Rizova, M. I., Wong, A. TC., & Ijomah, W. (Accepted/In press). A systematic review of decision-making in remanufacturing. Computers and Industrial Engineering.

A systematic review of decision-making in remanufacturing

Potential benefits have made remanufacturing attractive over the last decade. Nevertheless, the complexity and uncertainties associated with the process of managing returned products make remanufacturing challenging. Since this process involves enormous decision-making practices, various methods/techniques have been developed. This review is to specify the current challenges and opportunities for decision-making in remanufacturing. To achieve this, we perform a systematic review over decision-making in remanufacturing by classifying decisions into different managerial levels and areas. Adopting a systematic approach which provides a repeatable, transparent and scientific process, 241 key articles have been identified following a multi-stage review process. Our review indicates that most studies focuses on strategic-level (48%) and tactical-level (34%) with only 5% focusing on operational-level and the rest on two levels (13%). Regarding decision-making methods, most studies propose mathematical models (60%) followed by analytical models (31%). Furthermore, only 36% of the studies address uncertainties in which stochastic approach is mostly applied. A total of 21 knowledge gaps are highlighted to direct future research work.

Keywords: Decision-making; Remanufacturing; Operations Management; Uncertainty

1. Introduction

Remanufacturing is a process in which returned products (or cores/returns) are disassembled, all parts are inspected, repairable parts are fixed, the rest are replaced with new ones, and finally reassembled and tested to restore them into like-new condition (Thierry et al., 1995). It is the only recovery activity which provides the same quality, performance and warranty as the brand-new products (Ijomah, 2009). Remanufacturing has attracted widespread attention due to its potential benefits. Specifically, the economic benefits come from the cost savings (up to 50%) due to the reduction in energy (up to 60%) and material cost (up to 70%) (Jiang et al., 2016b). This cost advantage enables companies to offer remanufactured products at up to 40% lower prices than the new ones with nearly 20% profit margins (Ilgin & Gupta, 2016).

Compared with traditional manufacturing, remanufacturing is challenging due to the complexity and uncertainties associated with the process of managing returned products

(Denizel et al., 2010; Guide, 2000; Inderfurth, 2005). Researchers have developed various decision-making methods as traditional ones may not be applicable to address the tangled characteristics of returned products.

This research is urged due to a lack of a systematic review over decision-making in remanufacturing. The two most recent systematic reviews are Morgan & Gagnon (2013) and Priyono et al. (2016). The former focuses on remanufacturing scheduling while the latter concentrates on disassembly in remanufacturing. However, a more comprehensive review of remanufacturing is needed beyond its scheduling and disassembly decisions. Ilgin & Gupta (2010) examine environmentally conscious manufacturing and product recovery without considering remanufacturing. Goodall et al. (2014) review tools and techniques used to evaluate remanufacturing feasibility but do not specify at what managerial levels/areas these tools and techniques can be implemented. Souza (2008; 2013) and Bostel et al. (2005) review the managerial decisions in closed-loop supply chains (CLSC) and reverse logistics (RL) network but they do not adopt a systematic approach, thus the finding reliability may be reduced (Tranfield et al., 2003). Hence, this paper aims to systematically examine the current challenges and opportunities regarding decision-making in remanufacturing in order to address three main research questions (RQ):

RQ1: What decisions are made in remanufacturing and how those decisions are addressed?

RQ2: What is the role of uncertainties over decision-making in remanufacturing?

RQ3: What are the knowledge gaps about decision-making in remanufacturing?

The remainder of this paper is organised as follows. Section 2 reports our review methodology and findings. Section 3 discusses the decision-making methodologies and Section 4 examines the associated uncertainties. Section 5 summarises this paper with future research directions.

2. Review methodology

As recommended (Thomé et al., 2016) and widely accepted (e.g., Liao et al. (2017); Morgan & Gagnon (2013)), Scopus, Web of Science and Science Direct were used for our review. No filter was applied to time and study type to overcome bias (Tranfield et al., 2003). Our review methodology with four stages is detailed in Figure 1. The language criterion was applied in Stage 1. In Stage 2, quality assessment was conducted following citation metrics and journal ranking (Crossan & Apaydin, 2010). The former was used to evaluate studies dated before 2019 and the latter for studies dated 2019. Google citation metrics were used to assess studies pre-2019, and high-impact studies were defined as having at least five citations per year (Crossan & Apaydin, 2010). “Highest CiteScore percentile” provided by Scopus was used to assess studies dated 2019 which may have low citation metrics. The title and summary of the studies were reviewed in Stage 3 for further screening. In Stage 4, 241 studies were comprehensively reviewed to address the three research questions.

[Figure 1]

3. Review findings

Given the nature of managerial decisions in remanufacturing and their overall impact on businesses, it is useful to classify them into three levels: strategic, tactical and operational (Anthony, 1965; Schmidt & Wilhelm, 2000). Decisions at each level were then grouped by various management areas as shown in Figure 2 following Bostel et al. (2005) and Souza (2008; 2013) who performed the same classification to reverse logistics and CLSC decisions respectively.

[Figure 2]

3.1. Strategic decisions

Strategic-level decisions involve the determination and alteration of organisations’ objectives

(Anthony, 1965) which are made by the top management with long-lasting impact (2-5 years or beyond) (Schmidt & Wilhelm, 2000). Such decisions are engagement in remanufacturing, product design, network design, supply chain (SC) coordination, collection strategy and marketing management.

3.1.1. Engagement in remanufacturing

Given the benefits of remanufacturing and increasing environmental awareness, companies must consider their degree of involvement in remanufacturing practices. Research on engagement decisions in remanufacturing can be classified into four groups (Table 1): (i) critical drivers of original equipment manufacturers' (OEMs') decisions towards in-house remanufacturing; (ii) barriers towards remanufacturing in developing countries; and (iii) economic viability and technical feasibility of remanufacturing; and (iv) optimal timing of implementing in-house remanufacturing.

Our review suggests that both key drivers towards in-house remanufacturing and barriers towards remanufacturing vary among different countries and industries. For instance, technical concerns are the principal drivers for Chinese automotive parts companies (Abdulrahman et al., 2015) while drivers for American OEMs are operational assets, intellectual property and frequency (Martin et al., 2010). For automotive parts remanufacturing, the barrier is lack of fund for remanufacturing technology in China (Xia et al., 2015; Zhu et al., 2014) while it is the higher cost and lack of specific market for remanufactured products in India (Govindan et al., 2016). Table 1 reveals that automotive sector has attracted most attention because it is: (i) one of the earliest industries engaged in remanufacturing (Seitz, 2007), (ii) the leading industry involving most of the remanufacturing companies and remanufactured components (Abdulrahman et al., 2015), and (iii) governed by the regulatory directives on the collection and processing of end-of-life (EOL) vehicles (Karakayali et al., 2007).

[Table 1]

3.1.2. Product design

One of the barriers to remanufacturing is improper product design (Govindan et al., 2016) which affects the remanufacturing profitability (Kwak & Kim, 2015; Wu, 2012b; 2013). OEMs' product design decisions must consider both the pre-life and end-of-life stages of the product to maximise overall profit along the whole product life-cycle (Kwak & Kim, 2015; Ma et al., 2014) and enhance the product remanufacturability (Yang et al., 2017). Nevertheless, OEMs may intend to prevent competition by increasing the remanufacturing cost for third-party remanufacturers (Subramanian et al., 2013; Wu, 2012b; 2013).

Product design decisions are classified into four focuses (Table 2): (i) sustainable product design, (ii) product life-cycle approach of optimising product designs, (iii) component recovery options, and (iv) design for disassembly to reduce remanufacturing cost. Table 2 shows that the interest in product design from remanufacturing perspective has increased especially from its life-cycle aspects. From a methodological standpoint, three model types are noted: (i) conceptual and descriptive models mainly in the form of guidelines and roadmaps for sustainable product design studies, (ii) mathematical and analytical models for component and disassembly-based studies, and (iii) systematic models for studies with life-cycle perspective.

[Table 2]

3.1.3. Network design

Designing an efficient SC network is crucial to meet demand considering the reciprocal flows between customers and manufacturers (Souza, 2013). Determining the locations and capacities of facilities, optimal transportation mode and distribution channel, are the primary network design decisions. Other studies are found to investigate joint location-inventory problems (Abdallah et al., 2012; Lieckens et al., 2013) and integrated SC design and planning problems (Mota et al., 2017).

Network design models can be divided into two groups: (i) stochastic models addressing different types of real-world uncertainties, and (ii) deterministic models neglecting uncertainties. Table 3 shows that 61% of the models are deterministic for the sake of computational simplicity. However, ignoring uncertainties when designing network may be impractical or risky as it can endanger the business survival. On the contrary, the most addressed uncertainty among stochastic models is the demand for remanufactured products while the returns quality which helps determine the number of recoverable products is considered by very few studies. Regarding model objectives, most studies emphasise economic aspects, e.g. maximising the company profit (50%) or minimising the total system cost (32%), only a few studies have incorporated environmental and social aspects. Moreover, most models (86%) are single-objective.

[Table 3]

3.1.4. Supply chain coordination

Coordination is essential for resolving conflicts and disagreements between SC members (Xu & Meng, 2014). Researchers have proposed various mechanisms such as information sharing, contracts and other initiatives to improve SC coordination in remanufacturing.

SC coordination studies are divided into four focuses (Table 4). The first group investigates the impact of demand information sharing on the pricing and SC profit. The second group examines the use of contracts through correlating service level with pricing to increase SC profit. The third group addresses the trade-offs between pricing and remanufacturing effort when maximising SC profit. The final group examines the impact of different channel power structures (e.g., centralised; manufacturer-, retailer-, third-party-led decentralised; and Vertical

Nash) on pricing and collection effort. Table 4 shows that game theory modelling is the most popular method (92%) to resolve conflicts in SC coordination (An et al., 2007). Other methods are equilibrium and benchmark models. Regarding model objectives, most studies (96%) consider profit maximisation. Maximisation of collection efficiency and market share have received limited attention while minimisation of environmental impact has not been examined yet. It reinforces that financial incentives are still the main drivers to SC coordination.

[Table 4]

3.1.5. Collection strategy

Remanufacturers need to minimise the overall collection effort while keeping sufficient quantity of cores for meeting the remanufacturing demand. The choice of collection channels by comparing single and dual channels have been mostly investigated.

