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# Used product acquisition, sorting and disposition for circular supply chains: Literature review and research directions

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ABSTRACT

The vision of a circular economy (CE) inspires firms, governments, and scholars alike. The transition is underway in both practice and the literature, but success depends on the effective implementation of circular supply chains (CSCs), which encompass acquiring used products, sorting them by type and quality, and deciding which to dispose to various processing options. We review 131 high-impact journal articles on returns acquisition, sorting, and disposition (ASD) over the decade 2012–2021 to assess the current status of ASD research for CSCs and to discuss important research directions for supporting the transition to a CE. Uniquely synthesising the state of the art on all these three overarching decision areas, we find aspects of CSCs prominent in the decade's research agenda, such as closed loop supply chain coordination and ASD for remanufacturing, and highlight growing coverage of behavioural considerations. Research applicability has been constrained by a lack of empirical studies, limited practical validation of mathematical models, a focus on economic objectives, and restrictive modelling assumptions about behaviour and uncertainty in returns. We recommend further research in each part of ASD to facilitate a CSC, and as a whole, for transitioning to a CE. CE concepts such as joint decision-making between product design and returns management, cross-sector collaboration, and product-service systems should inform the agenda for CSC research.

## 1. Introduction

Not only is faster transition to a circular economy (CE) with its ultimate goal of eliminating waste and pollution crucial environmentally, but CE business models promise to outperform linear ones financially. In a striking recent global survey of 150 businesses, all firms averaged 6%–50% more revenue growth than competitors since adopting CE initiatives such as used product take-back (George, 2021a). A "take-back programme" is a firm's initiative to collect used products from consumers. Examples include take-back initiatives of H&M, Zara, Dell, HP and more recently, Walmart. Take-back in turn hinges on obtaining sufficient used products (i.e., *acquisition, A*); classifying them accurately by type and quality (*sorting, S*); and deciding their value-recovery option (*disposition, D*). Yet while take-back, driven also by regulatory and ethical imperatives, is increasingly common (Kant Hvass and Pedersen, 2019), the practice is young and challenging, so lacks full practitioner expertise (Corsini et al., 2020; Whalen et al., 2018). Uncertainty of quality, quantity and timing of returns significantly complicates it (Ferguson and Souza, 2010): Items arrive via varied channels, from numerous consumers, under diverse circumstances (Giri and Sharma, 2016). Many firms still miss their self-set take-back targets (George, 2021b) and the best or fastest transition path to a CE is not necessarily being followed.

From an academic perspective, A, S, and D (ASD) decisions have been commonly referred to as tactical level concerns in supply chain management (SCM) as opposed to strategic (e.g., product design, network design, whether to engage in take-back) or operational (e.g., disassembly planning, scheduling, process planning) level decisions (Ferguson and Souza, 2010). The integration of CE principles into SCM leads to circular supply chains (CSCs) which are more inclusive than closed loop supply chains (CLSCs) in value-recovery operations (Farooque et al., 2019). CSCs may employ two circularity archetypes depending on how materials are re-circulated (A. Zhang et al., 2021): (i) Closed loop circularity/CLSC entails the value-recovery from returns in the producer's original supply chain. CLSCs often entail material disposal, as full value-recovery within the original supply chain is challenging. For example, Dell acquires and remanufactures its used computers by disposing of some non-functional components. (ii) Open

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loop circularity involves firms from different supply chains working together to maximise resource use. For instance, HP feeds any materials remaining after remanufacturing into local supply chains for further value-recovery. Thus, both archetypes necessarily involve A, S and D for the reverse flow of materials.

Studies on CSCs are burgeoning (Farooque et al., 2019; Genovese et al., 2017; MahmoumGonbadi et al., 2021). However, there is no comprehensive review of the latest research in ASD decisions in the context of CSCs. The extant reviews have focused on acquisition more than sorting or disposition, and none treat all three. Moreover, acquisition studies mainly address acquisition decisions for a specific purpose (e.g., remanufacturing; Sitcharangsie et al., 2019) or selected topics (e.g., forecasting; Agrawal et al., 2015), but none consider all CSC dimensions (See Section 2.1 for the CSC dimensions). Table 1 characterises six earlier reviews treating returns ASD decisions, and contrasts with ours that fills the gap. We systematically review ASD decision making in CSCs, addressing both closed loop and open loop circularity archetypes. Only 39 articles from earlier reviews overlap with our paper.

Our review is motivated by both practice and research needs. We consulted fifteen businesses with current and upcoming take-back initiatives, who all responded that they would value a review of this type

**Table 1**
Literature reviews on acquisition, sorting and disposition decisions.

| Reference | Period | Number of articles | Articles also in our review | Scope |
|---|---|---|---|---|
| Rizova et al. (2020) | Until 2019 | 241 | 29 | • Systematic review of remanufacturing decision-making.<br>• Review some A and D decisions (channel selection, acquisition effort and disposition) briefly. |
| Sitcharangsie et al. (2019) | 1996–2018 | 100 | 12 | • Systematic review of remanufacturing decision-making.<br>• Review some ASD decisions (acquisition effort and disposition) briefly. |
| Jena and Sarmah (2016) | 2000–2014 | 92 | 2 | • Content analysis.<br>• Review some A decisions (acquisition channel and acquisition effort) briefly. |
| Wei et al. (2015) | Until 2014 | 87 | 13 | • Review of used product acquisition for remanufacturing.<br>• Review A and S decisions (forecasting, channel selection, acquisition effort and, sorting). |
| Agrawal et al. (2015) | 1986–2015 | 242 | 6 | • Review of five selected issues in reverse logistics.<br>• Two of the issues include some A and D decisions (forecasting and disposition). |
| *This review article* | 2012–2021 | 131 | – | • Systematic review of ASD decision-making in CSCs.<br>• Cover all the three parts of ASD decisions.<br>• Discuss future ASD research for transitioning to a CE. |

for their decisions. With the growing adoption of take-back schemes, scholars should be familiar with the status of research and areas warranting more research. Both scholars and practitioners will find value in how ASD practice and research could assist the transition to a CSC as legislatures and academic institutes prioritise their CE agenda. Accordingly, we ask three research questions: (1) What is the current state of research in used product returns ASD for CSCs? (2) How does ASD research provide insights to practitioner decision-making? and (3) How could CE principles better inform future research directions in returns ASD for CSCs?

Besides being more up to date in this fast-moving field, in answering the research questions our review synthesises the state of the art more fully, by assessing the impact of all three overarching decision areas of ASD (and areas within A) on CSC activities with a focus on how literature can more fully promote the transition to a CE. We also tabulate, and describe gaps around, coverage of five key research considerations we discerned – uncertainty, legislation, industry, technology, and behaviour– and devote an additional section to current coverage of behaviour as the consideration of stand-out significance. Thus, we provide a systematic overview; identify gaps, flaws and limitations; and suggest research avenues in, SCM, Operations Management, Operational Research, and Business Management. Our insights into ASD practices should also help policymakers and firms dealing with returns, like recyclers, retailers, and remanufacturers, grasp the ASD decisions in a CE context.

Among highlights, we find CLSC coordination for ASD, ASD for remanufacturing, and other aspects of CSCs dominated the decade. Open loop circularity and secondary markets, both important to CSC, were under-studied, as were behaviours of individuals. Moreover, scant empirical studies, little practical validation of mathematical models, a focus on economic goals and high-value items, and restrictive modelling assumptions about behavioural considerations and uncertainty in returns, all limited the literature's applicability. Considering returns from open loop circularity applications, understanding the conditions for sorting and sorting errors, and considering end-of-use disposition decisions at the product design stage are significant for future ASD research. In addition, legislation's role, especially in sorting and disposition, needs more exploration. How behaviour and technology affect A, S, and D are also significant for research and practice. Overall, we find only modest coverage of CSC and broad claims of CE relevance, rather than analysis of how to transition to it via CSCs. For transition, CE concepts such as joint decision-making between product design and returns management, cross-sector collaboration, and product-service systems could inform the agenda for CSC research.

This article proceeds as follows. Section 2 elaborates and justifies our theoretical framework. Section 3 delineates the methodology and scope. Sample statistics occupy Section 4. Section 5 discusses results on the current state of ASD research by decision area. In Section 6, we summarise knowledge gaps under headings of methods and assumptions, circularity archetypes, and the five key considerations, which raise individual research avenues to address them. Section 7 proposes future research directions specifically to support a transition across the board to a CE. Conclusions are in Section 8.

## 2. Theoretical framework and review themes

### 2.1. Theoretical background

EMF and McKinsey (2015) presented a six-action framework that can transition a linear economy to a circular one: regenerate, share, optimise, loop, virtualise, and exchange - the ReSOLVE framework. The *Regenerate* lever calls for a shift to renewable materials and energy and a safe return of biological nutrients to the biosphere to regenerate health of ecosystems. The *Share* lever exploits synergies between the sharing economy and the CE, while the *Optimise* lever lifts efficiency and performance of products, processes and supply chains. The *Loop* lever keeps components and materials in use, and the *Virtualise* lever delivers utility virtually. The *Exchange* lever replaces old with new materials, products, services, technologies, and business models to enhance resource circularity.

A CSC mainly relates to the loop lever, focusing on the material flow of a CE. CSC goes beyond a CLSC to include open loop circularity (Farooque et al., 2019; Genovese et al., 2017). Whereas open loops may convert used products to inputs for a different supply chain, in CLSCs, forward channel members take back to recover value in the same supply chain. Realistically, this is unlikely to eliminate waste, whereas by opening the loop, CSC members collaborate with firms outside the original supply chain to recover complete value from the returns. CSC is multidimensional (see Fig. 1), encompassing CLSC, remanufacturing supply chain, reverse supply chain (RSC), recycling supply chain, and industrial symbiosis (where one firm's disposed materials become another's inputs). Note that open loop circularity does not appear as a separate dimension but as a characteristic of all but CLSC dimension. A, S, and D are common to all CSC dimensions. Used products are acquired from primary and secondary markets, then sorted, and decisions made about value-recovery options via any CSC dimension. See A. Zhang et al. (2021) for an explanation of these dimensions.

### 2.2. Literature analysis framework

Under our overarching ASD structure, the review framework divides the literature more finely into a total of five decision areas, whereby the first splits into three: returns forecasting, acquisition effort, and channel selection (all three parts of acquisition); sorting process; and disposition. We inductively developed the framework as an outcome of reviewing the selected 131 papers. There are some overlaps and dependencies, but we follow academic literature and common practice that consider them separate and sequential activities. Fig. 2 conceptually maps the five decision areas. The paper reports them in this order (Sections 5.1-5.3); but within each area it clusters, compares and contrasts articles as illustrations of certain themes - topics or arguments we discern in the literature.

This five-area framework is based on problem-specific literature seeking to manage the quantity, quality, timing and value-recovery of returns. More specifically, *forecasting* decisions concern methods to estimate the quantity, quality and/or timing of used product returns. Logically, forecasting could be part of A, S, or D, but is more applicable to A and is usually the first decision area in practice. *Acquisition effort* essentially means the time, cost and other resources a firm uses to acquire returns. By deciding acquisition effort, firms control the flow of returns. Acquisition effort is not sequential but may spill over into forecasting and channel selection. However, in the literature, forecasting applies to determining returns that are independent of acquisition effort. Variability of returns partly depends on which supply chain member acquires the products - *channel selection* decisions. For example, a remanufacturer may acquire returns without using a third-party collector. However, this may limit acquisition quantity. In acquisition effort studies, acquisition decisions are considered under pre-determined supply chain channel structures, whereas channel selection decisions choose freely from a set of supply chain options by comparing acquisition effort and other economic, environmental and/or social parameters. At or after the acquisition, *sorting* decisions reduce uncertainty in quality to allocate returns to various value-recovery operations. Finally, *disposition* decides which value-recovery options or combinations yield most value.

