality of returned core	Personal Computer remanufacturing
Gao et. al. (2018) [38]	proposed a multi-criteria decision-making method to find the best EOL options of component	Quantitative AHP	Numerical example	1. Quality condition a. physical condition b. obsolescence condition	Electric motor
Meng et. al. (2020b) [44]	presented a review of smart product recovery decision-making	Qualitative	Review	Quality of returns Quantity of returns	N/A
Duberg *et. al.* (2020) [39]	identified factors that influence remanufacturing decisions for OEMs	Qualitative	Case study	Core acquisition and reverse Logistics	Electrical and electronics equipment manufacturer

3.3. Technology Metric

The aim of technological assessment metric is to consider the ease of putting an end-of-life or end of use product through the various remanufacturing steps or activities (shown in figure 3). It is suggested that technological assessment is closely linked to the assessment of product design for remanufacturability. Gonzalez and Adenso-Diaz (2005) proposed a model for determining the appropriate end of life strategy based on the product structure obtained from CAD representation [36]. The model based on product design information determines the disassembly sequence, disassembly depth and best end of life strategy for each component of a returned core. The proposed assessment tools by Ong *et. al.* (2016) and Fang *et. al.* (2014) also included metrics for technological assessment of remanufacturability [47], [48].

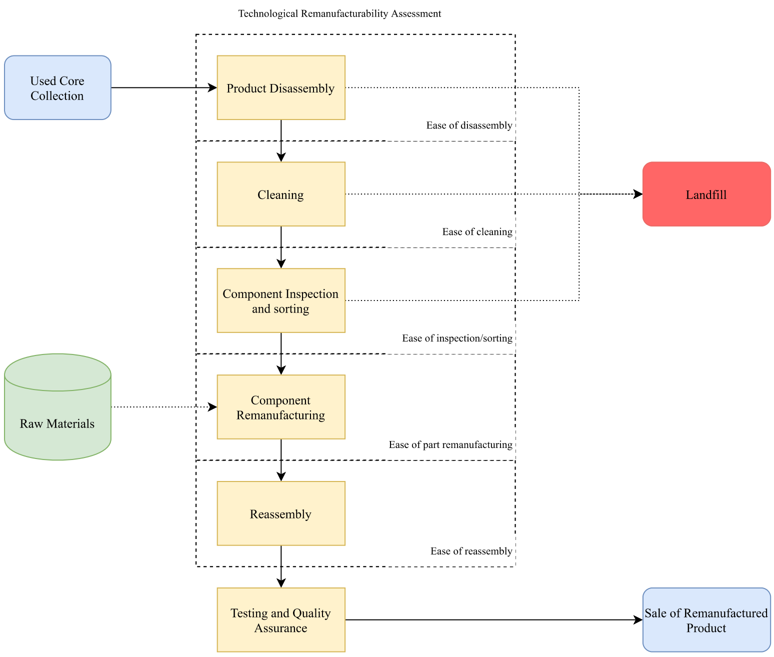

Figure 3: Remanufacturing process chart with remanufacturability assessment

Remanufacturability assessment method proposed by Ong *et. al.* (2016) was based on CAD information and it contained quantitative assessments of disassembly complexity, fastener accessibility, disassemblability and recoverability. These metrics measured the relative ease of disassembly, cleaning, part refurbishment and reassembly. Amezquita *et. al.* (1995) developed a design for remanufacturing guideline which emphasizes the ease of disassembly, ease of cleaning, ease of inspection, ease of part replacement and ease of reassembly [20].

Further, results obtained from workshops and case studies performed by Ijomah *et. al*. (2007) provided deeper insights into specific product features and characteristics that affect ease of the remanufacturing process [7]. Disassembly operation has received the most research attention in technological remanufacturability assessment. A review of remanufacturing production planning by Guide (2000) highlighted disassembly or disassemblability of cores as a critical factor that makes remanufacturing more difficult [27]. Disassembly operations was highlighted by Meng *et.al.* (2020b) as an important consideration during smart recovery decision making [44]. Zhang *et. al*. (2004) developed a web-based end of life decision support tool for remanufacturability assessment [8]. The tool included product disassembly as one of its five functions to assess remanufacturability. Gao *et. al*. (2018) studied the uncertainty associated with the complexity of disassembly operation in two phases: joint type complexity, and technical complexity of components of returned products [38].