The first stream addresses three single channels: (i) Re/manufacturer directly collects from customers (model M); (ii) Re/manufacturer persuades the retailer to collect from customers (model R); (iii) Re/manufacturer authorises the third-party to collect from customers (model 3P). The second stream examines dual channels involving two parties simultaneously: (i) Re/manufacturer and retailer (model M-R); (ii) Retailer and the third-party (model R-3P); (iii) Re/manufacturer and third-party (model M-3P).

Our review uncovers two major observations: (i) Dual channel is superior to single channel because collective effort can increase SC profit with higher collection rates and economies of scale (Hong et al., 2013; Huang et al., 2013; Yi et al., 2016), and (ii) Model R is the optimal collection channel for remanufacturer due to cost savings associated with collection investment (Hong et al., 2015; Savaskan et al., 2004; Savaskan & Van Wassenhove, 2006). Regardless of the channel structure (single or dual), the retailer's involvement is critical to optimise remanufacturer's collection effort (Zhao et al., 2017a). Table 5 shows that, apart from Esmaeili et al. (2016) who consider green costs, many studies examine collection effort by considering one or more of the following: wholesale price, retailer price, product return rate and transfer price.

Various assumptions have been made in these studies which may reduce their real-life impact: (i) 81% of the studies assume that all SC members may share sensitive information such as cost, demand and return which shapes the competition, (ii) 63% of the studies assume deterministic demand for remanufactured products which can be formulated as a linear function of its retail price. However, such demand can be non-linear and sensitive to other factors such as marketing effort, customers' willingness-to-pay, etc. (Esmaeili et al., 2016; Hong et al., 2017), (iii) 75% of the studies assume that the quality of the returned products is homogeneous, i.e. each has the same remanufacturing cost which enables researchers to compare only the quantity of used products from different channels (Karakayali et al., 2007). Such comparison may not be meaningful as the quality of returned products varies significantly in real practice (Denizel et al., 2010; Zhao et al., 2017a), and (iv) 69% of the studies assume new and remanufactured products of the same category can be sold in the same market at the same price. This assumption is valid for only specific categories such as single-use cameras and toner cartridges (Atasu et al., 2013; Liu et al., 2017). For other categories, new products are differentiated from the remanufactured ones which are generally perceived by customers as inferior, thus lower willingness-to-pay (Atasu et al., 2010).

[Table 5]

3.1.6. Marketing management

Marketing management is the process of devising marketing decisions to meet customer needs profitably (Kotler et al., 2009). The primary marketing decisions are pricing of new and remanufactured products, warranty length of remanufactured products and advertisement of remanufactured products.

OEMs' pricing strategies for new and remanufactured products have been examined from different perspectives. Some considers measuring consumers' willingness-to-switch to remanufactured products (Ovchinnikov, 2011); others examine trade-in related decisions (e.g., Xiao (2017)) and leasing duration (Robotis et al., 2012) for customers who want to replace their old products with new/remanufactured products. Some argue that OEMs can influence the pricing strategy of third-party remanufacturers in two ways: (i) Control the degree of disassemblability and interchangeability of OEMs' own products that affect the remanufacturing cost (Wu, 2012b; 2013) and (ii) Prevent market cannibalisation by collecting their products from end users with incentives (Wu, 2015). Another stream argues that pricing for remanufactured products are interrelated with acquisition price of cores to balance the demand for remanufactured products and returns quantity (e.g., Bakal & Akcali (2006)). It is worth noting that issues with market cannibalisation have been mostly examined while other forms of competition have been overlooked.

Apart from pricing, product warranty in which the provider is responsible for correcting or compensating product error during the warranty period can be used as a marketing tool for the remanufactured products. It helps address the product performance uncertainty from the customer's viewpoint (Alqahtani & Gupta, 2017; Kuik et al., 2015). Table 6 shows that pricing for new and remanufactured products is the most popular marketing decision. Although researchers have paid more attention to warranty policies, they have ignored the uncertainties. Also, here is still limited research in advertising decisions which is essential to support communication with customers (Lu et al., 2016).

[Table 6]

3.2. Tactical decisions

Tactical decisions over a mid-term horizon (6-24 months) made by the mid-level managers (Bostel et al., 2005) ensure the effective and efficient use of resources to support strategic-level decisions (Anthony, 1965). Tactical decisions mainly deal with material flow management to ensure the efficient use of available resources and optimisation of production activities and policies (Bostel et al, 2005). In the remanufacturing, these decisions include also the issues related to returned products and the recovery options (Bostel et al, 2005; Souza, 2008; 2013). Hence, tactical decisions are returns disposition, used product acquisition, inventory management and production planning.

3.2.1. Returns disposition

Returns disposition (or EOL option) refers to the selection of recovery option for returned products reaching their EOL to maximise the recovery value (Ferguson et al., 2011). This decision is more crucial for time-sensitive products like high-tech products as any delays in remanufacturing may reduce the product value due to obsolescence (Guide et al., 2008). Uncertain core condition also complicates the disposition decisions as it affects the recovery cost (Meng et al., 2017) as well as the quality of recovered products or harvested components (Ondemir & Gupta, 2014).

Table 7 shows that one stream emphasises returns disposition while another stream integrates returns disposition with disassembly planning where trade-offs between value recovery and cost of disassembly are noted (e.g. Lee et al. (2010)). The last stream promotes joint investigation over inventory control, production control and disposition since inventory level dictates both production and disposition (e.g., Inderfurth (2005)). The first two streams examine recovery options at both product-level and component-level while the last stream only addresses product-level recovery options. 83% of the studies consider economic objectives, i.e. profit maximisation and cost minimisation. Environmental aspects have been emphasised recently since returns disposition has a direct impact on the environment (Ondemir & Gupta, 2014). Interestingly, Meng et al. (2017) is the only study addressing social impact.

[Table 7]

3.2.2. Product acquisition management

The condition, return time and quantity of returned products shape the success of remanufacturing (Guide & Van Wassenhove, 2001; Zhou & Yu, 2011). Therefore, product acquisition management aims to determine the optimum quantities of returns in the optimum quality at the optimum price and time (Atasu et al., 2010). According to Guide and Van Wassenhove (2001), two types of acquisition system may be adopted: waste stream and market-driven. The former exposes companies with the uncontrollable volume of returns with various quality levels whereas the latter enables companies to control the quality and quantity of returned products with financial incentives. The objective of waste stream system is cost minimisation while that of the market-driven system is profit maximisation.

As pioneer in product acquisition, Guide & Van Wassenhove (2001) argue that companies do not have control on product returns and hence propose a conceptual and descriptive framework to analyse the profitability of recovery activities including remanufacturing, recycling, repair, etc. Since then, various quantitative models have been developed to address product acquisition together with different core sorting policies (e.g., Galbreth & Blackburn (2006)). Integration between product acquisition decisions and production decisions have been studied (e.g., Mukhopadhyay & Ma (2009)). Zhou & Yu (2011) argue that pricing of remanufactured product is a function of inventory level and acquisition effort decisions. Gaur et al. (2017) have investigated end users' disposal behaviour to enhance the quality of returned products. Table 8 shows that 75% of the studies address uncertainties. Uncertain core quality has attracted more attention than core quantity particularly in the studies that examine core sorting policies to assess the remanufacturability of returned products (cores). Moreover, all studies have formulated product acquisition as a single objective (mainly economic) rather than multi-objective optimisation problem.

[Table 8]

3.2.3. Inventory management

Inventory management deals with balancing supply and demand by securing adequate stock while avoiding overstocking or shortage (Jonsson & Mattsson, 2008). Managing inventory in remanufacturing is complicated for three reasons (Ilgin & Gupta, 2016): (i) Uncertainties in returns timing, quantity and quality may encourage remanufacturers to prevent shortage by holding more safety stocks, (ii) Environmental legislation may push remanufacturers to accept more returns than needed leading to excess inventories and increased disposal costs, and (iii) Having two sources of serviceable inventory, remanufactured and externally supplied parts, requires the coordination between remanufacturing and procurement (Inderfurth & Van Der Laan, 2001).

Considering demand for remanufactured products and returns quantity, inventory models are classified into two groups: deterministic and stochastic. Deterministic models investigate the effect of returns on the optimal order quantity by assuming that demand and return quantities are known throughout the entire planning period (Ahiska & Kurtul, 2014). Conversely, stochastic models which treats demand and return quantities as uncertain processes examine the optimal values for the parameters (e.g., disposal, remanufacturing, new supply) of a predetermined (not necessarily optimal) inventory control policy (Ahiska & Kurtul, 2014).

Stochastic models are further divided into two types according to the planning horizon: (i) periodic review (finite), and (ii) continuous review (infinite) (Ilgin & Gupta, 2010). Table 9 suggests that inventory management has attracted significant attention. However, about half of the models are deterministic ignoring uncertainties. 97% of the models address only economic objectives while the remaining models (3%) considering both economic and environmental aspects are deterministic.

[Table 9]

3.2.4. Production planning

Production planning in remanufacturing refers to determining the quantity of products to be disassembled, remanufactured, manufactured and/or ordered to achieve some specific goals under constraints at certain time. While manufacturing takes raw materials as inputs which are normally under strict quality control, remanufacturing relies on used products with uncertain characteristics. This makes production planning in remanufacturing much more complicated than that of manufacturing (Ilgin & Gupta, 2016).

Production planning models have been developed to address these complexities in remanufacturing. The first stream develops mathematical models to determine the number of cores to be disassembled, disposed and remanufactured within a predefined period (e.g., Jayaraman (2006)). The second stream investigates optimal production policies and develops mathematical models to minimise the total sytem cost (e.g., Kenné et al. (2012)). The third stream examines the impact of various regulations such as cap-and-trade mechanism, mandatory carbon emissions capacity, and carbon tax on remanufacturing production planning and optimise the profit (e.g., Chang et al., (2015)). However, these studies incorporate only uncertain demand (quantity) while overlooking other important uncertain characteristics. Table 10 shows that 76% of the developed models are multi-period. Remanufacturers are generally found to accept and produce a high variety of products (Li & Wu, 2014), however, only six studies are found considering multi-product.