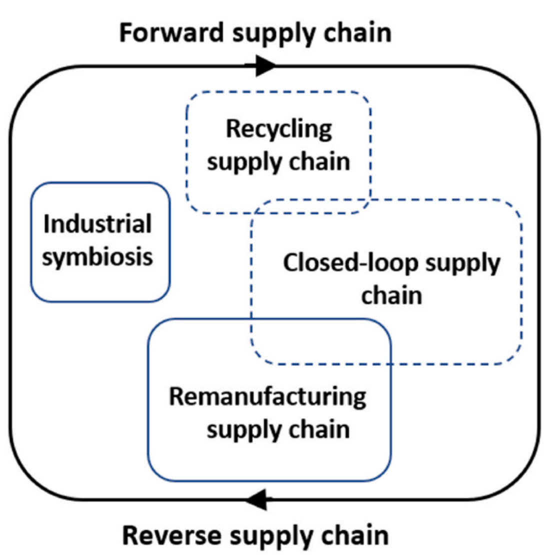


**Fig. 1.** Dimensions of a circular supply chain.
Source: Adapted from A. Zhang et al. (2021).

For the five decision areas mentioned above, the ASD literature suggests several influential factors-uncertainty, legislation, industry, technology, and behaviour, to consider for research. Thus, we incorporate these five research considerations into our literature analysis framework. The first consideration refers to whether the research incorporates uncertainty into decision-making (e.g., uncertainty relating to returns quantity, quality and timing, remanufacturing yield, lead time and capacity, and demand for value-recovered products). Indeed, one of the characterising features of RSCs is uncertainty from multiple sources (De Lima et al., 2021). Second, legislation relates to whether the study has considered the impact of regulations on decisions (Morseletto, 2020). According to Ponte et al. (2021), companies in competitive marketplaces may not include reverse logistics activities in their supply chains until regulation mandates it. Industry applications demonstrate the research's feasibility and associated benefits (Liao et al., 2021). As such, thirdly, we consider whether the research uses industry data for model validation or discusses how to apply the results to industry. Technologies emerge as a feasible approach for increased value creation in used product take-back (Tozanlı et al., 2020). Accordingly, fourth, technology concerns whether technology has been a tool to support ASD decision-making (Gebhardt et al., 2021). Finally, we examine whether the research incorporates behavioural aspects of supply chain members, employees and/or consumers (Pournader et al., 2021). We also single out behavioural concerns affecting ASD decisions as an additional sub-section (Section 5.4) due to their special significance in sustainable SCM research (Pournader et al., 2021; Seuring and Müller, 2008). ASD literature acknowledges decisions are significantly affected by the behaviour of supply chain members (e.g., Li et al., 2021; Simpson et al., 2019). Industry examples also show the importance of behavioural considerations in ASD decision-making to reduce uncertainty in returns' quantity, quality, and timing. We asked 15 firms in New Zealand, China, and the USA about the value of incorporating behaviour in ASD research. They were near unanimous in noting that behaviours of customers, employees and supply chain partners significantly impact take-back programmes.

## 3. Methodology and scope

### 3.1. Scope of review

Our basic scope, used product ASD literature, narrows to two types of products taken back, end-of-use (EOU) and end-of-life (EOL) products, rather than commercial returns (Gaur and Mani, 2018). Commercial returns (only 6–10% of sales) occur early, usually within the warranty period (Shaharudin et al., 2019), and mostly depend on product characteristics. See Abdulla et al. (2019) for a review. A further narrowing, whereby sorting means only within one product type, is explained at Section 5.2. EOU returns are those available for a "second life" through value-recovery (Gaur and Mani, 2018). EOL returns have exhausted

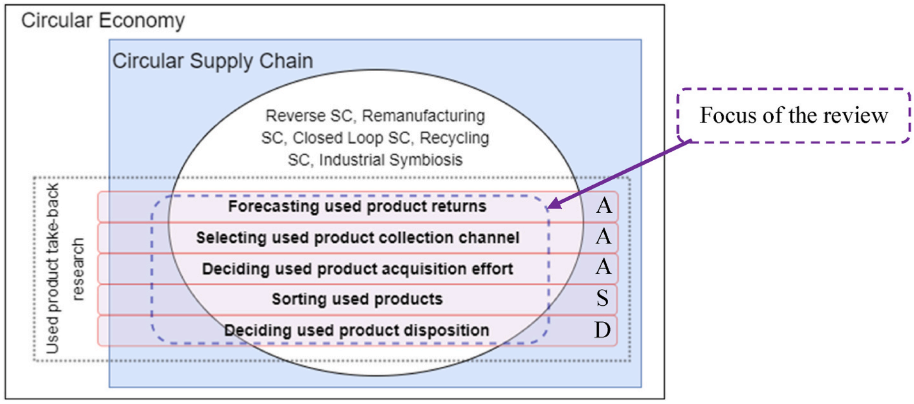


**Fig. 2.** Subject map of the review.

their useful life, due mostly to obsolescence or major damage (Shaharudin et al., 2019). Notably for our behaviour consideration, the quantity, quality, and timing of both depend heavily on consumer behaviour (Tsiliyannis, 2018).

### 3.2. Literature selection and content analysis process

For rigorous synthesis of ASD literature, we used a systematic literature review (Durach et al., 2017; Seuring and Gold, 2012; Tranfield et al., 2003), shedding light on common practice and gaps. We contribute to CE literature by taking a "deductive-internal" approach as identified by Seuring et al. (2021). Accordingly, we use constructs from A, S and D literature to review the material and then analyse how A, S and D decisions should facilitate the transition to a CSC.

Fig. 3 illustrates key steps of the literature selection methodology and numbers of articles remaining after the steps. The Scopus database was chosen for its broad coverage of disciplines (Harzing and Alakangas, 2016) and its high-quality content (Farooque et al., 2019). Since pre-2012 work has been reviewed in multiple studies, and ASD literature tracks fast-moving practice, we review articles available online from January 01, 2012 to December 31, 2021. However, we sometimes make points using sources before this. We further restrict the search to peer-reviewed scientific articles in English. Table 2 shows in six sets the many synonyms we used for supply chain, circular economy, (used) products, acquisition, sorting, and disposition decision, respectively, as search terms to catch pertinent articles. The three authors met repeatedly to review search keywords and results, so the process comprehensively identified the most relevant publications. Table 3 shows how we searched the literature on acquisition, sorting and disposition respectively using three distinct fourfold combinations of these search term sets. Fields searched were titles, abstracts and the articles' self-provided keywords. Table 3 abbreviates the sets by the number from Table 2: e.g., (1) represents (Supply Chain **OR** Logistics **OR** Operations Management). The lead author followed Seuring and Gold's (2012) content analysis procedures to code publications, by the five decision areas from Section 2. Ambiguity was resolved by discussions amongst the co-authors.

We retained only those articles published in journals with a Chartered Association of Business Schools (CABS) 2021 ranking of 2 or higher, leaving 251 studies. By reading all abstracts, introductions and conclusions, we applied the following inclusion and exclusion criteria to filter the 251 articles:

a) Focuses on an ASD decision; AND/OR

We retained articles that forecast the quantity, quality and timing of returns or decide about acquisition effort, acquisition channel, sorting categories, or the best value-recovery option for acquired used products. This includes both modelling and empirical studies. However, we excluded articles that simply analysed the general value of different disposition options or identified barriers and enablers of ASD operations as such studies do not directly deal with ASD decisions.

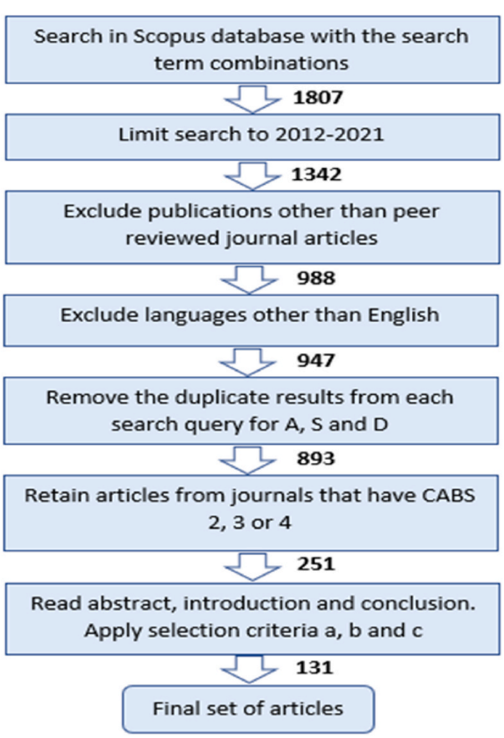


**Fig. 3.** Selection process of the reviewed articles.

**Table 2**
Search terms used for literature search.

| | |
|---|---|
| Search term set 1 | Supply Chain OR Logistics OR Operations Management |
| Search term set 2 | Circular **OR** Closed loop **OR** Closed-loop **OR** Regenerative **OR** Restorative **OR** Reverse **OR** Remanufacturing **OR** Recycling **OR** Industrial symbiosis |
| Search term set 3 | Product **OR** Core **OR** Good **OR** Item **OR** Return **OR** End of life **OR** End of use **OR** End-of-life **OR** End-of-use |
| Search term set 4 | Acquisition **OR** Obtain **OR** Take back **OR** Take-back |
| Search term set 5 | Sort* **OR** Grad* **OR** Inspect* **OR** Classif* |
| Search term set 6 | Disposition decision **OR** Disposition option **OR** Recovery decision **OR** Recovery option |

**Table 3**
Search criteria for the three overarching decision areas.

| Topic | Search query (refer to Table 2) | Results after search in Scopus | Results after removing duplicates |
|---|---|---|---|
| Acquisition | (1) **AND** (2) **AND** (3) **AND** (4) | 777 | 400 |
| Sorting | (1) **AND** (2) **AND** (3) **AND** (5) | 909 | 451 |
| Disposition | (1) **AND** (2) **AND** (3) **AND** (6) | 119 | 42 |
| Total | | 1805 | 893 |

b) Contributes to how an exogenous ASD variable impacts other CSC decisions; AND/OR

We included studies that analysed how exogenously-set returns quantity, quality and timing affected CSC decision-making.

c) Focuses on a factor affecting ASD of returned products

We retained the studies that focused on how one or more research considerations (i.e., uncertainty, legislation, industry, technology, and behaviour), as outlined in the literature analysis framework, directly affected ASD decisions.

Our final list comprises 131 articles. Fig. 4 presents the area-weighted Venn diagram of the articles' focal areas. The intersections represent articles that cover two/three areas, rather than inherent overlap of concepts.

## 4. Sample statistics

Fig. 5 shows publication dates of the 131 articles reviewed, which come from 28 journals. ASD coverage is fragmented; most (15) journals only have one article. Table 4 summarises the distribution of journals with at least two reviewed articles. For each journal, we indicate the number of articles reviewed relative to the journal's total published articles in-period, and its 5-year Impact Factor. This reflects journals' emphases and may help scholars make submission decisions.