Researchers have applied different approaches to technological assessment of product remanufacturability. Bras and Hammond (1996) identified design metrics which can be used to measure remanufacturability of a product based on the relative ease of the remanufacturing process [25]. These metrics include metrics for disassembly and reassembly, metrics for inspection and testing, metric for cleaning, and metrics for part refurbishing or replacement. These metrics were combined using factor weights obtained from pairwise comparison to give the overall remanufacturability index of a product. Karaulova and Bashkite (2016) proposed a decision support framework to quantitatively assess product remanufacturability using technological assessment, economic assessment and environmental assessment [21]. The technological assessment in [21] measured the ease of steps in the remanufacturing process such as disassembly, cleaning, inspection and sorting, part reconditioning, and reassembly (figure 5). Chakraborty *et. al.* (2017) proposed a method for remanufacturability assessment similar to [25] which evaluated the ease of conducting each step of the remanufacturing process based on design characteristics [42]. For example, the criteria for ease of cleaning can be evaluated using design surface smoothness, product geometry and material selection; criteria for inspection and salvaging can be evaluated using ease of part identification, part durability and restorability.

Some other scholars have also proposed tools to assist remanufacturers and decision makers with specific issues during the remanufacturing process. Ng *et. al*. (2013) proposed an OEM-focused decision support framework to assist decision makers during product disassembly, sorting and inspection phases of remanufacturing [37]. Kafuku *et. al*. (2016) proposed an evaluation framework for selecting remanufacturing technology or manual operations involved in the remanufacturing process [49]. Lahrour and Brissaud (2018) presented a framework for assessing additive remanufacturability of components based on specific product characteristics which include the type of defects that a returned cores has and the ease of component remanufacturing using additive technology [50]. A summary is presented in table 5.

Table 5: Summary of Technological remanufacturability assessment factors

References	Description	Method	Approach	Technological remanufacturability considerations	Product/Industry considered
Gonzalez and Adenso-Diaz, 2005 [36]	proposed a new approach for EOL strategy selection using information from 3D CAD representation, BOM, economic and technical data	Quantitative (Scatter Search Metaheuristics)	Case study	1. disassembly sequence 2. Disassembly depth	Mobile phone
Ong *et. al.* (2016) [47]	proposed a remanufacturability assessment method based on 3D CAD representation	Quantitative (Numerical Analysis)	Case study	1. Disassembly complexity 2. fastener accessibility 3. disassemblability 4. recoverability	Electric motor reducer
Fang *et. al.* (2014) [48]	proposed a remanufacturability assessment method based on 3D CAD representation	Quantitative (Numerical Analysis)	Case study	1. Disassembly complexity 2. fastener accessibility 3. disassemblability 4. recoverability	Automotive alternator
Amezquita *et al.*, 1995 [20]	proposed design for remanufacturing guideline to improve the ease of remanufacturing	Qualitative	Interview	1. Ease of disassembly 2. Ease of cleaning 3. Ease of inspection 4. Ease of part replacement 5. Ease of reassembly	Automobile door
Ijomah *et al.*, 2007 [7]	presented the findings of a study to understand product characteristics that complicate remanufacturing	Qualitative	Workshop	1. Core cleaning 2. Strip core (disassembly) 3. Component cleaning 4. Component remanufacture 5. Component storing 6. Product assembly 7. Product Testing	Automotive industry
Guide 2000 [27]	identified and discussed certain characteristics that complicate end of life strategy planning for remanufacturing firms.	Quantitative	Expert Survey	1. Disassembly of returned core 2. Material recovery uncertainty 3. Reverse logistics issues 4. Materials matching difficulties	1. automotive. 2. aerospace, 3. machinery, 4. office equipment, 5. bearings, 6. gears, 7. pumps