[Table 10]

3.3. Operational decisions

Operational-level decisions being made for day-to-day operations by the first line managers (Bostel et al., 2005; Schmidt & Wilhelm, 2000) aim to ensure efficient and effective execution of specific activities to meet both the goals and restrictions established by strategic- and tactical-level decisions (Anthony, 1965). Such decisions cover disassembly planning, scheduling and process planning.

3.3.1. Disassembly planning

Disassembly is a destructive (for recycling) or non-destructive (for reuse and remanufacturing) means of splitting up the returned products (Adenso-Díaz et al., 2008; Paksoy et al., 2013; Xanthopoulos & Iakovou, 2009). Being a crucial remanufacturing process of generating inputs to remanufacturing systems, it affects the reuse rates of components (Li et al., 2013a), the quality of recovered parts (Adenso-Díaz et al., 2008) and the remanufacturing cost. However, the uncertain condition of returned products and variability in their types imply uncertain resource/process requirements, hence make the disassembly process less predictable (Colledani & Battaïa, 2016; Paksoy et al., 2013). An effective disassembly planning is vital to improve the remanufacturing outcomes with maximum recovery value/profit and minimum cost/risk.

Table 11 shows that disassembly planning has been studied under three focuses: disassembly operation sequencing, selective disassembly planning, and disassembly line balancing. Key objectives of disassembly operation planning and selective disassembly planning are to minimise disassembly cost and hazardousness index respectively while disassembly line balancing aims to maximise profit and workstation performance. Like other remanufacturing operations, disassembly planning is influenced by the uncertain core characteristics. However, uncertain core quality is only addressed in Colledani & Battaïa (2016).

[Table 11]

3.3.2. Scheduling

Scheduling is a process of mapping limited resources with tasks and determining their sequences to optimise multiple objectives (Li et al., 2005). Unlike traditional manufacturing, scheduling in remanufacturing is more complex due to the uncertain core characteristics including quality, age and wear. Such uncertainties make processing time and routing less predictable, hence diluting the benefits of scheduling (Guide, 2000; Guide et al., 1997).

Table 11 reports that various approaches have been developed for remanufacturing scheduling including release mechanisms, dispatching rules, production line scheduling, flexible job shop scheduling, and economic lot sizing. All these approaches have considered several scheduling-related uncertainties such as demand for remanufactured products, lead time, process yield, returns timing, returns quality and routing.

3.3.3. Process planning

Process planning in remanufacturing refers to the selection of remanufacturing operations (Jiang et al., 2016a) and resources (Jiang et al., 2016b) to maximise remanufacturing outcomes by improving product quality, increasing remanufacturing rate and minimising cost. Selection of remanufacturing processes is challenging due to the uncertain condition of returned products and operation performance often depends on the operators which make operation time-consuming and error-prone (Jiang et al., 2016a). Choice of resource is another crucial decision as it affects the cost of remanufacturing and quality of remanufactured products (Jiang et al., 2014). Although process planning is important, only one study is found.

3.4. Analysis of literature in decision-making in remanufacturing

Among all reviewed studies, it is found that 48% of them examine strategic-level decisions followed by tactical-level (34%) and operational-level (5%) decisions. For the remaining studies (13%), they either investigate strategic- and tactical-level decisions, tactical- and operational-level decisions, or strategic- and operational-level decisions.

Despite vast interest over strategic-level decisions, this area is still growing thanks to the increasing strategic value of environmental aspects. Combining strategic- and tactical-level decisions under a single model has also attracted attention as the two levels are highly correlated. Although studies examining operational-level decisions have been increasing, the growth of this area is very moderate as operational decisions are only subsets of strategic and tactical decisions (Schmidt & Wilhelm, 2000).

4. Methodologies for decision-making in remanufacturing

To answer RQ1, decision-making methodologies are examined in two groups, namely modelling (i.e., to model decision-making problems) and solution (i.e., to solve these models) following the framework of Sasikumar & Kannan (2009). This framework has been widely used for analysing methodologies used in the review (Brandenburg et al., 2014). Modelling approach in remanufacturing can be further classified into four groups: (i) mathematical, (ii) analytical, (iii) simulation, and (iv) conceptual and descriptive, which together defines 19 different types (Table 12). The same is done to solution approach leading to 18 different types (Table 13).

[Table 12]

[Table 13]

Table 12 shows that most studies propose mathematical models (60%) followed by analytical (31%), simulation (4%) and conceptual and descriptive models (5%). Interestingly, certain approaches are often applied to address certain decision-making problems/areas. For example, 64% of network design problems are addressed by integer programming, mixed-integer linear programming and mixed-integer nonlinear programming followed by simulation (25%). Game theory and fuzzy theory are often applied to address SC coordination (88%) and collection strategy (100%) problems involving multiple SC stages. Engagement decisions in remanufacturing are usually addressed by multi-criteria decision-making models. Table 13 reports that most studies propose exact solutions (51%) followed by commercial software applications (17%), meta-heuristics (7%) and simple heuristic (5%). Although commercial software packages are widely used to address integer/linear/non-linear programming models, they might not be practical in some instances where computational effort is significant (Ma et al, 2011). Hence, meta-heuristic and simple heuristic algorithms are the two alternatives even though they do not always guarantee the optimal solutions.

5. Uncertainties addressed in remanufacturing decision-making

Inputs to remanufacturing are mainly the used products whose timing and quantity depend on the end users' willingness to give up the product (Jayaraman et al., 1999), and their quality depend on the end users' usage pattern (Ferguson et al., 2009). These inherent uncertainties of returned products make remanufacturing less predictable and controllable than traditional manufacturing (Ferrer & Ketzenberg, 2004; Galbreth & Blackburn, 2006; Guide, 2000). Hence, addressing these uncertainties can increase the control over remanufacturing outcomes.

Our review indicates that 36% of the studies address uncertainties in which 14% for one uncertainty type, 16% for two types, and 6% for more than two types. The remaining 64% either neglect uncertainties or assume uncertainties as deterministic. Specifically, a total of six uncertainty types are addressed: demand for remanufactured products (65 studies), returns quality (39), returns quantity (38), lead time (11), returns timing (4), and routing (1). The demand for remanufactured products is the most studied uncertainty as it drives and restricts many important remanufacturing decisions such as inventory management, product acquisition, network design, etc. The second most studied uncertainty is returns quality which has a huge impact on remanufacturing lead time (Aras et al., 2004; Guide, 2000) and remanufacturing cost (Aras et al., 2004; Ferguson et al., 2009; Teunter & Flapper, 2011). In order to cope with uncertain demand (Ferrer & Ketzenberg, 2004; Guide, 2000; Mukhopadhyay & Ma, 2009), the third most common studied uncertainty is the returns quantity.

Specifically, Govindan et al. (2017) have classified three approaches of addressing uncertainties as stochastic, fuzzy and robust. In stochastic case, probability distributions of uncertain (random) parameters are assumed to be known or estimated from historical data. In fuzzy case, random parameters are assumed to be fuzzy numbers which are normalised from fuzzy sets through membership functions (Demirli & Yimer, 2008). In robust case, it is not necessary to know the probability distributions of random parameters, but the value intervals of the uncertain parameters (Govindan et al., 2017). The most commonly used approach to address uncertainties in remanufacturing is stochastic (84 studies) followed by fuzzy (6) and robust (1). This result suggests that uncertainties in remanufacturing decision-making are mostly modelled using stochastical approach. However, the choice of probability distributions is often selected for the ease of model simplicity and computation. This may create a gap between the model and the reality. Hence, fuzzy and robust approaches have been explored to close this gap.

6. Discussion, conclusions, and future research directions

A comprehensive investigation of decision-making in remanufacturing is presented to address three research questions by systematically reviewing 241 papers. Decision-making practices are first classified into strategic-, tactical- and operational-level decisions. Decisions, under each level, are then examined in different management areas to address RQ1. The decision-making methods for remanufacturing are detailed in Section 3 to answer RQ1. In Section 4, uncertainties are examined to answer RQ2. Finally, future research needs are identified to address RQ3. Table 14 underlines the issues in the current literature for each area and highlights a total of 21 research needs with justifications.

[Table 14]

6.1. Future research

As discussed in Section 2.3, operational-level decisions are vital to maximise remanufacturing outcomes while supporting strategic- and tactical-level decisions. Process planning, as one of the operational-level decisions, is challenging subject to uncertainty and availability of shop floor resources. These challenges diminish the effectiveness of a process plan during the scheduling phase (Lian et al., 2012). In manufacturing systems, integration of process planning and shop floor scheduling have been proven effective. Unlike conventional manufacturing, both processing route and time of returned products are uncertain in remanufacturing systems due to uncertain returns quality (Guide, 2000). Hence, existing approaches of integrating process planning and shop floor scheduling would be less effective and efficient. Therefore, an integrated approach considering the inherent uncertain characteristics of returned products is one of the important gaps. Moreover, it is nearly impossible to capture full usage pattern of returned products, hence, such uncertainties would be addressed by robust optimisation in case of limited historical data. Hence, one line of our future work will be developing a robust optimisation model for integrating process planning and scheduling with an aim to maximise the remanufacturing outcomes.

6.2. Limitations

Although our review is comprehensive, there are some limitations. Firstly, this study might not cover all research work of decision-making in remanufacturing due to the use of inclusion/exclusion criteria. Secondly, some research gaps might be less industry-relevant as academic papers were mainly reviewed. Thirdly, the main findings of this study were derived from authors' analysis which might involve a certain degree of subjectivity. However, since a systematic approach was adopted, such subjectivity might be insignificant as compared to traditional literature review.