The geographic dispersion of ASD authors (not shown) is limited. The first authors of 56% of the studies are affiliated to three countries (China, 30%; USA, 16%; India, 10%). The other 44% are dispersed among 22 countries, none contributing over 5%. Also not shown, 43 (33%) of the articles refer to their models as applicable to one product type, 11 consider multiple products (9%), while the rest take a general approach. Electronic equipment as a general category (circuit boards, hard disks, mobile phones, personal computers, home appliances, etc.) leads the list: considered 23 times. Automobile parts (spare parts, engines, electric vehicle batteries, oil pump, timing cover, etc.) are assessed in 10 articles. Other products include industrial equipment, apparel, kitchen equipment, retreaded tyres, military equipment, and milk bottles.

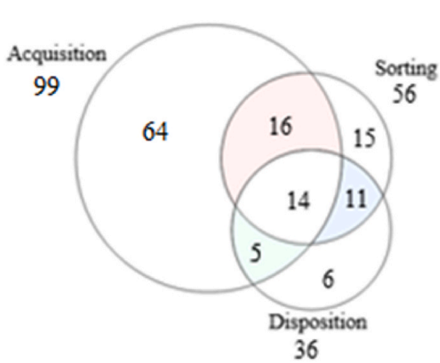


**Fig. 4.** Three overarching areas as focused on by the review.

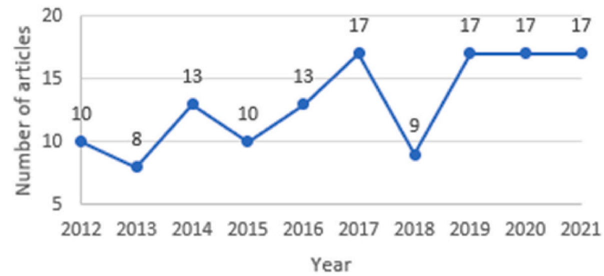


**Fig. 5.** Number of articles from 2012 to 2021.

**Table 4**
Distribution of the articles from journals with at least two reviewed articles.

| Journal name | Number of articles reviewed | As a % of journal's total publications | Five-year Journal Impact Factor (2020) |
|---|---|---|---|
| Journal of Cleaner Production | 39 | 0.15 | 9.444 |
| International Journal of Production Economics | 19 | 0.58 | 9.003 |
| International Journal of Production Research | 19 | 0.39 | 8.568 |
| European Journal of Operational Research | 13 | 0.19 | 5.808 |
| Computers and Industrial Engineering | 7 | 0.12 | 5.518 |
| Omega | 3 | 0.02 | 8.551 |
| Production and Operations Management | 3 | 0.19 | 4.930 |
| Industrial Management and Data Systems | 2 | 0.21 | 4.379 |
| Journal of Business Economics | 2 | 0.18 | 1.734 |
| Journal of Operations Management | 2 | 0.50 | 13.023 |
| Journal of the Operational Research Society | 2 | 0.12 | 3.050 |
| Production Planning and Control | 2 | 0.19 | 6.800 |
| Int. J. of Physical Distribution & Logistics Management | 2 | 0.47 | 7.824 |

The keyword co-occurrence network diagram (Fig. 6) demonstrates the research foci of the articles. We report the articles' self-assigned keywords which occur at least four times. Node sizes reflect the overall frequency; distances between nodes, the frequency of co-occurrence in an article. Thicker links mean more closely related pairs. Many articles co-use the keywords *CLSC*, *RSC*, and *remanufacturing*, but *recycling* or *industrial symbiosis* are less frequent. Three main related study clusters emerge: (i) CSC (red); (ii) used product ASD (green); and (iii) supply chain coordination (blue).

## 5. Review results

This section discusses review results according to our five decision areas from Section 2.2: *acquisition*, in terms of returns *forecasting*, *acquisition effort* and *channel selection* (Sections 5.1.1-5.1.3); quality uncertainty and returns *sorting* (Section 5.2); and *disposition* (Section 5.3). Accompanying them, Tables 5–9 summarise selected themes within each decision area. They also tabulate the modelling approach, performance measures, and the prevalence of our five key research considerations – uncertainty, legislation, industry, technology, and

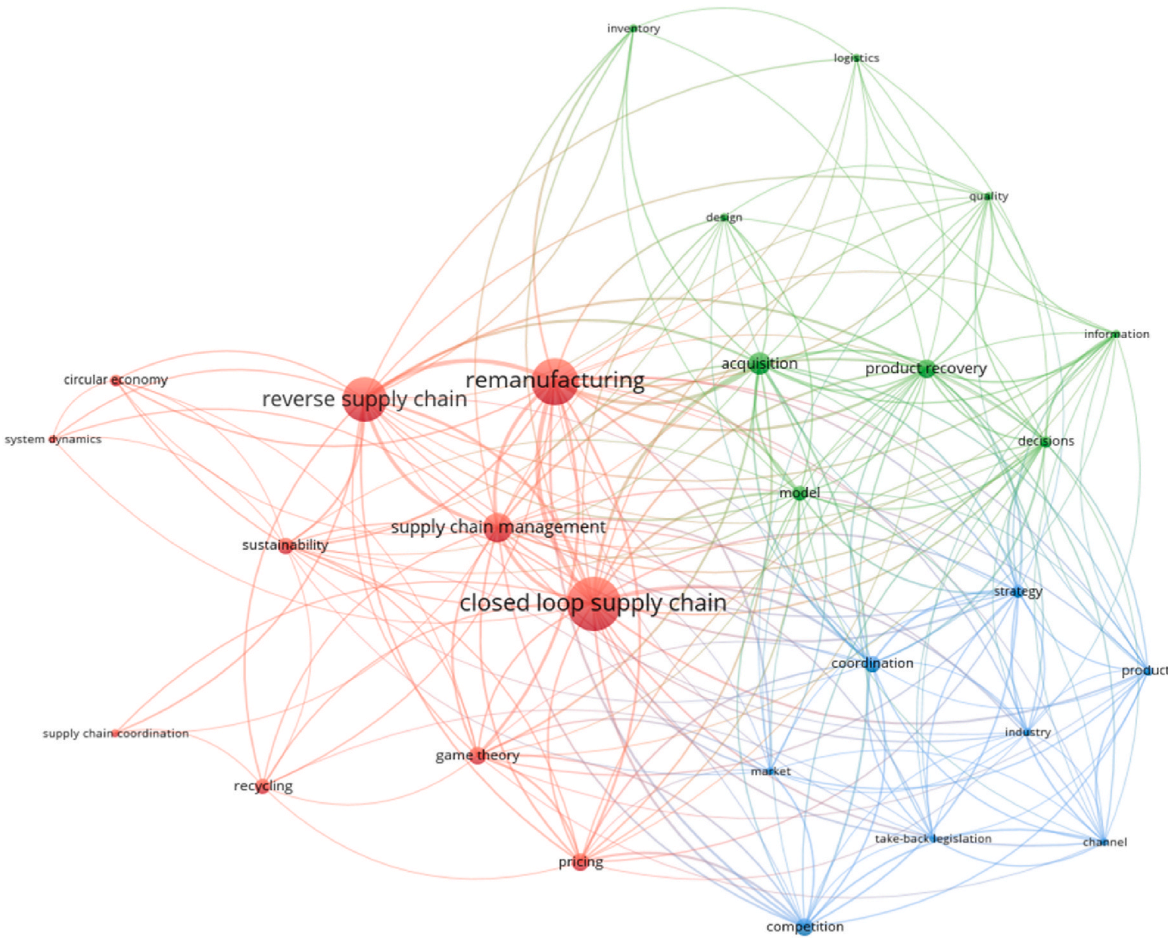


**Fig. 6.** Keyword co-occurrence network diagram.

**Table 5**
Summary of returns forecasting studies within acquisition literature.

| Reference | Forecast Parameter | | Number of periods | Modelling approach | Considerations | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Quantity | Quality | | | Uncertainty | Legislation | Industry | Technology | Behaviour |
| Goltsos et al. (2019) | ✓ | | Single | Z | ✓ | | ✓ | ✓ | |
| Tsiliyannis (2018) | ✓ | ✓ | Multi | C | ✓ | | ✓ | | |
| Clottey (2016) | ✓ | | Multi | B | | | | | |
| Clottey and Benton (2014) | ✓ | | Single | B | | | ✓ | | |
| Krapp et al. (2013) | ✓ | | Single | B | | | | | |
| Clottey et al. (2012) | ✓ | | Single | B | | | ✓ | | |

Key to Table 5:
Modelling approach: **B**- Bayesian estimation of the distributed lag; **C**- Monte Carlo simulation; **Z**- Simulation-based optimisation.

behaviour. These later become the basis for gap analyses in Section 6. Secondly, Section 5.4 discusses results on a stand-out consideration, behaviour.

### 5.1. *Used product acquisition*

#### 5.1.1. *Returns forecasting*

Forecasting is a logical first decision area – albeit covered little (six studies out of 131). Forecasting helps managers predict used products returns patterns to enable informed decisions for CSC activities (Clottey et al., 2012). Thematically, this decision area is dominated by debates over modelling approach and number of periods (see Table 5), and reflects industry more than in the other four key considerations, likely as product characteristics greatly influence returns pattern. Many studies assume that future periods returns relate linearly to past sales and recent product returns. Mathematical models capture this dependency in single-period-ahead (Krapp et al., 2013) or multiple-periods-ahead (Clottey, 2016) returns quantity forecasts (Clottey and Benton, 2014). Of the two, the latter applies better to product acquisition planning, as the typical sequence of activities involves planning for a fixed number of periods, implementing the first decision, and rolling the horizon to the next decision period.

As per Table 5, Krapp et al. (2013) use a Bayesian estimation of the distributed lag (BEDL) model with a discrete Poisson delay function to forecast returns. However, Clottey et al. (2012) had shown that such a model with a discrete delay function to account for continuous time can cause biases. Instead, they developed a method to estimate a continuous exponential delay function in the distributed lag model, which Clottey and Benton (2014) expanded to any specified continuous delay function. Clottey (2016) extends distributed lag models to multi-period