Zhang *et al.*, 2004 [8]	presented a web-based tool to assess remanufacturability of end-of-life products	Quantitative (Numerical Analysis)	Case study	1. product disassembly 2. materials recovery 3. recycling management	Desktop computer
Gao *et al.*, 2018 [38]	proposed a multi-criteria decision-making method to find the best EOL options of component	Quantitative AHP	Numerical example	1. Disassembly complexity a. Joint type of component b. Technical complexity	Electric motor
Bras and Hammond 1996 [25]	proposed design for remanufacturing metrics to measure remanufacturability of product designs	Quantitative Case study		1. Part interfacing 2. Quality assurance 3. Damage correction 4. Testing	1. Kodak Funsaver camera 2. Clutch disk and cover 3. Automobile alternator 4. Jeep Grand Cherokee four-wheel drive transfer
Karaulova and Bashkite, 2016 [21]	proposed an integrated method for evaluating remanufacturability of used industrial equipment.	Quantitative (Computation)	Case study	1. ease of disassembly 2. cleaning assessment 3. Inspection and sorting 4. Assessment of part reconditioning 5. Possibilities for machine upgrade 6. Ease of reassembly	Used Industrial equipment
Chakraborty *et. al.* (2017) [42]	proposed hierarchical model to evaluate remanufacturability based on design criteria	Quantitative Fuzzy AHP Fuzzy AD	Expert survey	1. Disassembly 2. Cleaning 3. Inspection and salvaging 4. Reassembly	Automotive diesel engine remanufacturing plant
Ng *et al.*, 2013 [37]	proposed a product assessment framework for the OEM	Quantitative (Computation)	Case study	1. Product collection 2. Product sorting and inspection 3. Part disassembly 4. part verification and value determination	Hair dryer
Kafuku *et al.*, 2016 [49]	proposed a holistic framework to assess the feasibility of remanufacturing operation	Quantitative (multi-input-multi-outputs (MIMO) parameters in fuzzy logic)	Case study	1. Technology Functions 2. Technology Quality 3. Technology Flexibility	Cylinder head for automotive engine
Lahrour and Brissaud, 2018 [50]	proposed a framework to assess remanufacturability of components using additive technology	Unclear	Unclear	1. Product failure and inspection 2. Part remanufacturing	Unspecified
Yang *et al.*, 2016 [13]	developed a decision support tool for planning product end of life recovery strategy	Mixed methods	Multi-stage approach using Case studies	1. remanufacturing know-how 2. remanufacturing capability	Desktop phones
Meng *et. al.* (2020b) [44]	presented a review of smart recovery decision-making	Qualitative	Review	1. Identification and sensing 2. Sorting and inspection 3. Disassembly operations	N/A

4. Discussions and Future Work

4.1. Stakeholder consideration in remanufacturability decision-making

Freeman *et. al.,* (2010) described stakeholders as "a group of individuals" whose actions influence or who can be impacted by decisions within a business, organisation, process or industry [51], [52]. Primary stakeholders within the remanufacturing business include the OEM, ER and the consumer whereas secondary stakeholders include, but not limited to, designers, sales vendors and distributors, core collectors and suppliers, local communities and governments etc [53]–[55]. Remanufacturability assessment includes many different considerations and perspectives. An inclusion of the requirements of stakeholders is necessary for the effectiveness of decision process, planning of remanufacturing process and ultimately the attainment of the sustainable development goals. The identified decision factors in literature are associated with primary stakeholders, which include: The OEM, the ER (Contracted or Third-Party) and the Consumer of the remanufactured product. The requirements of the secondary stakeholders are almost often incorporated within those of the primary stakeholders. For example, the OEM, which is mostly involved in the early stages of a product life cycle, covers decision factors of the product designers, distributors etc. The external remanufacturer (ER) refers to any remanufacturer other than the OEM which may include the contract remanufacturer (CR) or the third-party remanufacturer (TPR). The requirements of the ER cover factor that consider the core suppliers, sales vendors for remanufactured products etc. An efficient remanufacturing production line is dependent on these three stakeholders playing their parts. For example, the OEM is expected to ensure that their products are remanufacturable by using high-end design for remanufacturing guidelines, the external remanufacturer should be able to disassemble, clean, inspect, remanufacture and reassemble the components to make a remanufactured product that is acceptable to the consumer.