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Initial sample

Inclusion criteria:
- Include studies resulted from (reman* AND decision* AND NOT remand*) "Title, abstract and keywords search field of databases

Scopus	Web of Science	Science Direct	Total
• 1248	• 939	• 218	• 2405

After exclusion of duplication

Exclusion criteria:
- Exclude duplicated studies

Scopus	Web of Science	Science Direct	Total
• 1193	• 183	• 171	• 1547

Stage 1: After exclusion of language

Exclusion criteria:
- Exclude studies not English

Scopus	Web of Science	Science Direct	Total
• 1058	• 182	• 163	• 1403

Stage 2: After quality assessment

Exclusion criteria:
- Exclude studies dated before 2019 having less than 5 citations per year (Crossan & Apaydin, 2010)
- Exclude studies dated 2019 and published in journals having CiteScore Percentile of less than 96%

Scopus	Web of Science	Science Direct	Total
• 313	• 40	• 57	• 410

Stage 3: After title and abstract screening

Exclusion criteria:
- Exclude studies not relevant to decision-making in remanufacturing
- Exclude studies not specific to remanufacturing
- Exclude review papers

Scopus	Web of Science	Science Direct	Total
• 237	• 18	• 5	• 260

Stage 3: After full paper screening

Exclusion criteria:
- Exclude studies not relevant to decision-making in remanufacturing

Scopus	Web of Science	Science Direct	Total
• 222	• 15	• 4	• 241

Figure 1: Overview of our review methodology

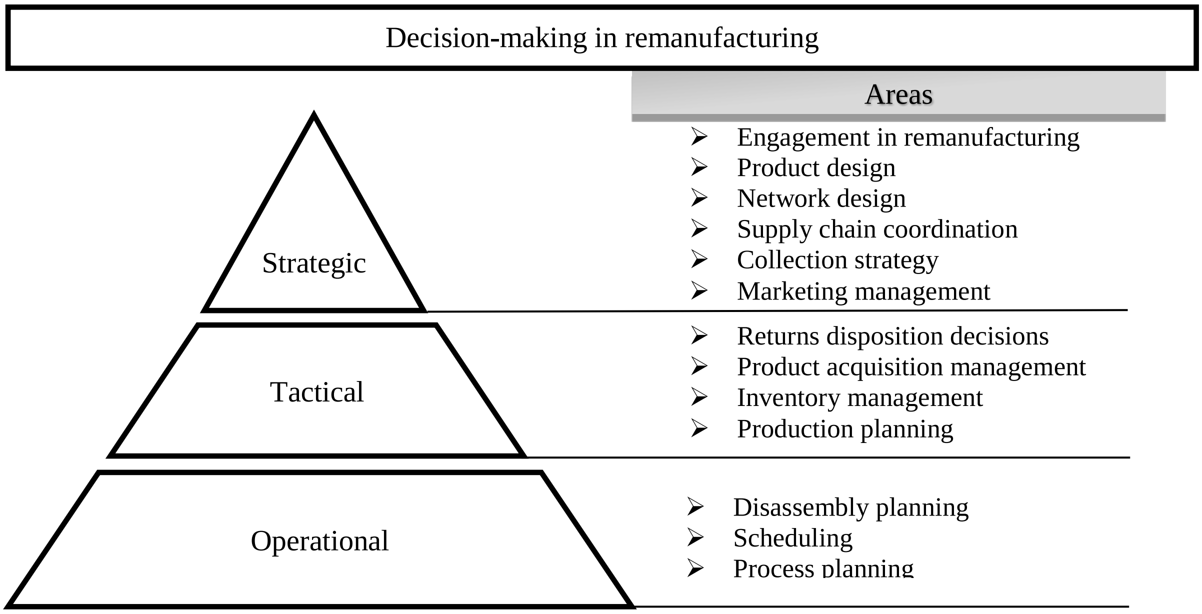

Figure 2: Classification of decision-making in remanufacturing

Table 1: Summary of decision-making models for engagement in remanufacturing

Focus	Ref	Focus Country	Industry	Barriers/Factors considered	Classification Approach (*)	Model type (**)	Model application (***)
Drivers for involving in remanufacturing	Ferrer (1997)		Automotive parts	Remanufacturing costs		AE	RCS
	Heese et al. (2005)		Hospital beds	Remanufacturing costs, market share		GT	RCS
	Lebreton & Tuma (2006)		Automotive parts	Market segmentation, return flow structure, reintegration potential	LR	LP/NLP	RCS
	Atasu et al. (2010)			Market segmentation		C&D	NA
	Martin et al. (2010)	USA	Various	Asset Specificity (operational assets, brand reputation, intellectual property), technological uncertainty, frequency, volume uncertainty, condition uncertainty, complexity	T	C&D	RCS
	Chen & Chang (2012)			Remanufacturing costs, competition intensity		NVM	IA
	Abdulrahman et al. (2015)	China	Automotive parts	Technical, management, financial, regulatory, environmental, market issues	CS	MCDM	RCS
	D'Adamo & Rosa (2016)		Various	Reduction of energy consumed, environmental improvement, job creation, potential profitability, government regulations, design for reman, sustainable solution, green marketing, health risks, production planning, availability of EoL products, remanufacturing costs, internal cannibalization, external competition, market positioning, organizational conflicts	S	MCDM	Survey
	Xiong et al. (2016)	China	Automotive parts	Remanufacturing costs		AE	NA
	Tian et al. (2017)	China	Automotive parts	Economy, society, technology	LR	MCDM	RCS
	Wang et al. (2017)		Consumer electronics	Remanufacturing costs, environmental impact		GT	RCS
	Chaowanapong et al. (2018)	Thailand	Various	Business feasibility, firm's strategic factors, policy factors	LR	C&D	RCS
Barriers for implementation of remanufacturing	Rathore et al. (2011)	India	Telecommunications	Market segmentation, government policy	LR & S	C&D	RCS
	Zhu et al. (2014)	China	Automotive parts	Strategic and operational		MCDM	RCS
	Xia et al. (2015)	China	Automotive parts	Tangible resources, intangible resources, capabilities		MCDM	RCS
	Govindan et al. (2016)	India	Automotive parts	Business, production, technical, stakeholder	LR & S	MCDM	Survey
	Bhatia & Srivastava (2018)	India	Electrical/electronic equipment	External barriers	AE & LR	MCDM	RCS
	Shi et al. (2019)	China	Office equipment	Government level, enterprise level	LR	MCDM	RCS
	Zlamparet et al. (2019)	China & UK	Electrical/electronic equipment	Reverse management, design for remanufacturing, reuse selection	S	C&D	RCS
Economic viability and technical feasibility of remanufacturing	Subramoniam et al. (2010)		Automotive parts	Financial, reman design, intellectual property, product recovery value, customer product specs, disposal cost, product lifecycle cost, core management, brand erosion, green perception, regional reman operations, organisational alignment, government alignment	T & LR	C&D	RCS
	Jiang et al. (2011)		Telecommunications	remanufacturing performance, environmental performance	LR	MCDM	IA
	Sabharwal & Suresh (2013)		Various	Procurement, processing, material recovery, marketing	LR	MCDM	RCS
	Subramoniam et al. (2013)		Automotive parts	Financial impact of reman, reman design, intellectual property, product recovery value, OE product specifications, disposal cost, intrinsic recovery value, product lifecyle cost, core management, brand erosion, green perception, organisational alignment, upfront financial investment, government regulations	LR & CS	MCDM	RCS
	Golinska et al.(2015)		Automotive parts	Environmental, economic and social indicators	LR & S	SM	IA
	van Loon & Van Wassenhove (2018)		Automotive parts	Remanufacturing costs, environmental impact		LP	RCS

(*) **AEx:** Academic expert; **CS:** Case study; **LR:** Literature review; **S:** Survey; **T:** Theory
(**) **AE:** Algebraic equation; **C & D:** Conceptual and descriptive; **GT:** Game theory; **LP:** Linear programming; **MCDM:** Multi-criteria decision-making; **NWM:** Newsvendor model
(***) **IA:** Illustrative application; **NA:** No application; **RCS:** Real case study

Table 2: Summary of decision-making models for product design

Focus	Reference	Decision output																	Model type (*)	Model application (**)
		Sustainable product design	Effort level of design for environment	Improving remanufacturability	Optimal product design	Improved product design	Optimal material selection	Take-back time	Components to be reused, recycled, or disposed	Take-back rate	Production quantity	Optimal component reuse volume	Acquisition costs	Connectors selection	Degree of disassemblability	Degree of component commonality	Degree of interchangeability	Remanufacturability level		
Sustainability	Gehin et al. (2008)	✓																	C&D	NA
	Ijomah (2009)	✓																	C&D	RCS
	Hatcher et al. (2013)	✓																	C&D	RCS
	Cheung et al. (2015)	✓		✓															C&D	IA
	Zheng et al. (2019)		✓								✓								Algebraic equation	NA
Life cycle	Schau et al. (2012)				✓														Systematic Model	RCS
	Ma et al. (2014)				✓														DTM & MINLP	IA
	Yang et al. (2015)					✓													Systematic Model	RCS
	Yang et al. (2017)						✓												MCDM	RCS
Component	Mangun & Thurston (2002)							✓	✓										NLP	IA
	Kwak & Kim (2015)									✓	✓								MILP	IA
	Wang et al. (2017)											✓	✓						Bass diffusion	RCS
	Liu et al. (2019)										✓							✓	Equilibrium model	NA
Disassembly	Güngör (2006)													✓					MCDM	IA
	Wu (2012)														✓				Game theory	IA
	Subramanian et al. (2013)															✓			Algebraic equation	RCS
	Wu (2013)																✓		Game theory	IA
	Qiang (2015)																	✓	Equilibrium model	IA
	Joshi et al. (2019)																		LPP	IA

(*) **C & D:** Conceptual and descriptive; **DTM:** Demand trend mining; **IP:** Integer programming; **LPP:** Linear physical programming; **MCDM:** Multi-criteria decision-making; **MILP:** Mixed-integer linear programming; **MINLP:** Mixed-integer non-linear programming; **MOO:** Multi-objective optimisation; **NLP:** Non-linear programming

(**) **IA:** Illustrative application; **NA:** No application; **RCS:** Real case study