**Table 6**
Summary of acquisition effort studies within acquisition literature.

| Reference | Supply chain members | | | | | | Supply chain Focus | | Returns | | | Performance measure | Modelling approach | Considerations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Supplier | Re/ manufacturer | 3P remanufacturer | Retailer | 3P collector | Independent remanufacturer | Integrated-firm | Supply chain coordination | Passive | Deterministic | Random | | | Uncertainty | Legislation | Industry | Technology | Behaviour |
| Jauhari et al. (2021) | | ✓ | | ✓ | | | ✓ | | | | ✓ | P | A | ✓ | ✓ | | | |
| Cai et al. (2021) | | ✓ | | ✓ | | | ✓ | ✓ | | ✓ | | P | G | | | | | ✓ |
| Matsui (2021) | | ✓ | | | ✓ | | | ✓ | | ✓ | | P | G | | | | | ✓ |
| Xintong et al. (2021) | | ✓ | | | | | ✓ | | | ✓ | | P/S | G | ✓ | ✓ | | | ✓ |
| Liao et al. (2021) | | ✓ | | | | | ✓ | | | | ✓ | P | A | ✓ | | ✓ | | |
| Liao and Li (2021) | | ✓ | | ✓ | | | ✓ | | | ✓ | | E | I | ✓ | | ✓ | | |
| Li et al. (2021) | | ✓ | | | | | ✓ | | | ✓ | | P | G | | ✓ | | | |
| Iqbal and Kang (2021) | | ✓ | | | | | ✓ | | | ✓ | | P | N | | | ✓ | | ✓ |
| Ponte et al. (2020) | | ✓ | | | | | ✓ | | ✓ | | | P | A | | | | | |
| Zheng et al. (2020) | | ✓ | | | | | ✓ | | ✓ | | | P | N | | ✓ | | | |
| Hosseini-Motlagh et al. (2020c) | | ✓ | | | ✓ | | ✓ | ✓ | | ✓ | | P | G | | | | | ✓ |
| Hosseini-Motlagh et al. (2020b) | ✓ | ✓ | | | ✓ | | ✓ | ✓ | | ✓ | | P | G | | | ✓ | | ✓ |
| Esenduran et al. (2020) | | ✓ | | | ✓ | | ✓ | | | | | P | G | ✓ | ✓ | | | ✓ |
| Kleber et al. (2020b) | | | | | | ✓ | | ✓ | | ✓ | | P | G | | | | | ✓ |
| Tozanlı et al. (2020) | | ✓ | | | | | ✓ | | | ✓ | | P | D | ✓ | | | ✓ | |
| Liu et al. (2020) | | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | | P | G | | | | | ✓ |
| Hosseini-Motlagh et al. (2020a) | | ✓ | | ✓ | | | ✓ | ✓ | | ✓ | | P | G | | | | ✓ | ✓ |
| Alizadeh-Basban and Taleizadeh (2020) | | ✓ | | ✓ | | | | ✓ | | ✓ | | P | G | | ✓ | | ✓ | |
| Bansal et al. (2020) | | ✓ | | | | | ✓ | | | ✓ | | P | N | | | | | |
| Lechner and Reimann (2020) | | ✓ | | | | | ✓ | | | ✓ | | P | N | ✓ | ✓ | | | |
| Lechner and Reimann (2020) | | ✓ | | | | | ✓ | | | ✓ | | P | N | ✓ | ✓ | | | |
| Farahani et al. (2019) | | | ✓ | | | | ✓ | | | ✓ | | P | N | ✓ | | ✓ | | |
| Taleizadeh and Sadeghi (2019) | | ✓ | ✓ | ✓ | | | | ✓ | | ✓ | | P | G | | | | ✓ | ✓ |
| Narayana et al. (2019) | | | | | | | ✓ | | | ✓ | | P | V | | | | | ✓ |
| Li et al. (2019) | | ✓ | | | | | ✓ | ✓ | | ✓ | | P | G | | | | | ✓ |
| Li et al. (2019) | | ✓ | | ✓ | | | | ✓ | | ✓ | | P | G | ✓ | | | | ✓ |
| Taleizadeh et al. (2019) | ✓ | ✓ | | ✓ | ✓ | | ✓ | | | ✓ | | P/E/S | T | ✓ | | ✓ | ✓ | ✓ |
| Hong and Zhang (2019) | | ✓ | ✓ | | | | | ✓ | | ✓ | | P | G | | | | | ✓ |
| Simpson et al. (2019) | | ✓ | | | | | ✓ | | | | | P/E | X | | | | | ✓ |
| Wang et al. (2019) | | ✓ | | ✓ | | | ✓ | ✓ | | ✓ | | P/E/S | G | | | | | ✓ |
| Franco (2019) | | | | | | | | | | | | P/E/S | V | | | | | ✓ |
| Ponte et al. (2019) | | ✓ | | | | | ✓ | | | | ✓ | P | A | ✓ | | | | |

(continued on next page)

**Table 6** (*continued*)

| Reference | Supply chain members | | | | | | Supply chain Focus | | Returns | | | Performance measure | Modelling approach | Considerations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Supplier | Re/ manufacturer | 3P remanufacturer | Retailer | 3P collector | Independent remanufacturer | Integrated-firm | Supply chain coordination | Passive | Deterministic | Random | | | Uncertainty | Legislation | Industry | Technology | Behaviour |
| Bal and Satoglu (2018) | | | | | | | ✓ | | | ✓ | | P/E/S | Y | | | ✓ | | |
| Xie et al. (2018) | | ✓ | | ✓ | | | | | | | | P | G | | | | | ✓ |
| Bhattacharya et al. (2018) | | ✓ | | | | | ✓ | | | | ✓ | P | N | | | | | |
| Gu et al. (2018b) | | | | | | | | | | | | P | G | | | | | ✓ |
| Gu et al. (2018a) | | | | | | | | | | | | P | G | | | | | ✓ |
| van Loon and Van Wassenhove (2018) | | ✓ | | | | | ✓ | | | ✓ | | P | T | ✓ | | ✓ | | |
| Wang et al. (2017) | | ✓ | | ✓ | | | ✓ | ✓ | | | | P | G | | | ✓ | | ✓ |
| He (2017) | | ✓ | | | ✓ | | ✓ | ✓ | | | ✓ | P | G | ✓ | | | | |
| Huang and Wang (2017) | | ✓ | | ✓ | ✓ | | | | | ✓ | | P/E | G | | | | | ✓ |
| Hahler and Fleischmann (2017) | | | | | | | | | | | | P | G | ✓ | | ✓ | ✓ | ✓ |
| Heydari et al. (2017) | | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | | P | G | | ✓ | | ✓ | |
| Alegoz and Kaya (2017) | | | | | ✓ | | ✓ | | | | ✓ | P | K | ✓ | | | | |
| Gaur et al. (2017) | | ✓ | | | | | ✓ | | | | | P | X/Q | | | | | |
| Masoudipour et al. (2017) | | | | | | | | | | | | P | N | | | ✓ | | |
| Liu et al. (2016) | | ✓ | ✓ | | | | | ✓ | | ✓ | | P | G | | ✓ | | | ✓ |
| Hong et al. (2016) | | ✓ | | ✓ | ✓ | | | ✓ | | ✓ | | P | G | | | | | |
| V. V. Agrawal et al. (2016) | | ✓ | ✓ | | | | | ✓ | | ✓ | | P | G | | | | | ✓ |
| Zhu et al. (2016) | | ✓ | | | | | | ✓ | | ✓ | | P | G | | ✓ | | | ✓ |
| Mutha et al. (2016) | | | | | | | | | | | | P | S | | | | | |
| Dutta et al. (2016) | | | | | | | | | | | | P | A | ✓ | ✓ | | | ✓ |
| Wu and Wu (2016) | | ✓ | ✓ | | | | | ✓ | | ✓ | | P | G | | | | | ✓ |
| Aydin et al. (2016) | ✓ | ✓ | | ✓ | | | | ✓ | | ✓ | | P | G/U | | | ✓ | | |
| Jena and Sarmah (2015) | | | | | | | | | | | | P | X | | | | | ✓ |
| Gönsch (2015) | | ✓ | ✓ | | | | | ✓ | | | | P | G | | | | | ✓ |
| Wu (2015) | | ✓ | ✓ | | | | | ✓ | | | | P | G | | | | | ✓ |
| Wei et al. (2015) | | ✓ | | ✓ | | | | | | | | P | G | ✓ | | | | |
| Xie et al. (2015) | | ✓ | | | | | ✓ | | | | ✓ | P | K | ✓ | | | | |
| Das and Dutta (2015) | | | | | | | | | | | | P | N | ✓ | ✓ | | | ✓ |
| He (2015) | ✓ | ✓ | | | | | ✓ | ✓ | | | | P | G | ✓ | | | | |
| Kwak and Kim (2015) | | ✓ | | | | | ✓ | | | ✓ | | P/E/S | J | | | ✓ | | |
| Gönsch (2014) | | ✓ | ✓ | | | | | ✓ | | ✓ | | P | G | | | | | ✓ |
| Jena and Sarmah (2014) | | ✓ | ✓ | | | | ✓ | ✓ | | | ✓ | P | G | | | | | ✓ |
| Li et al. (2014) | | ✓ | | | ✓ | | | ✓ | | | | P | G | | ✓ | | | ✓ |
| Benedito and Corominas (2013) | | ✓ | | | | | ✓ | | | | ✓ | P | H | ✓ | | | | |
| Pokharel and Liang (2012) | | ✓ | | | | | ✓ | ✓ | | | | P | A | ✓ | | | | |

(*continued on next page*)

**Table 6** (*continued*)

| Reference | Supply chain members | | | | | | Supply chain Focus | | Returns | | | Performance measure | Modelling approach | Considerations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Supplier | Re/manufacturer | 3P remanufacturer | Retailer | 3P collector | Independent remanufacturer | Integrated-firm | Supply chain coordination | Passive | Deterministic | Random | | | Uncertainty | Legislation | Industry | Technology | Behaviour |
| Corominas et al. (2012) | | ✓ | | | | | ✓ | | | | | P | N | | | | | |
| Xu et al. (2012) | | ✓ | | | | | | | | ✓ | | P | K | ✓ | | | | |
| Minner and Kiesmüller (2012) | | ✓ | ✓ | | | | ✓ | ✓ | | | | P | G | | | | | ✓ |
| Nenes and Nikolaidis (2012) | | ✓ | | | | | ✓ | | ✓ | | | P | L | | | | | |

Key to Table 6.

Performance measure: **E**- Environmental benefit; **P**- Profit; **S**- Social welfare.

Modelling approach: **A**- Analytical modelling; **D**- Discrete event simulation; **F**- Fuzzy theory; **G**- Game theory; **H**- Quadratic programming; **J**- Mixed integer nonlinear programming; **K**- Stochastic programming; **L**- Mixed integer linear programming; **N**- Nonlinear programming; **Q**- Multiple-criteria decision-making; **R**- Robust optimisation; **U**- Mathematical programming (algorithms); **V**- System dynamics simulation; **W**- Convex and concave programming; **X**- Multivariate; **Y**- Chance constrained programming; **Z**- Simulation-based optimisation.

forecasting. Goltsos et al. (2019) consider the value of item-level serialised data to characterise the returns distributions as opposed to estimating parameters of hypothesised distributions, e.g., by Clottey et al. (2012) and Clottey and Benton (2014). They find such an approach worthwhile for products with high-value, low-volume sales.

By assuming specific, or fixed-structure regressive, sales–returns relations, most studies so far continue to overlook the impact originating from factors such as consumer behaviour, demographics, technological change, green legislation, and firms' competition to acquire returns. Recently, Tsiliyannis (2018) presents a 10-step forecasting procedure using Markov Chain Monte Carlo simulation (unique in this cluster) incorporating the above sources of uncertainty. His method showed about a 60% reduction in forecast error over previous BEDL models, and unlike those models, forecasts returns *quality*, based on the usage period of the returned product and the number of past recovery cycles.

### 5.1.2. *Returns acquisition effort*

Acquisition effort studies (75/131) far outnumber the other two acquisition decision areas. This may be as it occurs across the whole acquisition phase. The "acquisition function" relates a firm's acquisition investments to returns volume. Table 6 shows themes that emerge: the supply chain members involved, the focus on integrated-firm or supply chain coordination approaches, and ultimately whether returns are passive, deterministic, or random. Returns on investment are thus a recurring issue, as we explain next.

Firms taking back used products incur an initial fixed investment in setting up the system and communicating to potential customers. Some consumers will spontaneously or "*passively*" return used products based only on their initial awareness. In such cases, modelling studies assume the collector's marginal take-back costs are zero (Esenduran et al., 2020). However, a passive policy may not generate enough volume (Minner and Kiesmüller, 2012), whereas ongoing investments in take-back may (V. V. Agrawal et al., 2016).