Findings from this study indicated that remanufacturing a product without a comprehensive consideration of the requirements of the different stakeholders during the remanufacturability decision process may be unsustainable [33], especially if consumer acceptance is low.

Three decision stages identified in literature and the decision factors used in each stage are summarised in table 6. These stages (strategic, tactical and operational) have been discussed extensively in [15]. Table 6 also show the stakeholders whose considerations are included in the three decision stages. The next sections discuss the findings about the consideration of different stakeholders in the remanufacturability decision process.

Table 6: Decision stages and stakeholder considerations

Decision Stage	Description	Stakeholder considered
Strategic	*Strategic* decision stage targets early phases of product development to ensure its remanufacturability. Metric often used to assess remanufacturability include: 1. Sustainability metric including factors such as economic, environmental and social considerations.	Original equipment manufacturer (OEM)
Tactical	*Tactical* decision stage mostly focuses on product design as a tool to assess remanufacturability. This decision stage is mostly applicable to contract remanufacturers or OEMs that remanufacture their products. Remanufacturability metric used include: 1. Product design assessment focusing on considerations such as the effect of product design on the ease of remanufacturing. 2. Sustainability metrics: *in some cases,* focusing on economic and environmental assessment.	OEM and ER
Operational	*Operational* decision stage focuses on the actual remanufacturing process. In this stage, considerations of the person performing the remanufacturing are included. Metrics used in this stage include: 1. Core management metric such as the quality, quantity and timing of returned cores 2. Technological assessment metric such as the ease of disassembly, ease of cleaning, ease of inspection, ease of cleaning, ease of part remanufacturing, ease reassembly and ease of product testing.	External remanufacturer (ER)

Researchers have used sustainability factors to represent OEM considerations when assessing the viability of remanufacturing. Sustainability factors (such as the economic, environmental and social assessment) and product metric (such as product design assessment) have been discussed extensively in literature, and in this report. Some studies have also developed tools for original manufacturers to assess the remanufacturability of their products using specific product features and product design characteristics [37], [39], [46], [56]. The implication of this is the development of product designs that reduce the difficulty of the remanufacturing process thereby, improving sustainability. The considerations of the external remanufacturer (ER) used in remanufacturability assessment include the product and technology factors such as product design assessment, technological assessment and returned product assessment. Other scholars have incorporated sustainability thinking as one of the considerations of the ER which include factors such as economic and environmental assessments. This has resulted in the development of tools and methods to assess the condition of returned items for remanufacturability. Early assessment of returned products against the requirements of the remanufacturing process reduce wastes sent to landfill while also avoiding any unnecessary use of limited resources on parts recovery for products or industries with low consumer acceptance [46]. Table 7 shows a summary of decision factors that have been used in remanufacturability assessment and the stakeholders they mostly represent.

Table 7: Remanufacturability factors associated with different stakeholders

Stakeholder	Remanufacturability Assessment factor	References
Original manufacturer (OEM)	1. Sustainability Metric:	
	a) Economic assessment	[8], [9], [11], [20], [26], [36]
	b) Environmental assessment	[9], [15], [20], [26], [33], [37], [57]
	c) Social impact assessment	[12], [37]
	2. Product Metric:	
	a) Product design (Design for remanufacturing)	[10], [25], [33], [43]
External remanufacturer (ER)	1. Sustainability Metric:	
	a) Economic assessment	[12], [13], [29], [37], [38]
	b) Environmental assessment	[10], [12], [21], [38]
	2. Product and Technology Metric	
	a) Product design assessment	[10], [13], [26], [41], [42]
	b) Technology assessment	[8], [20], [21], [36], [42], [47]–[50]
	c) Returned product assessment	[13], [27], [29], [30], [32], [38], [45], [46]