Table 3: Summary of decision-making models for network design

Model type	Reference	Objectives (*)					Decision variables							Source of uncertainty				Multi-product	Multi-period	Model type (**)	Model application (***)
		Min. TC	Min. L	Max. P	Min. EI	Max. SB	Location	Capacity	Supplier selection	Retailer selection	Technology selection	Transportation	Returner incentives	Demand	Returns quantity	Returns quality	Returns timing				
Deterministic	Jayaraman et al. (1999)	✓					✓												✓	MILP	RCS
	Krikke et al. (1999)	✓					✓													MILP	RCS
	Beamon & Fernandes (2004)		✓				✓												✓	MILP	IA
	Georgiadis & Vlachos (2004)							✓												S	IA
	Srivastava & Srivastava (2006)						✓	✓											✓	S	RCS
	Tan & Kumar (2006)			✓			✓												✓	S	RCS
	Srivastava (2008)			✓			✓	✓										✓	✓	MILP	RCS
	Easwaran & Üster (2010)	✓					✓											✓		MILP	IA
	Georgiadis & Athanasiou (2010)			✓				✓												S	IA
	Sasikumar et al. (2010)			✓			✓												✓	MINLP	RCS
	Das & Dutta (2013)																		✓	S	IA
	Alshamsi & Diabat (2015)			✓			✓	✓										✓	✓	MILP	RCS
	Das & Dutta (2015)			✓																NLP	IA
	Rezapour et al (2015)			✓			✓	✓												ILP	RCS
	Alshamsi & Diabat (2017)			✓			✓											✓	✓	MILP	RCS
	Turki et al. (2017)	✓						✓												S	IA
	Coelho & Mateus (2018)	✓					✓													MILP	IA
Stochastic	Francas & Minner (2019)			✓				✓						✓	✓			✓		SLP	IA
	Abdallah et al. (2012)	✓					✓							✓	✓					MINLP	IA
	Amin & Zhang (2013)			✓				✓	✓					✓				✓		MINLP	IA
	Georgiadis & Athanasiou (2013)		✓					✓						✓		✓	✓	✓		S	IA
	Ozceylan & Paksoy (2013)	✓										✓		✓	✓			✓	✓	MILP	IA
	Qiang et al. (2013)			✓					✓					✓		✓				E	IA
	Mohajeri & Fallah (2016)	✓										✓		✓	✓					MIP	RCS
	Amin et al. (2017)			✓			✓		✓	✓				✓	✓			✓	✓	MILP	IA
	Mota et al. (2018)			✓	✓	✓	✓	✓	✓		✓	✓		✓				✓	✓	MILP	RCS
	Baptista et al. (2019)			✓			✓							✓	✓	✓		✓	✓	MILP	RCS
	Ruiz-Torres et al (2019)	✓						✓					✓		✓					MILP	IA

(*) **Min. TC:** Minimum total cost; **Min. L**: Minimum loss; **Min. EI**: Minimum environmental impact; **Max. SB:** Maximum social benefits

(**) **E:** Equilibrium model; **MILP:** Mixed-integer linear programming; **MINLP:** Mixed-integer non-linear programming; **NLP:** Non-linear programming; **S:** Simulation; **SLP:** Stochastic linear programming; **AHP:** Analytic hierarchy process; **ILP:** Integer linear programming

(***) **IA:** Illustrative application; **NA:** No application; **RCS:** Real case study

Table 4: Summary of decision-making models for supply chain coordination

Focus	Reference	Coordination Mechanism												Equilibrium decision variables (*)															Objective(s) (**)			Model type (***)	Model application
						Contract																											
		Information sharing	Reward-driven	Reward-penalty	Profit distribution	Revenue-sharing	Quantity discount	Profit-sharing	Two-part tariff	Supply risk sharing	Low price promotion	Multilateral compensation-based wholesale price	Cooperative advertising	WP	RP	AP	SL	QL	CE	RE	ME	SE	RA	RI	WL	ER	GI	Max. P	CE	Max. MS		
Effect of demand information sharing	Huang & Wang (2017)	✓												✓	✓	✓												✓			GT	IA
	Li et al (2017)	✓												✓	✓	✓												✓			GT	IA
Contracts	Xiao et al. (2011)					✓									✓		✓											✓			GT	IA
	Jena & Sarmah (2016)						✓								✓		✓											✓			EM	IA
	Zhang & Ren (2016)					✓			✓					✓	✓	✓												✓			GT	IA
	He (2017)									✓						✓				✓								✓			GT	IA
	Zheng et al. (2017)	✓							✓					✓	✓	✓			✓									✓			GT	IA
	Giri et al. (2018)					✓								✓	✓										✓		✓	✓			GT	IA
	Heydari & Ghasemi (2018)					✓																	✓					✓			AE	IA
	Hosseini-Motlagh et al. (2018)											✓													✓		✓	✓			GT	IA
	Taleizadeh et al. (2018)	✓							✓				✓	✓	✓	✓		✓	✓			✓						✓			GT	IA
	He et al. (2019)							✓	✓						✓								✓	✓				✓	✓		GT	IA
Pricing and remanufacturing effort	Wei & Zhao (2011)													✓	✓		✓											✓			GT & FT	IA
	Wu (2012)														✓		✓			✓								✓			GT	IA
	Zhou et al. (2013)																			✓	✓							✓			GT	NA
	Wei & Zhao (2015)													✓	✓					✓								✓			GT	IA
	Aydin et al. (2016)													✓	✓				✓	✓	✓							✓		✓	MOO & GT	RCS
	Chen & Akmalul'Ulya (2019)			✓										✓	✓												✓	✓			GT	IA
Impact of different channel power structures	Maiti & Giri (2015)													✓	✓			✓	✓									✓			GT	IA
	Gao et al. (2016)										✓			✓	✓				✓		✓								✓		GT	IA
	Saha et al (2016)		✓											✓	✓				✓			✓						✓			GT	IA
	Giri et al. (2017)													✓	✓				✓									✓			GT	IA
	Xu & Wang (2018)				✓									✓	✓											✓		✓			GT	IA
	Wang et al (2019)													✓		✓												✓			GT	IA

(*) **WP:** Wholesale price; **RP:** Retail price; **AP:** Acquisition price; **SL:** Service level; **QL:** Quality level; **CE:** Collection effort; **RE:** Remanufacturing effort; **ME:** Manufacturing effort; **SE:** Sales effort; **RA:** Reward amount offered to consumers; **RI:** Reverse-channel investment; **WL:** Warranty length; **ER:** Emission reduction ; **GI:** Green innovation/effort rate

(**) **Max. P:** Maximum profit; **CE:** Collection efficiency; **Max MS:** Maximum market share

(***) **AE:** Algebraic equation; **BM:** Benchmark; **EM:** Equilibrium model; **FT:** Fuzzy theory; **GT:** Game theory; **MOO:** Multi-objective optimisation

(****) **IA:** Illustrative application; **NA:** No application; **RCS:** Real case study

Table 5: Summary of decision-making models for collection strategy

Reference	Collection Channel Structure						Performance measures		Decision outputs (*)												Information (**)	Demand (***)					Competition exists	Multi-period	New and remanufactured products are substitutable	Homogenous quality of returned products	Model type (****)	Model application (*****)
	Single Model			Dual Model																		Deterministic linear function of				Fuzzy						
	M	R	3P	M-R	R-3P	M-3P	Supply chain profit	Product return rate	WP	RP	AP	TP	PRR	AI	LF	RQ	GC	D		SP	ME	CWTP	RPC							
Savaskan et al. (2004)	✓	✓	✓				✓	✓											S	✓									GT	NI
Savaskan & Van Wassenhove (2006)	✓	✓					✓	✓	✓	✓			✓						S	✓									GT	NI
Karakayali et al. (2007)	✓		✓				✓	✓	✓	✓	✓								A	✓									GT	IA
Atasu et al. (2013)	✓	✓	✓				✓			✓			✓						S	✓							✓	✓	GT	IA
Hong et al. (2013)				✓	✓	✓	✓	✓	✓	✓			✓						S								✓	✓	GT	IA
Huang et al. (2013)					✓		✓	✓	✓	✓		✓	✓						S	✓					✓		✓	✓	GT	NI
Wei & Zhao (2013)	✓	✓	✓				✓	✓	✓	✓			✓						S					✓			✓		GT & FT	RCS
Hong et al. (2015)	✓	✓	✓				✓	✓	✓	✓			✓	✓					S	✓	✓						✓	✓	GT	NI
Esmaeili et al. (2016)	✓	✓		✓			✓		✓	✓			✓			✓	✓		S	✓	✓						✓	✓	GT	IA
Yi et al. (2016)					✓		✓	✓	✓	✓		✓	✓			✓			A							✓		✓	GT	IA
Han et al. (2017)	✓	✓					✓		✓	✓		✓	✓			✓			A	✓						✓	✓	✓	GT	IA
Hong et al. (2017)	✓						✓	✓					✓		✓			✓	S			✓			✓	✓		✓	GT	IA
Liu et al. (2017)				✓	✓	✓	✓	✓	✓	✓		✓	✓						S						✓		✓	✓	GT	NI
Xu & Liu (2017)	✓	✓	✓				✓		✓	✓		✓	✓						S	✓			✓				✓	✓	GT	IA
Zhao et al. (2017)				✓		✓	✓	✓	✓	✓		✓	✓						S						✓		✓	✓	GT	IA
Wan & Hong (2019)					✓		✓		✓	✓		✓	✓						S	✓							✓	✓	GT	RCS

(*) **WP:** Wholesale price; **RP:** Retailer price; **AP:** Acquisition price; **TP:** Transfer price; **PRR:** Product return rate; **AI:** Advertisement investment; **LF:** Licencing fee; **RQ:** Remanufacturing quantity; **GC:** Green cost; **D:** Demand for new and remanufactured products

(**) **A:** Asymetric; **S:** Symetric

(***) **SP:** Selling price; **ME:** Marketing expenditure; **CWTP:** Consumer WTP; **RPC:** Reference price of the consumer

(***) **GT:** Game theory; **FT:** Fuzzy theory

(*****) **IA:** Illustrative application; **NA:** No application; **RCS:** Real case study