Given this drawback, authors such as Jena and Sarmah (2014) and Wang et al. (2019) assume firms will prefer an active policy, where acquisition depends on the rate of investment in collecting, e.g., marketing activities, public relations and training front-line employees (Azevedo et al., 2021), but with no direct payment to consumers per unit of return. In this case, it may be assumed that higher investment raises returns acquisition (Bhattacharya et al., 2018). Moreover, an incentive paid per unit of return increases returns on the investments above (Azevedo et al., 2021). Along these lines, several papers consider quantity of returns as a *deterministic* function of the acquisition price (or discount) offered per unit of return. The acquisition function may be linear (Minner and Kiesmüller, 2012; Xie et al., 2015) or nonlinear (Corominas et al., 2012), such as increasing concave in acquisition price.

All the above cases consider the effect of acquisition price on the reverse flow of used products. However, another strand of the literature shows the acquisition price offered can also influence forward demand (Taleizadeh et al., 2019). Other dual effects may occur in competitive environments. For example, a channel's return rate may depend on self- and cross-rewards offered to the customer by competitors (Zheng et al., 2021). Several studies have thus built *randomness* into the returns function (Ponte et al., 2019; He, 2015, 2017). Nevertheless, modelling studies generally consider acquisition effort to be monetary, entailing direct payments, i.e., acquisition price (He, 2015), or discounts, e.g., discount coupons (Azevedo et al., 2021), trade-in discounts on product returns (Das and Dutta, 2015), or a mix such as a trade-in value with a government consumption subsidy (Zhu et al., 2016). Sometimes consumers pay a fee to return used products. For example, suppose the product contains toxic materials. Here, collectors may charge consumers to deal with it (Jin et al., 2021; Xie et al., 2015). However, acquisition efforts can also be non-monetary, e.g., providing an *emotional reward* to customers, such as promising to donate products or proceeds to charity (Simpson et al., 2019).

Timing of acquisition effort arises as another theme. Since

**Table 7**
Summary of returns channel selection studies within acquisition literature.

| Reference | Acquisition channel structure | | | | | | | | | | Performance measure | Modelling approach | Considerations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Single | | | Hybrid | | | | Integrated | | | | | | | | | |
| | M | R | 3P | M-M | M-R | R–3P | M-3P | MR | M3P | MR3P | | | Uncertainty | Legislation | Industry | Technology | Behaviour |
| Zheng et al. (2021) | | | ✓ | | | | ✓ | | | ✓ | P | G | | | | ✓ | ✓ |
| Jin et al. (2021) | ✓ | | ✓ | | | | | | ✓ | | P | G | | | | | ✓ |
| Sarkar and Bhala (2021) | ✓ | ✓ | | | | | | | | | P | G | | | | | ✓ |
| C. Zhang et al. (2021) | ✓ | ✓ | ✓ | | | | | | | | P/E/S | G | | | | ✓ | ✓ |
| Wei et al. (2021) | | | ✓ | | | | | | ✓ | | P | G | | | | | ✓ |
| Kleber et al. (2020a) | | | | ✓ | | | | | | | P | G | | | | | ✓ |
| Wu et al. (2020) | ✓ | ✓ | ✓ | | | | | ✓ | | | P | G | | | ✓ | | ✓ |
| Taleizadeh and Sadeghi (2019) | | | | | ✓ | | | | | | P | G | | | | | ✓ |
| Chen and Akmalul'Ulya (2019) | ✓ | ✓ | ✓ | | | | | ✓ | | | P | G | | ✓ | | | ✓ |
| Tian et al. (2019) | ✓ | ✓ | ✓ | | | | | | | | P/E/S | Q | ✓ | ✓ | ✓ | ✓ | |
| Liu et al. (2017) | | | | | ✓ | ✓ | ✓ | | | | P | G | | | | | ✓ |
| Hong et al. (2017) | | | | ✓ | | | | | | | P | G | | | | ✓ | ✓ |
| Zhao et al. (2017) | | | | | ✓ | | ✓ | | | | P | G | | | | | ✓ |
| Wang et al. (2015) | ✓ | | ✓ | | | | | | | | P/S | G | | ✓ | | | ✓ |
| Chuang et al. (2014) | ✓ | ✓ | ✓ | | | | | ✓ | | | P | G | ✓ | ✓ | | | ✓ |

Key to Table 7.
Single: M- Re/manufacturer; R- Retailer; 3P- Third-party collector.
Hybrid: M-M- Two re/manufactureres; M-R; Re/manufacturer and retailer; R-3P- Retailer and third-party collector; M-3P–Re/remanufacturer and third-party collector.
Integrated: MR- Re/manufacturer with retailer; M3P–Re/remanufacturer with third-party collector; MR3P–Re/manufacturer, retailer with third-party collector.
Performance measures: **E-** Environmental benefit; **P-** Profit; **S-** Social welfare.
Modelling approaches: **G-** Game theory; **Q-** Multiple-criteria decision-making.

acquisition and inventory costs trade off, a firm should acquire used products to fill a fraction of the demand for the remanufactured products before demand is realised, leaving the rest until after realisation (Mutha et al., 2016). This especially applies when returns are less frequent, or returns qualities are idiosyncratic (Alegoz and Kaya, 2017). Moreover, price bargaining is more cost-effective than a fixed price incentive when a monopolist firm has a last mover advantage (Gönsch, 2014). Otherwise, a menu of prices is preferable to fixed pricing as almost all customers will return the products with the former (Li et al., 2019). However, Matsui (2021) shows an instance where first mover advantage arises, i.e., that a firm constituting their own acquisition as well as a 3P, should announce its own acquisition price before the 3P.

Several studies involve legislation (Table 6). In general, a high legislated acquisition target decreases a manufacturer's profit (Li et al., 2021). As the target passes a firm's optimal acquisition level, acquisition price rises, raising overall cost (Dutta et al., 2016). However, with economies of scale in acquisition cost, the legislator may set a relatively high target (Chuang et al., 2014), enforced via reward-penalty mechanisms. By lowering wholesale and retail prices, rewards may boost forward channel sales (and profits) and the returns acquisition rate (Chen and Akmalul'Ulya, 2019; Gu et al., 2018b; Wang et al., 2017). However, the total acquisition quantity does not always increase with government subsidy, as a high salvage value from returns may decrease profit from new product sales (Li et al., 2021; Zhu et al., 2016). Providing rewards (i.e., incentives) to the manufacturer rather than the retailer to achieve the acquisition target costs the legislator less (Heydari et al., 2017; Zheng et al., 2020). When used products' potential recovery value is high but the government subsidy is not substantial, lower operation costs may give informal collectors a competitive advantage (Liu et al., 2016).

### 5.1.3. *Returns channel selection*

Selecting an appropriate channel is the next real-world step, yet, little examined (18/131 papers). It matters as it facilitates achieving regulatory, economic, environmental and ethical imperatives in acquiring used products. The typical CLSC structure consists of a manufacturer (making new and remanufacturing used products), and other players. Both product types are sold through a retailer to meet market demand. The main organising theme in this decision area is that the manufacturer may acquire through single, hybrid, or integrated channel structures, as per Table 7. The following paragraphs trace the corresponding three literature streams.

First, single-channel structures (most reported in the literature possibly because of the relative ease in modelling) comprise a remanufacturer collecting directly from consumers (model M), or outsourcing to a retailer (model R) or third-party (model 3P). A useful general finding is that, *ceteris paribus,* model 3P can never be more financially favourable than models R or M (Chuang et al., 2014; Wu et al., 2020). The choice between models M and R depends on the acquisition cost structures of the manufacturer and retailer (C. Zhang et al., 2021). If the transfer price exceeds the average profit per used product (Wu et al., 2020), or a symmetric structure (of the retailer, manufacturer, and third-party firm) and economies of scale in acquisition cost apply (Chuang et al., 2014), then model R yields the least cost solution. For instance, the transfer price may exceed the average profit per used product when an acquisition target is legislated. Model M, though, is best when the acquisition cost is linear (Sarkar and Bhala, 2021; Wu et al., 2020) or exhibits diseconomies of scale (Chuang et al., 2014). Using a 12-criteria decision-making approach, Tian et al. (2019) convincingly propose that a manufacturers' *alliance*, however, dominates model M. In a special case where a 3P engages in sorting to sell low-quality used products to a manufacturer (for remanufacturing) and high-quality ones to a retailer (for reuse), model 3P is optimal for environmental benefit and social welfare (C. Zhang et al., 2021).

Second, in the little-reported hybrid strategy two or more reverse channel members acquire used products simultaneously (e.g., model M-

**Table 8**
Summary of returns sorting literature.

| Reference | Point of sorting | | | Quality | | Number of discrete quality classes | | Sorting error | Performance measure | Modelling approach | Considerations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-acquisition | Pre-disassembly | At disassembly | Discrete | Continuous | Two | Three or more | | | | Uncertainty | Legislation | Industry | Technology | Behaviour |
| Ponte et al. (2021) | | ✓ | | ✓ | | | ✓ | | P | I | ✓ | | | | |
| Hosoda et al. (2021) | | ✓ | | ✓ | | ✓ | | | P | I | ✓ | | | | |
| Hosseini-Motlagh et al. (2020b) | ✓ | | | | ✓ | | | | P | G | | | | | ✓ |
| Hosseini-Motlagh et al. (2020c) | ✓ | | | ✓ | | ✓ | | | P | G | | | | | ✓ |
| Tozanlı et al. (2020) | ✓ | | | ✓ | | | ✓ | | P | D | ✓ | | | ✓ | |
| Khara et al. (2020) | ✓ | | | ✓ | | ✓ | | | P | N | | | | | |
| Liu et al. (2020) | | ✓ | | ✓ | | | ✓ | | P | G | | | ✓ | | |
| Esenduran et al. (2020) | | ✓ | | ✓ | | ✓ | | | P | G | ✓ | ✓ | | | ✓ |
| Liao et al. (2020) | | ✓ | | | ✓ | | ✓ | | E | S | ✓ | | ✓ | | |
| Geda et al. (2020) | | ✓ | | | ✓ | | | | P | G | | | | | |
| Farahani et al. (2020) | | ✓ | | | ✓ | | | | P | M | ✓ | | | | |
| Xu et al. (2019) | ✓ | | | ✓ | | ✓ | | | P | A | | | | ✓ | |
| Farahani et al. (2019) | | ✓ | | | ✓ | | | | P | N | ✓ | | ✓ | | |
| Taleizadeh et al. (2019) | ✓ | | | | | | ✓ | | P/E/S | T | ✓ | | ✓ | ✓ | ✓ |
| Bhattacharya et al. (2018) | ✓ | | | | ✓ | | ✓ | | P | N | | | | | |
| Xie et al. (2018) | ✓ | | | | ✓ | | | | P | G | | | | | |
| Gu et al. (2018a) | ✓ | ✓ | | ✓ | | ✓ | | | P | G | | | | | ✓ |
| Gu et al. (2018b) | ✓ | ✓ | | ✓ | | ✓ | | | P | G | | | | | ✓ |
| van Loon and Van Wassenhove (2018) | | | ✓ | ✓ | | ✓ | | ✓ | P | T | ✓ | | ✓ | | |
| Heydari and Ghasemi (2018) | ✓ | | | | ✓ | | | | P | G | ✓ | | | | ✓ |
| Heydari et al. (2018) | ✓ | | | ✓ | | ✓ | | | P | G | ✓ | | | | ✓ |
| Hahler and Fleischmann (2017) | ✓ | | | | | | | | P | G | ✓ | | ✓ | ✓ | ✓ |
| Wang et al. (2017) | | | | | | | | | P | G | | | ✓ | | ✓ |
| Masoudipour et al. (2017) | ✓ | | | ✓ | | | ✓ | | P | N | | | ✓ | | |
| Zikopoulos (2017) | | ✓ | | ✓ | | ✓ | | | P | A | ✓ | | | | |
| Panagiotidou et al. (2017) | | ✓ | | ✓ | | ✓ | | ✓ | P | A | ✓ | | | | |
| Meng et al. (2017) | | | | | | | | | P | U | ✓ | | ✓ | | |
| Giri and Glock (2017) | | ✓ | | ✓ | | ✓ | | | P | I/A | ✓ | | | | ✓ |
| Zhu et al. (2016) | ✓ | | | | | | | | P | G | | ✓ | | | ✓ |
| Meng et al. (2016a) | | ✓ | | | | | | | P/E/S | F/U | ✓ | | | | |
| Dutta et al. (2016) | ✓ | ✓ | | | | | | | P | A | ✓ | ✓ | | | ✓ |
| Liu et al. (2016) | ✓ | | | | | | | | P | G | | ✓ | | | ✓ |
| Mutha et al. (2016) | | ✓ | | ✓ | | | ✓ | | P | S | | | | | |
| Das and Dutta (2015) | ✓ | | | | | | | | P | N | ✓ | ✓ | | | ✓ |
| Zikopoulos and Tagaras (2015) | | | ✓ | ✓ | | ✓ | | ✓ | P | A | ✓ | | | | |
| Gönsch (2015) | ✓ | | | | | | | | P | G | | | | | ✓ |