4.2. Consumer considerations

Results from this review showed that the OEM and ER factors are the most considered in remanufacturability decision-making. Only few studies have given attention to the requirements of the consumers in the remanufacturability decision mix. It is not surprising that consumer considerations and factors have not been duly included in remanufacturability decision making. This stem from a general belief that since consumers are not involved in the actual decision process, they are unable to influence key factors such as design, disassembly and inspection. However, growing research points towards the need understand the impact of consumer factors on key stages of remanufacturability decision making. Consideration of consumers requirements in remanufacturability decision is achieved using either the supply and/or demand requirements [45]. The supply side covers consumers' willingness to return their used products to serve as cores for the remanufacturing operation [45]. This is often linked to returned product assessment which evaluates the availability of cores in terms of the timing, quantity and quality of used products. This has been covered in section 3.2.2. The demand side covers issues relating to consumer acceptance of the remanufactured product which is critical to the success of remanufacturing. Different studies have discussed the impact of consumer considerations in remanufacturing decision making, as shown in Table 8. However, most studies considered this from a high level, separated from the remanufacturability decision process and as such key factors that make up consumer considerations of remanufactured product have not been duly incorporated into remanufacturability decision-making [58].

Guide (2000) highlighted the need to balance supply and demand in remanufacturing planning to ensure maximum profitability of remanufacturing [27]. Ostlin *et. al.* (2009) also discussed the importance of balancing the supply of cores with the demand for remanufactured products to increase consumer acceptance [45]. The authors described the possibility of improving the relationship between the consumers and the remanufacturer so that potential products can be identified for remanufacturing. Sarkis (2003) argued that there is a need to include consumer requirements when making decisions such as the location of distribution systems to ensure the efficiency of distribution networks [59], saving costs and reducing environmental pollution associated with transportation. Subramoniam *et. al.* (2009) also identified an absence of good tools and information that can be used to convince consumers to use remanufactured products [9]. The author went further to discuss the impact of this on the long-term growth and profitability of remanufacturing operations. Subramoniam *et. al.* (2013) took the discussion further by asking experts in remanufacturing business the question: *"Do OE customer specifications and requirements with respect to reman influence your decision to reman?"* [26]. The results from the study contained a pairwise comparison of key factors that impact remanufacturing decision-making for original manufacturers. The study also ranked the impact of customer product requirements on remanufacturability decision-making as 5th (out of 9 factors), pointing out the importance of consumer considerations in the decision-making process. Since consumers are an integral part of sustainable development [60], remanufacturing will only reach its full potentials when products are accepted by the consumers.

Table 8: Summary of studies that consider consumers in remanufacturability decision-making

References	**Description**		**Sustainability Metrics**			**Product and Technology Metrics**			**Considers consumer requirements?**
	Method	Product/ Industry	Economic	Environment	Social	Product Design	Technological Assessment	Core Assessment	
Guide 2000 [27]	Qual	N/A	O	O	O	O	X	X	Yes
Sarkis, J. (2003) [59]	Quant	N/A	X	X	O	O	O	X	Yes
Subramoniam *et. al.* (2009) [9]	Qual (Review)	Automotive aftermarket	X	X	O	O	X	O	Yes
Ostlin *et. al.* (2009) [45]	N/A	N/A	X	X	X	O	X	O	Yes
Subramoniam *et al.* (2013) [26]	Quant	Automotive aftermarket	X	X	O	X	O	X	Yes
Yang *et al.* (2016) [13]	Mixed	Desktop phones	X	X	O	X	X	X	Yes
Li *et. al.* (2017) [61]	Quant	Apple MP3 Player	X	O	O	O	O	O	Yes
Gao *et al.* (2018) [38]	Quant	Electric Motor	X	X	O	O	X	X	Yes
Singhal *et. al.*, (2020) [40]	Quant	N/A	O	O	X	X	O	X	Yes