Table 6: Summary of decision-making models marketing management

	Objectives			Decision Outputs (*)													Source of uncertainty			
Reference	Max. Profit	Min. Cost	Max. Revenue	SNP	SRP	SOP	AP	BBP	W	PD	A	RQ	MQ	SSP	Q	Demand	Returns quality	Model type (**)	Model application (***)
Ray et al. (2005)	✓			✓	✓			✓										AE	IA
Bakal & Akcali (2006)	✓				✓		✓										✓	AE	IA
Jung & Hwang (2011)	✓			✓	✓			✓										GT	IA
Ovchinnikov (2011)	✓				✓							✓						AE/C&D	RCS
Toktay & Wei (2011)	✓			✓	✓							✓	✓					AE	IA
Vadde et al. (2011)		✓	✓		✓	✓	✓											MOO & MCDM	IA
Chen & Chang (2012b)	✓			✓	✓							✓	✓			✓		NVM	IA
Wu (2012b)	✓				✓					✓								GT	
Wu (2013)	✓				✓					✓								GT	
Abbey et al. (2015)	✓			✓	✓							✓	✓					AE/C&D	RCS
Gan et al. (2015)	✓			✓	✓		✓											AE	IA
Li et al. (2015)	✓				✓							✓				✓	✓	DP	IA
Wu (2015)	✓			✓	✓			✓										GT	IA
Yazdian et al. (2016)	✓				✓		✓		✓									NLP	IA
Abbey et al. (2017)	✓				✓													AE/C&D	RCS
Cui et al. (2017)	✓														✓			AE	RCS
Gan et al. (2017)	✓			✓	✓		✓											GT	IA
Kwak &Kim (2017)	✓				✓		✓					✓						MILP	IA
Zhao et al. (2018)	✓				✓									✓				GT	IA
Alqahtani et al. (2019)	✓								✓									Simulation	RCS
Hong & Zhang (2019)	✓			✓							✓	✓	✓					GT	NA

(*) **SNP:** Selling price of new product; **SRP:** Selling price of remanufactured product; **SOP:** Selling price of other recovered products; **AP:** Acquisition price; **BBP:** Buy-back/trade-in price/trade-in discount; **W:** Warranty policies/length; **A:** Advertising; **RQ:** Remanufacturing quantity; **MQ:** Manufacturing quantity; **SSP:** Subsidy sharing percentage with customers; **Q:** Quality of remanufactured product

(**) **AE:** Algebraic equation; **BDM:** Bass diffusion model; **C&D:** Conceptual and descriptive model; **DP:** Dynamic programming; **GT:** Game theory; **MCDM:** Multi-criteria decision-making model; **MILP:** Mixed-integer linear programming; **MINLP:** Mixed-integer non-linear programming; **MOO:** Multi-objective

(***) **IA:** Illustrative application; **NA:** No application; **RCS:** Real case study

Table 7: Summary of decision-making models for returns disposition

Focus	Reference	Product recovery option (*)			Component recovery option (**)							Objective(s) (***)									Decision output (****)				Source of uncertainty				Model type (*****)	Model application (******)
		ReM	DisM	DisP	ReU	ReM	ReC	ReF	Shred	Incin	DisP	Max. P	Max. R	Min. RC	Min. DC	Max. R	Min. W	Max. ES	Max. SI	Min. EI	PRS	CRO	DD	DS	Demand	Lead time	Returns quantity	Returns quality		
Only returns disposition	Jun et al. (2007)				✓	✓					✓			✓		✓						✓							MILP	RCS
	Ferguson et al. (2011)	✓	✓									✓									✓				✓		✓		MDP	IA
Integrated disassembly planning and returns disposition	González & Adenso-Díaz (2005)				✓	✓	✓				✓	✓										✓		✓					MOO	RCS
	Lee et al. (2010)					✓					✓	✓			✓							✓	✓						IP	IA
	Ma et al. (2011)				✓	✓	✓	✓	✓	✓	✓	✓											✓	✓					IP	RCS
	Johnson & McCarthy (2014)	✓	✓									✓									✓		✓						IP	RCS
	Ondemir & Gupta (2014)					✓	✓				✓		✓	✓		✓	✓					✓	✓				✓	✓	GP	RCS
	Meng et al. (2017)	✓	✓		✓	✓					✓	✓						✓	✓		✓	✓	✓	✓				✓	MOO	RCS
Integrated inventory management and returns disposition	Aras et al. (2004)	✓		✓										✓							✓					✓		✓	MDP	IA
	Inderfurth (2005)	✓		✓										✓							✓				✓		✓	✓	DP	IA
	Guide et al. (2008)	✓		✓								✓									✓					✓		✓	Queuing models	RCS
	Mashhadi & Behdad (2017)	✓		✓								✓									✓							✓	Systematic models	RCS
	Farahani et al. (2019)	✓		✓				✓			✓	✓									✓	✓						✓	MINLP	RCS

(*) **ReM:** Remanufacturing; **DisM:** Dismantling; **DisP:** Disposal

(**) **ReU:** Reuse; **ReM:** Remanufacturing; **ReC:** Recycling; **ReF:** Refurbishing; **Shred:** Shredding; **Incin:** Incineration; **DisP:** Disposal & replacement

(***) **Max P:** Maximum profit; **Max R:** Maximum recovery quality; **Min RC:** Minimum disassembly cost; **Max R:** Maximum revenue; **Min DC**: Minimum disassembly cost; **Min. W:** Minimum waste; **Max. ES:** Maximum energy saving; **Max. SI:** Maximum Social impact

(****) **PRS:** Product recovery strategy; **CRO:** Component recovery options; **DD:** Disassembly depth; **DS:** Disassembly sequence

(*****) **DP:** Dynamic programming; **GP:** Goal programming; **MCDM:** Multi-criteria decision-making model; **MDP:** Markov decision process; **MILP:** Mixed-integer linear programming; **MINLP:** Mixed-integer non-linear programming; **MOO:** Multi-objective; **IP:** Integer programming

(******) **IA:** Illustrative application; **RCS:** Real case study

Table 8: Summary of decision-making models for product acquisition

Reference	Objective(s) (*)			Decision Output (**)									Sorting	Source of uncertainty			Model type (***)	Model application (****)
	Min. C	Max. EP	Max. DP	AQ	AP	AE	EDB	I-TB	R/M-Q	IQ	AQ	SP		Demand	Returns quality	Returns quantity		
Guide et al. (2001)				✓	✓										✓	✓	C&D	RCS
Robotis et al. (2005)		✓		✓					✓					✓		✓	NVM	IA
Galbreth & Blackburn (2006)	✓			✓									✓	✓	✓		LP & NVM	IA
Mukhopadhyay & Ma (2009		✓		✓					✓					✓	✓		AE	IA
Kaya (2010)		✓						✓	✓					✓			NVM	IA
Shi et al (2010)		✓			✓				✓					✓		✓	NLP	IA
Van Wassenhove & Zikopoulos (2010)		✓		✓										✓	✓		AE	RCS
Teunter & Flapper (2011)	✓			✓					✓					✓	✓		NVM	IA
Zhou & Yu (2011)			✓			✓								✓		✓	AE	NA
Loomba & Nakashima (2012)		✓		✓									✓	✓	✓		MDP	RCS
Minner & Kiesmller (2012)	✓				✓				✓								DP	IA
Nenes & Nikolaidis (2012)		✓		✓					✓		✓						MILP	IA
Atamer et al. (2013)		✓			✓				✓					✓			AE	IA
Li et al. (2013b)		✓			✓				✓						✓	✓	DP	IA
Bulmus et al. (2014)		✓			✓				✓								GT	IA
Gu & Tagaras (2014)				✓									✓	✓			GT	IA
Xiong et al. (2014)	✓				✓									✓	✓	✓	MDP	RCS
He (2015)		✓			✓				✓					✓		✓	AE	IA
Mutha et al. (2016)		✓		✓									✓	✓	✓		AE	RCS
Panagiotidou et al. (2017)		✓		✓					✓	✓						✓	AE	IA
Bhattacharya et al. (2018)		✓		✓	✓							✓	✓			✓	NLP	IA
Gaur et al. (2018)		✓					✓										MCDM	RCS
Gu et al. (2018)		✓			✓				✓								GT	RCS
Xu et al. (2019)		✓			✓				✓			✓					AE	NA

(*) **Min. C:** Minimising total cost; **Min. EP:** Maximising the expected profit; **Min. DP:** Maximising the total discounted profit

(**) **AQ:** Acquisition quantity; **AP:** Acquisition price; **AE:** Acquisition effort; **EDB:** End users' disposal behaviour; **I-TB:** Incentive to offer take-back; **R/M-Q:** Re/manufacturing quantities; **IQ:** Inspection quantities; **SQ:** Salvage quantities; **SP:** Selling price

(***) **AE:** Algebraic equation; **C&D:** Conceptual and descriptive; **DP:** Dynamic programming; **LP:** Linear programming; **MCDM:** Multi-criteria decision-making; **MDP:** Markov decision process; **MILP:** Mixed-integer linear programming; **NLP:** Non-linear programming; **NVM:** Newsvendor model; **GT:** Game theory

(****) **IA:** Illustrative application; **RCS:** Real case study

Table 9: Summary of decision-making models for inventory management

Inventory policy		Reference	Objective(s)				Demand/return distribution (*)		Number of stocking points	Disposal option	Multi-period	Back order	Perishability	Model type (**)	Model application (***)
			Max. profit	Min. total cost	Min. total lead time	Min. total CO2 emissions									
Deterministic		Ferrer (2003)		✓					2					NLP	IA
		Ferrer & Ketzenberg (2004)		✓					3		✓			IP	IA
		Atasu & Çetinkaya (2006)		✓					1		✓			IP	IA
		Tang et al. (2007)		✓					1	✓			✓	IP	IA
		Chung & Wee (2008)		✓					2	✓	✓			IP	IA
		Roy et al. (2009)	✓						2	✓	✓		✓	CO	IA
		Roy et al. (2009)		✓					2	✓	✓		✓	IP	IA
		Yang et al. (2010)		✓					6		✓		✓	AE	IA
		Yuan & Gao (2010)	✓						6		✓			LP	RCS
		Chung & Wee (2011)		✓					2	✓	✓			DP	NA
		El Saadany & Jaber (2011)		✓					2	✓				AE	RCS
		Yang et al. (2013)	✓						4		✓			DP	IA
		Su & Lin (2015)		✓	✓				1	✓				LP	IA
		Bazan et al (2017)		✓					4	✓	✓			Simulation	IA
		Shu et al. (2017)		✓		✓			2	✓				NM	NA
Stochastic	Continuous review	Inderfurth & Van Der Laan (2001)		✓			P	P	2	✓	✓	✓		AE	IA
		Aras et al. (2006)		✓			P	P	3	✓				MDP	IA
		Jin et al. (2011)		✓			P	P	1		✓			AE	IA
		Clottey et al. (2012)		✓					3	✓	✓			NVM	IA
		Jin et al. (2013)		✓			P	P	1				✓	CO	RCS
	Periodic review	Inderfurth (1997)		✓			A	A	2	✓	✓	✓		Simulation	IA
		Kiesmüller (2003)		✓			N/G	N/G	2		✓	✓		DP	NA
		Mahadevan et al. (2003)		✓			P	P	2			✓		DP	IA
		Inderfurth (2004)	✓				G	G	3	✓				MDP	IA
		Bhattacharya et al. (2006)	✓				G	G	1		✓			MDP	IA
		Inderfurth & Mukherjee (2008)		✓			G	G	2	✓	✓	✓		NVM	RCS
		Ahiska & King (2010)		✓			T1	T2	2			✓		MDP	IA
		Inderfurth & Kleber (2013)		✓			N	N	2	✓	✓	✓		DP	IA
		Ahiska & Kurtul (2014)	✓				T3	T3	3	✓	✓	✓		MDP	RCS
		Niknejad & Petrovic (2014)		✓			F	F	4	✓	✓			MILP	IA
		Mashhadi et al. (2015)	✓				N	N	1	✓				CCO	RCS
		Giri & Sharma (2016)	✓				U	U	1					AE	IA
		Macedo et al. (2016)		✓			U	U	2	✓	✓	✓		MILP	IA
		Zikopoulos (2017)		✓			N		2		✓	✓			RCS
		García-Alvarado et al (2017)		✓			D	D	2	✓	✓	✓		MDP	IA
		Wang et al. (2019)	✓				U		1					NVM	IA