(*continued on next page*)

**Table 8** (*continued*)

| Reference | Point of sorting | | | Quality | | Number of discrete quality classes | | Sorting error | Performance measure | Modelling approach | Considerations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-acquisition | Pre-disassembly | At disassembly | Discrete | Continuous | Two | Three or more | | | | Uncertainty | Legislation | Industry | Technology | Behaviour |
| Gu and Tagaras (2014) | | ✓ | | ✓ | | ✓ | | ✓ | P | G | ✓ | | | | |
| Panagiotidou et al. (2013) | ✓ | | | ✓ | | | | | P | A | ✓ | | | | |
| Hahler and Fleischmann (2013) | ✓ | | | ✓ | | | ✓ | | P | A | ✓ | | | | |
| Robotis et al. (2012) | | ✓ | | ✓ | | ✓ | | | P | S | | | | | ✓ |
| Loomba and Nakashima (2012) | | ✓ | | | | | | | P | S | | | ✓ | | |
| Mahapatra et al. (2012) | | ✓ | | | | | | | P | N | ✓ | | ✓ | | |
| Corominas et al. (2012) | ✓ | | | ✓ | | ✓ | | | P | N | | | | | |
| Pokharel and Liang (2012) | ✓ | | | ✓ | | | ✓ | | P | A | ✓ | | | | |

Key to Table 8.

Performance measure: **E-** Environmental benefit; **P-** Profit; **S-** Social welfare.

Modelling approach: **A-** Analytical modelling; **C-** Monte Carlo simulation; **F-** Fuzzy theory; **G-** Game theory; **I-** Inventory theory; **M-**Markov decision process; **N-** Nonlinear programming; **T-** Integer programming; **U-** Mathematical programming (algorithms).

R, model R–3P, model M-3P). Hybrid approaches dominate single-channel acquisition since collective effort can increase supply chain profit through higher acquisition rates and economies of scale. For a manufacturer, *ceteris paribus*, competition with a retailer (model M-R) is more profitable than with a 3P (model M-3P) (Zhao et al., 2017).

The third stream, moderately reported, involves integrated acquisition by two or more reverse channel members, but acting as centralised decision-makers (potentially model MR, M3P, MR3P). Centralised acquisition reaps more supply chain profit than single-channel or hybrid channels of the same supply chain entities. This is as there is no double marginalisation effect, and all decisions are optimal. Offered partial integration, a manufacturer should always integrate (vs not integrate), and integrating the retailer (regardless of potential competition from the 3P) provides higher supply chain profit than integrating the 3P (Wei et al., 2020).

The recommerce business model, also called reverse commerce or the reverse marketplace, entails acquiring and selling used products via an e-commerce website, platform or app. In practice, recommerce platforms are becoming popular for increasing single, hybrid and integrated channels' efficiency. Channels employing recommerce platforms outperform their traditional counterparts due to increased efficiency (Jin et al., 2021; Zheng et al., 2021).

### 5.2. *Used product sorting*

Whereas acquisition often concerns quantity, the issue in sorting decisions is quality, as reflected in two column headings of Table 8. Recovering value profitably depends on returns' quality characteristics and the system's economic parameters. A firm's ability to assess quality makes value-recovery output less uncertain (Robotis et al., 2012), significantly improving profitability (Panagiotidou et al., 2013). Sorting thus takes on high importance (56/131 papers) in the literature.

The quality metrics of a return may vary by industry. For example, key quality indicators of textiles include brand, durability and softness (Masoudipour et al., 2017), while usage condition is a standard indicator for returned waste electrical and electronic equipment (WEEE) (Tozanlı et al., 2020). More generally, and across industries, yield values can indicate quality (Loomba and Nakashima, 2012). A lower yield (i.e., lower-quality) return requires more materials and labour to remanufacture (Mutha et al., 2016), e.g., higher-quality returns of a mobile phone type may need only simple exterior cleaning. In contrast, lower-quality ones may require replacing circuitry (Hahler and Fleischmann, 2013). The literature generally considers recovery cost as quality-dependent and linear in yield (Bockholt et al., 2020; Farahani et al., 2019). However, Hosoda et al. (2021) show that the system-wide cost is convex in the yield rate, revealing a paradox. They conclude this is due to penalty costs for disposal, expected returns, and unit remanufacturing cost significantly impacting the system-wide cost function. They also show that in some economic conditions no incentive to remanufacture exists, even if the unit remanufacturing cost is below the cost to manufacture new items.

As Table 8 shows, modelling literature has debated whether quality is discrete (e.g., Ponte et al., 2021) or continuous (e.g., Farahani et al., 2019). The inherent quality uncertainty of returns stems from many factors including product characteristics and consumer usage behaviours. Researchers have assigned probability distributions such as Uniform (Heydari and Ghasemi, 2018), Normal (Robotis et al., 2012), Exponential and Beta (Farahani et al., 2020) to define quality variability. The Uniform distribution prevails in literature mainly due to its ease of application in modelling.

Sorting thus means classifying returns into classes by quality (Mutha et al., 2016). A common modelling assumption is that all returns in a particular quality class have a similar yield and so require the same processing time. Terms need clarifying, as the *grading* (a search term synonym we used) and *sorting* are used interchangeably for sub-categorising a *single type* of product by quality value. Grading is a

**Table 9**
Summary of returns disposition decision literature.

| Reference | Study type | | | Level of disposition | | Performance measure | Modelling approach | Considerations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Identify disposition options | Returns allocation | | Product level | Component level | | | Uncertainty | Legislation | Industry | Technology | Behaviour |
| | | Exogenous | Optimisation | | | | | | | | | |
| Almaraj and Trafalis (2021) | | | ✓ | ✓ | | P/E/S | L | ✓ | | | | |
| Esenduran et al. (2020) | | | ✓ | ✓ | | P/E/S | G | | | | | |
| Liao et al. (2020) | | ✓ | | ✓ | ✓ | E | C | ✓ | | ✓ | | |
| Taleizadeh et al. (2019) | | | ✓ | ✓ | | P/E/S | L | ✓ | | ✓ | ✓ | |
| Farahani et al. (2019) | | | ✓ | ✓ | ✓ | P | J | ✓ | ✓ | ✓ | | |
| van Loon and Van Wassenhove (2018) | | | ✓ | | ✓ | P/E | A | ✓ | | ✓ | | |
| Masoudipour et al. (2017) | | | ✓ | ✓ | | P | J | | | ✓ | | |
| Wang et al. (2017) | | | ✓ | | | P | A | ✓ | ✓ | ✓ | | ✓ |
| Meng et al. (2017) | | | ✓ | ✓ | ✓ | P/E | L | ✓ | | ✓ | | |
| Meng et al. (2016b) | | | ✓ | ✓ | ✓ | P | U | ✓ | | ✓ | | |
| Meng et al. (2016a) | ✓ | | ✓ | | | P/E | L/Q | | | | | |
| Khor et al. (2016) | ✓ | | | | | P | Q | | ✓ | | | |
| S. Agrawal et al. (2016) | ✓ | | | | | P/E | Q | | ✓ | ✓ | | |
| Dutta et al. (2016) | | | ✓ | ✓ | ✓ | P | C | ✓ | ✓ | | | ✓ |
| Kwak and Kim (2015) | | | ✓ | | ✓ | P/E | J | | ✓ | | | |
| Ondemir and Gupta (2014) | | | ✓ | ✓ | ✓ | P/E | L | ✓ | | ✓ | | |
| Johnson and McCarthy (2014) | | | ✓ | ✓ | ✓ | P | L | | ✓ | ✓ | | |
| Guo et al. (2014) | | | ✓ | ✓ | ✓ | P | K | ✓ | | | | |
| Dhouib (2014) | ✓ | | | ✓ | | P/E/S | Q | | ✓ | ✓ | | |
| Atasu and Souza (2013) | ✓ | | | ✓ | | P/E | A | | ✓ | | | |
| Das and Dutta (2013) | | ✓ | | ✓ | ✓ | P | V | ✓ | | | | |
| Mishra et al. (2012) | ✓ | | | ✓ | ✓ | P/E | U | | | | | |
| Minner and Kiesmüller (2012) | | ✓ | ✓ | ✓ | | P | U | | | | | ✓ |
| Nenes and Nikolaidis (2012) | | | ✓ | ✓ | | P | L | | | | | |

Key to Table 9.
Performance measure: **E**- Environmental benefit; **P**- Profit; **S**- Social welfare.
Modelling approach: **A**- Analytical modelling; **C**- Monte Carlo simulation; **G**- Game theory; **J**- Mixed integer nonlinear programming;; **K**- Stochastic programming; **L**- Mixed integer linear programming; **Q**- Multiple-criteria decision-making; **U**- Mathematical programming (algorithms); **V**- System dynamics simulation.

more precise term for this, as sorting can also refer to classifying products into *distinct types*. As another basic matter, sorting may be executed before acquisition (Bhattacharya et al., 2018), after acquisition (but before disassembly) (Mutha et al., 2016), and/or at point of disassembly (Zikopoulos and Tagaras, 2015), with Table 8 showing lowest reported frequency for the last.

An important practice on point of sorting and discussed by a third of studies (17/56) is paying a quality-dependent acquisition price (Hahler and Fleischmann, 2017). This effectively transfers the sorting task to customers, pre-acquisition (Ferguson and Souza, 2010). Alternatively, a firm may first acquire all available used products, then sort them by expected yield. Here, the fractions of various classes obtained are uncertain, and the quality determinable only at a point of sorting after acquisition (Mutha et al., 2016). Developing this point, Zikopoulos (2017) observes that with proper lot-sizing choices, quality uncertainty may not incur a substantial cost increase. Mutha et al. (2016) counter this by showing that firms acquiring only sorted used products (in all but the growth stage of the remanufactured products' lifecycle) can manage the risk of demand uncertainty for remanufactured products. The related literature (e.g., Zikopoulos and Tagaras, 2015) convincingly argues that disassembly is the point of most accurate quality assessment of returns. Yet, disassembly takes time and money. Therefore, it is valuable to obtain quality information, even if not entirely accurate, earlier in the RSC (Gu and Tagaras, 2014). Technology such as radio frequency identification (RFID) may help determine quality without the need for expensive product disassembly (Taleizadeh and Sadeghi, 2019; Tozanlı et al., 2020).