On the consumer side of literature, extensive research has been done to present a better understanding of the role and importance of consumers in the remanufacturing system. In attempts to improve consumer return of cores, Harrell and McConocha (1992) identified consumer factors that affect returns of used products [62]. Jena and Sarmah (2015) proposed a model to measure consumers' rationale for returning used products [63]. Govindan, Soleimani and Kannan (2015) reviewed published literature on reverse logistics to clarify what has been achieved and to create a clear path for future research [64]. Gaur *et. al.*, (2017) aimed to bridge the gap between core acquisition management and consumer disposition behaviour by proposing a framework which reduces the complexity of core acquisition using consumer disposition behaviour [65]. Although extensive research has been carried out on consumer behaviour and return of used products (*see also* [66]–[68]), the impact of consumer behaviour on remanufacturability assessment is understudied. To date, the problem has received scant attention in the research literature.

Recent studies in remanufacturability assessment have begun to include consumer considerations in the decision-making process. For example, Yang *et. al.* (2016) included market acceptance into the remanufacturability decision mix of mobile phones considered in the study [13]. Li *et. al.* (2017) incorporated consumer perception into remanufacturing production planning and investigated the impact of consumer considerations on OEM and TPR remanufacturing strategies [61]. Gao *et. al.* (2018) included customer reference in the multi-criteria decision model for remanufacturability assessment, focusing on the market value and consumer acceptance of the remanufactured product [38]. Also, using fuzzy DEMATEL method, Singhal et. al., (2020) identified consumer factors such as branding, green awareness, purchase intention, return intention and pricing strategy as critical factors which influence remanufacturing and must be adequately considered during remanufacturing decisions [40].

There is always an uncertainty with consumers return of used cores and acceptance or rejection of remanufactured product, especially when consumer considerations are not comprehensively accounted for. Unaccepted remanufactured product may be put into other uses or disposed. This poses a challenge to the attainment of sustainability. When remanufactured products are not accepted, all the energy and resources associated with the original manufacturing and subsequent remanufacturing become wasted and there is a greater pressure on the environment. Also, costs associated with obtaining and remanufacturing returned items are unrecoverable, causing significant economic loss to the remanufacturer.

4.3. Research Gap

Despite increasing discussions about the need to consider consumer requirements in remanufacturability decision-making, the actual makeup of consumer considerations in remanufacturability assessment is somewhat vague. The general terms "*market acceptance*", "*consumer perception*", "*consumer reference*", "*consumer returns*" and "*core acquisition*" etc. are broad topics which must be evaluated and included in the decision process. For remanufacturing to be sustainable, there must be a consistent supply of cores and acceptance of remanufactured products. With the direction of existing research, it is clear that understanding how best to fit consumer requirements into remanufacturability decision-making is important to improve supply of cores and enhance acceptance of remanufactured products to reduce the time required to market remanufactured products [61]. This will encourage remanufacturing and ensure a constant cycle of profit for the remanufacturer.

4.4. Future work

Going forward, researchers must aim to bridge the gap between consumer considerations and remanufacturability decision-making. Consumer return of used products and market acceptance of remanufactured products pose a significant threat to the goals of remanufacturing [33] and sustainability [69]. Thus, this must be considered early in the remanufacturability assessment. Future work can take this research further in the following ways.

First, to improve sustainability and increase acceptance of remanufactured products [45], especially in industries where equipment performance is tied to safety (e.g. due to the human element) such as the medical devices industry, consumer considerations must be included in the remanufacturability decision process. Evidence shows that there is a massive body of scholarly work, which have assessed consumers' purchase intentions and willingness to use a remanufactured product [58], [61]. Consumers' inclination to purchase and use remanufactured item is impacted by a number of factors such as the quality, brand, warranty and price, which have been discussed in literature. Thus, it may be necessary to review these consumer decision factors and include them in remanufacturability decision-making. Including consumer considerations in remanufacturing planning and decision making can improve market acceptance and reduce the time required to market remanufactured products. Researchers may also attempt to close this knowledge gap by proposing frameworks, methods, or tools to connect literature on consumer decision-making with remanufacturability assessment.