(*) **N:** Normal; **G:** Gamma; **P:** Poisson process; **T1:** Trapezoidal; **T2:** Triangular-shape; **T3:** Transition; **A:** Arbitrary; **F:** Fuzzy numbers; **U:** Uniform; **D:** Discrete; **G:** General

(**) **AE:** Algebraic equation; **CO:** Convex optimisation; **DP:** Dynamic programming; **ILP:** Integer linear programming; **IP:** Integer programming; **MDP:** Markov decision process; **MILP:** Mixed-integer linear programming; **MOO:** Multi-objective optimisation; **NVM:** Newsvendor model; **QM:** Queuing models

(***) **IA:** Illustrative application; **RCS:** Real case study; **NA:** No application

Table 10: Summary of decision-making models for production planning

	Objective(s)			Decision Output														Source of uncertainty				Regulations					
Reference	Max. P	Min. C	Max. W	Multi-product	Multi-period	Selection of components to be disassembled	Aggregate production planning	Optimal production policy	Remanufacturing quantity	Manufacturing quantity	Required minimum quality level of returned	Length of re/manufacturing	Production rates	Remanufacturing capacity	Selling price	Stock capacity	Inventory levels	Vehicle routes	Demand	Returns quality	Returns quantity	Lead-time	Carbon cap and trade mechanism (CCT-	Mandatory carbon emissions capacity	Carbon emission tax	Subsidy	Model type (*)	Model application (**)
Nakashima et al. (2004)		✓			✓			✓											✓								MDP	IA
Jayaraman (2006)		✓		✓	✓		✓													✓							LP	RCS
Rubio & Corominas (2008)		✓												✓													AE	IA
Ferguson et al. (2009)	✓				✓				✓										✓	✓	✓						LP	RCS
Xanthopoulos & Iakovou (2009)	✓			✓	✓	✓	✓												✓	✓	✓						MILP& GP	RCS
Denizel et al. (2010)	✓				✓				✓											✓							LP	RCS
Subramanian et al. (2010)	✓			✓	✓		✓																				NLP	IA
Wang et al (2011)		✓			✓			✓											✓		✓						CO	IA
Kenné et al. (2012)		✓											✓									✓					MDP	IA
Chang et al. (2015)	✓				✓				✓	✓													✓				AE	IA
Liu et al. (2015)	✓								✓	✓									✓				✓	✓	✓		AE	IA
Esenduran et al.(2016)			✓		✓				✓	✓																	SM	IA
Yenipazarli (2016)	✓		✓		✓				✓	✓															✓		GT	IA
Chang et al.(2017)	✓				✓				✓	✓																	AE	IA
Shu et al. (2017)	✓								✓	✓					✓										✓	✓	AE	IA
Wang et al. (2017c)	✓								✓	✓									✓				✓				AE	IA
Miao et al. (2018)	✓								✓	✓					✓								✓		✓		NLP	IA
Turki et al. (2018)	✓				✓							✓				✓							✓				DF	RCS
Wang et al. (2018)	✓			✓	✓				✓	✓					✓										✓		NLP	RCS
Bensmain et al. (2019)		✓			✓								✓														MINLP	IA
Dou et al. (2019)	✓			✓	✓				✓	✓					✓										✓		AE	IA
Guo et al. (2019)		✓			✓				✓	✓	✓	✓								✓						✓	MILP	IA
Liu et al. (2019)		✓			✓				✓	✓									✓		✓						MIP	RCS
Shuang et al. (2019)	✓			✓	✓				✓	✓						✓	✓	✓	✓				✓		✓		NLP	RCS
Zhang W., He Y.	✓				✓			✓	✓						✓												AE	IA

(*) **AE:** Algebraic equation; **CO:** Convex optimisation; **GP:** Goal programming; **GT:** Game theory; **LP:** Linear programming; **MDP:** Markov decision process; **MILP:** Mixed-integer linear programming; **NLP:** Non-linear programming; **SM:** Systematic models

(**) **IA:** Illustrative application; **RCS:** Real case study

Table 11: Summary of decision-making models for disassembly planning, scheduling and process planning

Management Area	Reference	Focus	Objective(s)													Source of uncertainty				Model type (**)	Model application (***)
			Min. C	Max. P	Min. H	Min. CYT	Min. NW	BW	Min. CT	Min. MW	Min. DL	Min. M	Min. FT	Min. T	Max RQ	Demand	Lead time	Returns timing	Routing		
Disassembly planning	Adenso-Díaz et al. (2008)	Optimal disassembly sequence plan	✓																	MOO	IA
	Li et al. (2013a)	Selective disassembly planning			✓															MOO	RCS
	Paksoy et al (2013)	Disassembly line balancing				✓	✓	✓												MIP	RCS
	Guiras et al. (2018)	Disassembly/Assembly planning	✓														✓			MOO	IA
Scheduling	Guide et al. (1997)	Release mechanisms and priority dispatching rules												✓			✓	✓		S	IA
	Guide et al. (2018)	Release mechanism									✓		✓				✓	✓	✓	AE & S	RCS
	Souza et al. (2002)	Dispatching rules, routing		✓									✓			✓	✓			QM & NLP & S	RCS
	Teunter et al. (2008)	Economic lot scheduling	✓																	MIP	RCS
	Gao et al. (2016b)	Flexible job shop scheduling							✓	✓							✓			MOO	IA
	Gao et al. (2016c)	Flexible job shop scheduling & rescheduling								✓		✓					✓			MOO	IA
Process planning	Jiang et al. (2014)	Optimal process plan selection	✓												✓	✓				Statistics	IA

(*) **Min. C:** Minimum Cost; **Min P:** Maximum profit; **Min. H:** Minimum hazardousness index; **Min. CYT:** Minimum Cycle time; **Min. NW:** Minimum number of workstation; **BW:** Balanced workstation workload; **Min. CT:** Minimum completion time; **Min. MW:** Minimum machine workload; **Min. DL:** Minimum delivery lateness; **Min. M:** Minimum makespan; **Min. FT:** Minimum average flow time; **Min T:** Minimum tardiness; **Max RQ:** Maximising remanufacturing quality

(**) **AE:** Algebraic equation; **MILP:** Mixed-integer linear programming; **MIP:** Mixed-integer programming; **MOO:** Multi-objective optimisation; **NLP:** Non linear model; **QM:** Queuing models; **S:** Simulation; **SP:** Stochastic programming

(***) **IA:** Illustrative application; **RCS:** Real case study

Table 12: The model types used for decision-making in remanufacturing

Decision Areas		Strategic						Tactical				Operational			**Grand Total**
	Model Type	Engagement in remanufacturing	Product design	Network design	Supply chain coordination	Collection strategy	Marketing management	Returns disposition	Product acquisition	Inventory management	Production planning	Disassembly planning	Scheduling	Process planning	
Analytical models	Game theory/Fuzzy theory	2	2		21	16	5		3		1				**50**
	MCDM	11	2				1	1	1						**16**
	Statistics									1				1	**2**
	Systematic models	1	2					1			1				**5**
Mathematical models	Algebraic equation	2	2		2		8		8	6	8		1		**37**
	Bass diffusion model		1												**1**
	Convex optimisation									2	1				**3**
	Chance-constrained optimisation									1					**1**
	Discrete flow model										1				**1**
	Dynamic programming						1	1	2	5					**9**
	Equilibrium model		2	1	1										**4**
	Goal programming							1							**1**
	IP/MILP/MINLP		2	18			1	5	1	7	4	1	1		**40**
	Linear physical programming		1												**1**
	LP & Newsvendor model								1						**1**
	LP/NLP	2	1	2			1		2	3	7				**18**
	Markov decision process							2	2	6	2				**12**
	Multi-objective optimisation						1	2				3	2		**8**
	Newsvendor model	1					1		3	3					**8**
	Queuing models							1					1		**2**
Simulation	Simulation			7			1			2			1		**11**
Conceptual and descriptive	Conceptual and descriptive	6	4				3		1						**14**
Grand Total		**25**	**19**	**28**	**24**	**16**	**23**	**14**	**24**	**36**	**25**	**4**	**6**	**1**	**245**

IP: Integer programming; **MILP:** Mixed-integer linear programming; **MINLP:** Mixed-integer non-linear programming; **LP:** Linear programming; **NLP:** Non-linear programming; **MCDM:** Multi-criteria decision-making