In general, as a cost/benefit matter, the literature reveals agreement that sorting is more beneficial when it isn't possible to accurately estimate each unit's quality characteristics (Loomba and Nakashima, 2012; Robotis et al., 2012) and average returns quality is poor (Mahapatra et al., 2012; Zikopoulos, 2017). By prioritising remanufacturing of better-quality parts, sorting may aid capacity management (Loomba and Nakashima, 2012) and help level production (Ponte et al., 2021). With the need for sorting established, another issue is the number of quality classes into which the used products are sorted (see the columns "Two" and "Three or more" in Table 8). Categorisation can mitigate the Bullwhip Effect in CLSCs (Ponte et al., 2021). However, assigning used products into just two classes is the most common. Examples are high-quality and low-quality (Loomba and Nakashima, 2012), "remanufacturable" or "non-remanufacturable" (Giri and Glock, 2017), and pass or fail (Heydari and Ghasemi, 2018).

Most studies consider returns to be exogenously assigned to different quality classes as a rate (Heydari et al., 2018; Liao et al., 2020) or probability (Heydari and Ghasemi, 2018) of total returns. In contrast, several authors have built mathematical models (e.g., Khara et al., 2020; Xie et al., 2018; Hosoda et al., 2021) to find optimum "acceptance quality levels" for different quality classes. In the latter cases, each class refers to a nominal quality level that characterises the amount of work needed to recover the product (Mahapatra et al., 2012). A common assumption in acceptance quality level studies is that available quality information (i.e., expected yield) is accurate. However, the expected yield may not be directly observable. Helpfully, Panagiotidou et al. (2017) develop a method for estimating the relationship between partial information (e.g., product usage data) and acceptance quality levels.

Finally, sorting literature inevitably discusses classification errors. It shows that acquisition quantities (and therefore costs) rise with Type I error ("acceptable" units misclassified as "non-acceptable") and fall with Type II errors (the converse) (Gu and Tagaras, 2014). Sorting errors also affect a supply chain's preference of sorting location. Zikopoulos and Tagaras (2015) analytically derive the cost conditions for the best sorting site between a centralised manufacturer or multiple acquisition centres when the locations are prone to sorting errors. However, *ceteris paribus,* centralised sorting is more profitable than decentralised (Gu and Tagaras, 2014; Loomba and Nakashima, 2012).

### *5.3. Used product disposition decisions*

Ultimately firms engaging in take-back need to decide which disposition option(s) best recover value for returned products or their components (Farahani et al., 2019). The literature has considered options such as reuse (Mishra et al., 2012), refurbish (van Loon and Van Wassenhove, 2018), remanufacture (Meng et al., 2017), recycle (Johnson and McCarthy, 2014), and dispose (Wang et al., 2017). These may be characterised by the extent of processing required, for which product quality is a proxy. Highest quality allows reuse; lowest consigns to disposal. This is why disposition decisions (and by definition disposition itself) should follow sorting.

The disposition literature (36/131 papers) distils two key decisions firms face when implementing disposition tactics: (1) identifying suitable disposition options, and (2) finding an optimal subset of the returns to allocate to the specified options (Meng et al., 2017; Ondemir and Gupta, 2014). As Table 9 shows, a minority of modelling studies set the latter as exogenous values, while most endogenously optimise the quantity that needs to be allocated to each recovery option to maximise benefit. Most research deals with the two sub-problems separately. Exceptions include Meng et al. (2016a) and Meng et al. (2017), which integrate the sub-problems by first identifying the best recovery strategies, then deciding the allocation quantity.

As to the first sub-problem, suitable disposition options depend on many factors, including the supply of returns, used product characteristics, demand for recovered products, regulations, economic, social and/or environmental impact (Khor et al., 2016; Mishra et al., 2012). Unsurprisingly, multiple-criteria decision-making (MCDM) approaches noted as a group in Table 9 have been commonly applied to identify suitable recovery options for a given context with conflicting objectives (Ondemir and Gupta, 2014). While MCDM methods suit evaluating and ranking discrete alternatives, they are inefficient when the diversity of scenarios to analyse increases. Further, they lack efficiency in optimisation problems with quantitative goals and dynamic constraints (Meng et al., 2016b).

As to the second sub-problem, mathematical model-based optimisation studies determine optimal quantity allocations to the identified disposition options, by maximising the benefit from a given set of returned products under various trade-offs and system-wide constraints, including processing cost, recovery rate, capacity, and inventory (Esenduran et al., 2020). Optimisation-based disposition decisions are commonly coupled with inventory management (Farahani et al., 2019; Guo et al., 2014) and/or disassembly planning (Johnson and McCarthy, 2014; Ondemir and Gupta, 2014). Further, optimisation modelling studies typically assume equal unit processing cost for all used products in a given quality category (Dutta et al., 2016; Guo et al., 2014). More realistically, albeit with greater difficulty, a few authors (Farahani et al., 2019; Meng et al., 2017) assign individual processing costs that depend on a continuous quality function of the returns.

### *5.4. Behavioural considerations present across ASD research*

We now examine the stand-out consideration of behaviour across the three overarching areas of ASD. Notable is the lack of a framework to systematically investigate behavioural considerations in ASD or general SCM research. Table 10 organises studies by actor level: supply chain, firm or customer (Pournader et al., 2021).

The main focus has been interactions among CLSC firms reflecting the blue network in Fig. 6. This "macro-level lens" focuses on supply chain member firms pursuing their own aims while interacting with each other. These supply chain behaviour studies may be characterised by the participating channel members (i.e., raw material suppliers, original equipment manufacturers (OEMs) with/without remanufacturing, independent remanufacturers, retailers, and 3P collectors), supply chain integration (centralised or decentralised), power structure (Stackelberg leader and follower) and competition availability. These characteristics influence the A, S, and D of used products.

At the macro-level, supply chain members may vertically *coordinate* to acquire used products. In most cases, the manufacturer is the Stackelberg leader (i.e., the player with most power) of a vertically differentiated CLSC (Jena and Sarmah, 2014; Wei et al., 2015). For instance, manufacturers like Apple and HP have supply chain power when encouraging retailers to acquire used products., e.g., Walmart over small supplier brands. However, in CLSCs, few studies have considered the retailer as the leader (Alizadeh-Basban and Taleizadeh, 2020; Wei et al., 2015). In a decentralised CLSC, the Stackelberg leader obtains the highest profit. When that leader (whether the manufacturer, retailer or collector) directly acquires used products from consumers, they can secure a higher acquisition rate than acquisition via another member (Liu et al., 2020). Alternatively, a Nash game occurs with the retailer and the manufacturer equal in power, which is less profitable for the supply chain than the Stackelberg scenarios (Alizadeh-Basban and Taleizadeh, 2020). Due to potential economic benefits or legislation targets, RSC members may have to *compete* for used products – a horizontal interaction with other supply chains. In the studies we review, horizontal competition has been mainly considered in Stackelberg game theoretic scenarios. Exceptions are Hosseini-Motlagh et al. (2020b) and Hosseini-Motlagh et al. (2020a), who consider Cournot and Bertrand competition. The Cournot model considers firms that make identical products (e.g., two manufacturers) and simultaneously make output decisions. Conversely, the Bertrand model considers firms making identical products but competing on price and simultaneously making pricing decisions. When a channel member employs two independent collectors, the *collusion* behaviour of the collectors in a Cournot model heavily reduces the return rate of used products compared to the Stackelberg and Bertrand games (Hosseini-Motlagh et al., 2020b).

As a unifying strand, in all supply chain coordination cases, centralised acquisition by supply chain members obtains higher volumes than decentralised acquisition with the same setting. However, the same acquisition rate as a centrally coordinated system can be reached via simple contracts among supply chain members. Pertinently, a multitude of two-party contracts such as two-part-tariffs (Wang et al., 2019), compensation-based wholesale prices (Hosseini-Motlagh et al., 2020a), menus of contracts (Li et al., 2014), revenue sharing (Jena and Sarmah, 2014), effort cost-sharing (Azevedo et al., 2021), supply chain risk sharing (He, 2015), quantity discounts (Heydari et al., 2017), and increasing fees (Heydari et al., 2017) have been discussed. Further, multilateral two-part-tariff contracts (Hosseini-Motlagh et al., 2020b) can coordinate multiple supply chain participants.

Unlike coverage of macro-level (i.e., supply chain level) behaviour, ASD literature takes little account of the behaviour of micro-level (i.e., individuals-consumers or, especially sparsely, employees), even though such behavioural characteristics significantly impact uncertainty of quantity, quality, and timing of returns in two ways. First, the uncertainty in acquisition varies with consumer behaviour characteristics, including temperament, culture, sense of duty, subjective norms, perceived control, attachment and frugality (Gaur et al., 2017; Khan et al., 2019; Simpson et al., 2019). Second, employee behaviour characteristics such as learning and forgetting (Giri and Glock, 2017) affect post-acquisition sorting. Moreover, these consumer characteristics also raise uncertainty in pre-acquisition sorting. Outputs of the sorting step affect disposition decisions, too. As Table 10 reveals, in ASD modelling literature, behavioural characteristics of individuals have mainly been treated as parameters in supply (acquisition) or inspection (sorting) functions. In returns acquisition these parameters are usually given as specific exogenous values, or a Uniform distribution – indicating consumer heterogeneity. In such cases, the Uniform distribution has been used to represent a random variable in a linear relationship of acquisition price and the returns quantity. Even though studies incorporate behavioural parameters, conspicuously few analyse sensitivity of those parameters for ASD decision models' performance.

*Behavioural operations* refer to the *deviation* from normative models that assume profit-maximisation behaviour of the entities (Fahimnia et al., 2019). Interestingly, all the above behavioural studies use normative models. In contrast, Sarkar and Bhala (2021) show that when a retailer is inequality-averse (i.e., concerned about profit-sharing fairness), the acquisition rate and channel profits are higher for both model M (remanufacturer acquires directly from consumers) and model R (remanufacturer outsources to a retailer) than profit-maximising case.