Second, there is need for further research to understand the extent of the inter-relationships between the factors identified in this study. For example, this report has suggested that product design assessment is closely related to technological assessment. While some existing studies have simultaneously assessed the design of a product and the technology of the remanufacturing process [36], there appears to be no research effort to understand how this relationship might influence remanufacturability decision-making. Understanding the inter-relationship between factors would enable researchers to develop methods and guidelines to improve remanufacturability assessment, consumer acceptance and sustainability of the remanufacturing process.

Third, the automotive industry is the most mature remanufacturing sectors and as such it has received scrutiny from researchers. However, several other industries hold huge promise for remanufacturing such as the marine and offshore [41] and medical devices [70]. There is potential for researchers to advance remanufacturing knowledge and sustainable practise by developing methods and tools to assess remanufacturability of products within specific industries. This will increase the industrial scope of the remanufacturing and improve its potency as a strategy for sustainable production and consumption [71].

Finally, the relationship between stakeholders is key to smooth remanufacturing process planning. Players in the remanufacturing industry and, especially the decision makers must begin to consider consumer factors when deciding whether or not to remanufacture. To improve the effectiveness of remanufacturing, efforts must be made to understand specific aspects of consumer expectations [58]. To assist the building of consumer-focused remanufacturing operations, researchers must focus on determining how specific consumer requirements can be included in the remanufacturability decision mix. Also, remanufacturing firms must begin to pay more attention to the complex issue of consumer behaviour, which is plagued by rapidly changing technology and unstable world economy.

5. Conclusion

The impact of remanufacturing as an important approach to sustainable development is well documented in literature [33], [72]. However, any end-of-life recovery strategy may well become a deterrent for sustainability if consumers' acceptance is low. Alongside consumers, the original manufacturer (OEM) and the external remanufacturer (ER) are the primary stakeholders whose requirements must be considered when deciding to remanufacture a product. Although the importance of considering stakeholder factors during remanufacturability decision-making has often been discussed [27], [45], there is no comprehensive review and understanding of how different stakeholders have been considered in the remanufacturability decision process. This study set out to perform a critical analysis of stakeholder considerations in remanufacturability decision-making and to present the state of art using the systematic literature review method. Forty-three (43) high quality articles were identified and reviewed in this study.

This study identified knowledge gaps relating to inclusion of consumer considerations in remanufacturability decision-making. Further research should be undertaken to improve understanding of consumer factors in certain industries and then include these factors in remanufacturability decision-making. This approach will improve the efficiency of remanufacturability decision by ensuring that products are remanufactured to meet specific consumer requirements thereby improving market acceptance for remanufactured products. This study will improve the understanding of remanufacturability to researchers and industry practitioners and assist them to identify the factors that have been used to assess product remanufacturability. The implication of this is that, including consumers' considerations in remanufacturability will help decision makers efficiently identify prospective products to remanufacture instead of the selection and remanufacturing of products which may not be accepted by consumers, such as in the mobile phone industry. This finding is critical to the realisation of the full potentials of remanufacturing as a sustainable strategy to reduce wastes and energy consumption by returning used products to 'like-new' condition [7], [73].

Review of extant literature indicated that this study is the first, to both perform a comprehensive review of factors used to assess 'whether or not' to remanufacture a product and to understand the stakeholder that each decision factor represents. This study identified several opportunities for future research and proposed ways to improve the success of remanufacturing operation by optimising the remanufacturability decision process. Insights from this study provides a groundwork for future research in remanufacturability assessment, having clearly and comprehensively described the decision factors considered in the decision process. This study contributes to sustainable development by suggesting areas for future research to improve the effectiveness of the remanufacturability decision process and increase consumer acceptance of remanufactured products.

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