Table 13: Solution approaches among different model types

	Analytical models			Mathematical models																				
Solution Approach / Model type	Game theory/ Fuzzy theory	MCDM	Statistics	Systematic models	Algebraic equation	Algebric equation	Bass diffusion model	Chance-constrained optimisation	Convex optimisation	discrete flow model	Dynamic programming	Equilibrium model	Goal programming	IP/MILP/MINLP	Linear physical programming	LP & Newsvendor model	LP/NLP	Markov decision process	Multi-objective optimisation	Newsvendor model	Queuing models	Simulation	Conceptual and descriptive	**Grand Total**
AHP / Fuzzy AHP		7																						**7**
ANP/ Fuzzy ANP		2																						**2**
Benders' decomposition														2										**2**
branch and bound technique														1										**1**
Case study																							2	**2**
Commercial solver (AMPL/MINOS/CPLEX/Excel/LINDO/LINGO/GAMS/OptQuest/XpressIVE/MATLAB)	1			1	3					1		1		23			8	2			1			**41**
Cumulative Energy Demand				1																				**1**
DEMATEL		4																						**4**
Discrete-event					1																	4		**5**
Exact solution	48			2	30	1	1		3		6	3	1	7	1	1	5	7		8				**124**
Fuzzy linguistic		1																						**1**
Fuzzy TOPSIS		1																						**1**
Fuzzy TOPSIS / fuzzy G-TOPSIS		1																						**1**
Graph theoretic approach		1																						**1**
ISM																								
max–min approach					1																			**1**
Meta-heuristics (EA, NSGA-II, GA, PSO, SS, GRASP, IABCA, TSNDSGA-II)	1													5			2		7			1		**16**
Other Approaches				1																			5	**6**
Simple heuristics					1						3			2			3	3			1			**13**
Statistics			2																				4	**6**
System dynamics																						6		**6**
Grand Total	**50**	**17**	**2**	**5**	**36**	**1**	**1**		**3**	**1**	**9**	**4**	**1**	**40**	**1**	**1**	**18**	**12**	**7**	**8**	**2**	**10**	**11**	**241**

IP: Integer programming; **MILP:** Mixed-integer linear programming; **MINLP:** Mixed-integer non-linear programming; **LP:** Linear programming; **NLP:** Non-linear programming; **MCDM:** Multi-criteria decision-making; **AHP:** Analytic hierarchy process; **ANP:** Analytic network process; **ISM:** Interpretive structural modelling; **DEMATEL:** Decision-Making Trial and Evaluation Laboratory; **TOPSIS:** Technique of ranking Preferences by Similarity to the Ideal Solution; **LCA:** Life cycle assessment; **NSGA-II:** Non-dominated sorting genetic algorithm-II; **GA:** Genetic algorithm; **PSO:** Particle swarm optimisation; **SS:** Scatter search; **GRASP:** Greedy randomized adaptive search procedure; **IABCA:** Improved artificial bee colony algorithm; **TSNDSGA-II:** Tabu search non-dominated sorting genetic algorithm-II

Table 14: Future research directions for decision-making in remanufacturing

Decision level	Area	Issues in the existing literature	Research needs	Justifications
Strategic	Engagement in remanufacturing	Focus on automotive parts industry	Models for engagement in electrical and electronic equipment remanufacturing.	The fundamental barriers and key factors for engagement in remanufacturing vary according to different product types. Besides, environmental legislation, such as the WEEE (Waste Electrical and Electronic Equipment) Directive, has become more stringent, and companies are forced to participate in electrical and electronic equipment remanufacturing.
		Focus on China and India	Models to examine the barriers and factors to launch remanufacturing practices effectively in other developing countries.	The fundamental barriers and critical factors differ for specific countries. Accordingly, existing models developed for India and China may not apply to other developing countries.
	Network design	The majority of the models consider a single objective which is economic.	Multi-objective models that combine both economic and environmental objectives, as well as dealing with uncertainties and appropriate solution approaches to solve these complex problems.	In the real world, remanufacturing network design problems are complex problems that are subject to uncertainties as well as conflicting objectives.
	Supply chain coordination	Investigate the applicability of revenue-sharing, quantity discount, two-part tariff, supply risk sharing, low price promotion and three-way price discount contracts in remanufacturing.	Investigation of alternative contracts such as trade-policy, quantity flexibility, sales rebate.	Only in recent years, researchers have been interested in the coordination of supply chains in remanufacturing, and have examined the application of various contracts in remanufacturing. Nevertheless, there are remainder contracts to be studied. Hence, to find the most appropriate contract to be adopted by supply chain members, the applicability of these remaining contracts in remanufacturing systems should be examined.
	Collection strategy	The current models assume that symmetric information, deterministic demand, homogeneous return products, and new and remanufactured products are perfect substitutes and single periods.	Models that assume real-life cases such as asymmetric information, uncertain demand, heterogeneous return products, new and remanufactured products are not perfect substitutes and multiple periods.	As discussed intensely in Section 2.1.5, although these assumptions are useful for solving the proposed models, they do not reflect real-life cases. Consequently, the proposed models under these assumptions cannot adequately meet the needs of the companies.
	Marketing management	Proposed models for optimal warranty policies neglect uncertainties.	Models that determine optimal warranty policies when dealing with uncertainty	Proposing warranty is a powerful marketing tool for hindering potential customers bias on remanufactured products' quality.
		Limited research has been done on advertisement decisions for remanufactured products.	Models that explore various promotional types and their influences on remanufactured products.	Advertising activities in the remanufacturing environment can increase consumer awareness of the benefits of remanufactured products as well as the company's used product collection policy, therefore, play a significant role in influencing consumer demand and company's profitability (Hong et al, 2015).
Tactical	Returns disposition	Existing models neglect environmental objectives.	Models that assess various recovery options at the product and component level, taking environmental factors into account.	As discussed in Section 2.2.1, returns disposition decisions have a direct impact on the environment as the disposal of the product or component lead to depletion of landfill sites and even cause a hazard (Ondemir & Gupta, 2014). Hence, the direct impact of returns disposition decisions on environment cannot be ignored.
	Product acquisition management	The current models aim to maximise profits, which means that they serve a market-driven acquisition system.	Models aim to minimise the costs while dealing with uncertainties in demand for remanufactured products, the quality, quantity and timing of returned products.	In many cases, companies, especially those operating in European countries, acquire products through the waste stream system. In other words, as discussed in Section 2.2.2, it is necessary to minimise the costs for these companies, since they acquire the products without control over quality and quantity.
		Models combining both product acquisition management and sorting policies deal only with uncertainties in demand for remanufactured products and quality of returned products.	Models deal with uncertainties in demand, returns quality, quantity and timing simultaneously.	As explained in Section 2.2.2, product acquisition management is responsible for obtaining optimum quantities of returns in the optimum quality at the optimum price and time (Atasu et al, 2010). For this reason, the effective decisions must also deal with the uncertainties in returns timing and quantity.

	Inventory management	Stochastic inventory models neglect to consider environmental objectives.	Stochastic inventory models that deal with uncertainties as well as minimise the environmental impact.	Governments and customers become more and more aware of environmental aspects. Companies need to accommodate themselves to this new environment while dealing with uncertainties.
	Production planning	There is no research considers multi-product in the proposed models.	Models consider multi-products as well as deals with demand, returns quantity, returns quality and lead time uncertainties and aim to minimise the environmental effects.	Remanufacturing companies generally deal with varied product types (Li & Wu, 2014). Hence, single-product models may become inefficient for such companies.
Operational	Disassembly planning	Existing models neglect uncertainties.	Models that consider uncertainties in quantity and quality of returns, routing, lead time and demand simultaneously.	Disassembly process of returned products is subject to high degree of uncertainties such as the timing, quality and quantity of returns, routing, lead time and demand. Hence, integrating uncertainties into models will result in more effective decisions
		Commonly different meta-heuristic solution methods that, do not guarantee the optimal solution, are proposed.	Application of different heuristic solutions.	Disassembly planning problems are NP (nondeterministic polynomial time) problems (Adenso-Díaz et al, 2008) which are difficult to solve with analytical approaches. For these complex problems, meta-heuristics algorithms are an efficient solution approach. Nonetheless, this approach does not provide the optimal solution only good enough solutions. For this reason, it is worth investigating various algorithms to improve the disassembly process.
	Scheduling	No model aims to utilise the labour.	Model for remanufacturing that minimise the labour utilisation.	Remanufacturing is a labour-intensive process (Bazan et al., 2017; Yang et al., 2015). Efficient use of workforce can significantly reduce remanufacturing costs.
	Process planning	There is limited research for remanufacturing process planning.	Remanufacturing process planning models that improve the reliability of the remanufactured products while dealing with uncertainties.	The success of remanufacturing depends on the process planning being affected by the uncertainty of the quality and quantity of the returned products (Jiang et al, 2016a). To be successful in price competition, the remanufactured product must have high reliability and quality (Kin et al, 2014), which is provided by the process planning (Jiang et al, 2016b).
	Operational level general	The proposed decision-making models for operational level have not considered any integration such as disassembly planning and scheduling, scheduling and process planning.	Integrated models for operational level decisions in remanufacturing.	The integrated models improve the performance of operations as each decision is linked.
	Methodological aspects	Most studies used mathematical models (65%) and analytical models (26%) for making decisions in remanufacturing. Only a few studies applied multi-objective optimisation models.	The development of more multi-objective models.	In real practices, decision-making in remanufacturing is subject to conflicting objectives.
		Exact solution approach and the use of commercial software applications were found to be the two most preferred approaches, and only a limited number of algorithms have been developed.	The development of more meta-heuristics and simple heuristics algorithms to provide more practical and fast solutions.	Exact solution approach is criticised as not being practical due to high computational effort (Ma et al., 2011). On the other hand, simple heuristic and meta-heuristic algorithms can provide good enough, if not optimal, solutions.
	Uncertainty aspects	More than half of the studies reviewed in this study, either ignored uncertainty or assumed as being deterministic variables in their decision-making models.	Existing deterministic models need to evolve into models that integrate uncertainty.	Companies that undertake remanufacturing operations face additional uncertainties associated with returned products which are not a case for traditional manufacturing. Decisive models that ignore uncertainty in decision-making models can result in less effective decisions.

	Stochastic based optimisation is found to be the most commonly used approach for modelling uncertainty.	Investigating the applications and the results of robust optimisation in remanufacturing decision-making is another promising future research area as this approach does not require the probability distribution hence historical data.	Stochastic approach has some disadvantages as the probability distribution of the uncertain variable is required to be known based on historical data. As well as that, in many real-world practices, there is not enough historical data to estimate the distributions of parameters readily or accurately for decision makers (Govindan et al., 2017; Mohajeri & Fallah, 2016; Wei & Zhao, 2013).