**Table 10**
Behavioural considerations in acquisition, sorting and disposition literature.

| Behavioural considerations | Reference |
|---|---|
| **Supply chain level** | |
| Coordination | Azevedo et al. (2021), (Hosseini-Motlagh et al. (2020a)), Liu et al. (2020), (Alizadeh-Basban and Taleizadeh (2020)), Heydari et al. (2017), Wang et al. (2019), He (2015), Li et al. (2014), Jena and Sarmah (2014) |
| Collusion | Hosseini-Motlagh et al. (2020b) |
| Competition | Wu (2015), (V. V. Agrawal et al. (2016)), Hosseini-Motlagh et al. (2020b), Zhu et al. (2016), Kleber et al. (2020b) |
| **Firm level** | |
| Employee learning and forgetting in the inspection of returns | Giri and Glock (2017) |
| **Customer (consumer) level** | |
| Consumers' sensitivity to corporate environmental responsibility investment | Wu et al. (2020) |
| Consumers' willingness to sell/return | Kleber et al. (2020b), Heydari et al. (2017) |
| Customer loyalty to the manufacturer | Hosseini-Motlagh et al. (2020a) |
| Customer price sensitivity to the sales price | Huang and Wang (2017) |
| Sensitivity to acquisition price | Iqbal and Kang (2021) |
| Consumer willingness to accept buy-back offer | Dutta et al. (2016) |
| Factors affecting consumer returns behaviour (sense of duty, attitude, subjective norms, and perceived control) | Gaur et al. (2017), (Simpson et al. (2019), Khan et al. (2019) |
| Consumer return intention index | Jena and Sarmah (2015) |
| Consumers' willingness to return between online-recycling and offline-recycling channels | Li et al. (2019) |
| Purchase utility/return utility | Wu and Wu (2016) |

## 6. Knowledge gaps, flaws and limitations in terms of methods and key considerations

Despite significant advances, ASD literature over 2012–2021 leaves ample room for progress. Here we present gaps (unexplored topics), flaws (problems with study design) and/or limitations (constraints on the applicability of study findings) across all decision areas. We discuss research methods and assumptions in Section 6.1, and circularity archetypes in Section 6.2. Sections 6.3-6.7 focus on knowledge gaps in our five key research considerations influencing ASD decisions. These gaps, flaws and limitations point to specific future research avenues to address them individually. Later, Section 7 turns to avenues needed across the board to reorient ASD research towards the transition to a CSC.

### 6.1. Methods and assumptions

Each article can be characterised by its use of one or two methods and covering one or more decision areas and research considerations, as noted in Tables 5–9 Table 11 overviews the methods and their association with the full five ASD decision areas and five research considerations. 113 studies use one method. The remaining studies utilise two (16) or three (2) methods and each appears in more than one row in Table 11, bringing the total to 131. The TOTALS column indicates the number of articles in each method. We note that the "blanks" or low values in Table 11 do not necessarily indicate a limitation in applying modelling methods (e.g., G is unlikely to help solve forecasting problems). However, these unexplored modelling approaches may be fruitful in solving ASD problems. As observed in Tables 5–9, model objectives focus mainly on economic imperatives. To varying degrees though, all ASD options impact the environment via energy consumption and greenhouse gas emissions. Given developments like the "Right to Repair" movement and employee wellbeing concerns at hazardous sorting facilities, social aspects of ASD also deserve consideration.

Many models assume that remanufacturing produces "as new"' units saleable at the same price as a new product. This assumption may hold for products such as disposable cameras, copiers and wheelchairs (Corominas et al., 2012) which may be remanufactured to the same standard and priced similar to a new product. However, for many other products, consumer willingness to pay for remanufactured products may be lower than for a new counterpart. For example, remanufactured printer cartridges sell at on average 30–70% below new prices (Wu, 2015). Consumers may even have different utilities for new, OEM-remanufactured and independent remanufacturer products (Wu and Wu, 2016). These differences should be incorporated into mathematical models for used product ASD.

As to sectors, current literature focuses on high-value products including electronics and automobiles. Research on environmentally impactful products like apparel and plastics is key as ASD decisions may depend on product characteristics. In addition, ASD literature mainly focuses on discrete production systems, whereas continuous production systems such as oil, paper and aluminium also require attention. Importantly, the scantness of empirical research across ASD decisions calls for research in both empirical and mixed methods. While modelling studies provide prescriptive solutions for practitioners, adoption of take-back, which is an emerging concept, should be enhanced with empirical studies providing predictive and descriptive consideration.

### 6.2. Circularity archetypes

Ninety-three (71%) of the 131 articles consider closed loop circularity/CLSC only, while the remaining 38 consider both open and closed loop circularity archetypes. Most of the 93 articles consider remanufacturing as the only value-recovery option while assuming perfect material circularity. Moreover, they mainly consider high-value items. The remainder of the 93 CLSC studies considers multiple disposition options, including disposal. Yet, they ignore collaboration with other supply chains for fuller value-recovery with open loop circularity. However, with appropriate partners and alliances in place, other supply chains can divert more materials from being sent to landfills, thus characterising an open loop circularity. While high-value items are generally remanufactured, low-value items are recycled, for which sorting is a prerequisite. Nevertheless, contaminated returns (items mixed with non-recyclable materials such as organic waste) are difficult to sort and go into landfills, violating the open loop circularity concept.

**Table 11**
Distribution of research methods by ASD decisions and research considerations.

| | ASD decision area | | | | | TOTALS | Research considerations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Modelling method | Forecasting | Acquisition effort | Channel selection | Sorting | Disposition | | Uncertainty | Legislation | Industry | Technology | Behaviour |
| Game theory | | 26 | 16 | 2 | 2 | **64** | 14 | 9 | 7 | 4 | 35 |
| Mathematical programming (algorithms) | | 9 | | 9 | | **18** | 6 | 3 | | | 4 |
| Mixed integer linear programming | | 3 | | | 9 | **12** | 6 | 2 | 5 | 3 | 1 |
| Nonlinear programming | 1 | | | 8 | 3 | **12** | 3 | | 3 | | |
| Multivariate | | 2 | | 6 | 4 | **12** | 2 | | | 1 | 2 |
| Stochastic programming | | 5 | | 2 | 4 | **11** | 6 | | 4 | 4 | |
| Integer programming | | 2 | 2 | | 6 | **1** | | 1 | | | 5 |
| Mixed integer nonlinear programming | | 4 | | | 5 | **9** | 1 | | 2 | | |
| Inventory theory | | 6 | | | | **6** | 6 | | 1 | | 1 |
| Bayesian estimation of the distributed lag | | | | 6 | | **6** | 1 | | | | 1 |
| Chance constrained programming | | 5 | | | | **5** | | | | 1 | |
| Fuzzy theory | | | | 4 | | **4** | 1 | 2 | 3 | 1 | |
| Monte Carlo simulation | 4 | | | | | **4** | | | 1 | | |
| Simulation-based optimisation | 1 | 1 | | | 3 | **5** | 2 | | | | 1 |
| Analytical modelling | | 3 | | | | **3** | 1 | 2 | | | 1 |
| Discrete event simulation | | 2 | | | | **2** | 2 | | 2 | | 1 |
| Markov decision process | | 2 | | | | **2** | 1 | | | | |
| Multiple-criteria decision-making | | 2 | | | | **2** | 1 | | 1 | | |
| System dynamics simulation | | 1 | | | | **1** | 2 | 1 | | | |
| Convex and concave programming | | 1 | | | | **1** | 2 | | | 2 | |
| Quadratic programming | | | | 1 | | **1** | 2 | | 1 | | |
| Robust optimisation | | 1 | | | | **1** | 1 | | | | |

Even so, returns contamination and the value of sorting for open loop circularity are unexplored in ASD research. Furthermore, industrial symbiosis, a dimension that reflects open loop circularity, has received very little attention in the ASD literature.

### 6.3. Uncertainty considerations

As noted in Tables 5–9, 62 of the 131 articles (47%) consider an aspect of uncertainty (e.g., returns quantity, quality and timing, remanufacturing yield, lead time and capacity, demand for value-recovered products). This suggests the need to further incorporate it. Moreover, studies often consider only one uncertainty factor, whereas in reality many co-occur, and they interact. Uncertainty is also often represented using exact probability distributions. Likely for lack of historical data from ASD practice, decision-makers often make assumptions and approximations about the distributions. Further research may be necessary to verify their applicability in different contexts.

### 6.4. Legislation considerations

Twenty of the 131 articles (15%) consider the impact of legislation on ASD activities. Extended Producer Responsibility (EPR) is a highly relevant policy approach making producers responsible for collecting and treating used products. Research relating to legislation has dealt with how EPR acquisition targets affect ASD decisions (Xintong et al., 2021) and how to design regulatory policies for promoting remanufacturing (Zhang et al., 2020), but not on legislation's role in incentivising consumers to returns. Given that optimal regulatory policies related to remanufacturing depend on the quality of available cores and the environmental treatment cost (Zhang et al., 2020), it is important to tailor legislation to its implementation context to maximise its effectiveness. From the EPR perspective, acquisition channels, acquisition price, and disposition decisions have received research attention, but EPR impact on sorting process to improve take-back system performance may also be worthy of research. Furthermore, modelling/empirical investigations could assist in understanding the system-wide effects of government policies on all phases of a product, from its creation to disposal. For example, the UK's plastics ban to cut environmental impacts may perversely triple the country's packaging emissions by replacement products (Mace, 2020).

### 6.5. Industry considerations

Only 31 of the 131 modelling articles (24%) articles involve industry collaboration, either by model application or using industry data for model validation. The rest use conceptual and stylised mathematical models that may have limited use for practitioners unless elaborated with industry applications. An opportunity exists for future research into data elicitation methods for hard-to-obtain model parameters. Also, the reference of mathematical models to products and sectors is rather limited. Research is needed into whether model assumptions for one industry or product type apply to others.

### 6.6. Technology considerations

As noted in Tables 5–9, only 17 of the 131 articles (13%) consider an application of technology. The long-term success of used product take-back will depend on public credibility concerning its economic, environmental and social effectiveness. Improving transparency and traceability of the RSC of used products may build confidence. How sensor-based technologies such as RFID can aid this requires future research. Recent innovations such as reverse vending machines could facilitate better sorting for recycling, yet are unexplored in ASD research. In transitioning more fully to a CSC, online communication channels and mobile applications are a prime way to inform and nudge customers to return products via take-back programmes. Industry 4.0 and related technologies will open new research into managing the uncertainties of returns quantity, quality, and timing. Advances in information technology, data sciences, and artificial intelligence (AI) will help describe, predict, utilise, and improve behavioural tendencies including at individual level. More research is needed into whether, when, and how combining human and automated decisions (e.g., intelligent algorithms) can improve ASD operational results. Closing literature gaps may require complex mathematical models (e.g., integrated forecasting of primary and secondary market returns). Using big data and analytics might relax these constraints.

### 6.7. Behavioural considerations

Fifty-two of the 131 articles (40%) considered supply chain, firm, and/or individual behaviour. In ASD literature, the main behavioural focus has been the macro-level interactions among CLSC firms as in Section 5.4. This may be as analytic infrastructure for supply chain -level behaviour has long featured in game theory and lends itself to neat mathematical models, whereas individual behaviours have come to the fore only with behavioural economics and tend to complicate models.

Research on consumer willingness to purchase notes a considereable gap between claim versus practice, leading to uncertainty. For example, 40% of the Europeans say they would buy used e-products, while only 6% have ever bought such (Parajuly et al., 2020). There's ample room to test such claim versus practice gap for willingness to return. While individual returns behaviour directly impacts used product acquisition, it can also impact sorting. For example, (Hart and Erica, 2020) find the US recycling system has become less economically viable as consumer sorting errors have made recycling more complicated and costly. However, impact of consumer behaviour on sorting has rarely been addressed. Moreover, studies should extend to more employees and managers, whose idiosyncrasies also heavily impact ASD decisions.

Literature on behavioural operations in the ASD context is almost non-existent. Assuming decision-makers are "hyper-rational beings optimising behaviour toward a single monetary goal" (Croson et al., 2013) may be unrealistic, especially because A, S and D are driven by beliefs, value systems, or sophistication. Multidisciplinary literature shows that ignoring these factors in game theoretic models, supply chain contracts and newsvendor problems leads to deviations from practice.

## 7. Future research directions to support transition to a CSC and a CE

Whereas Section 6 gaps, flaws and limitations entailed some specific remediating research avenues, this section suggests systematic future research across the board to accelerate and complete the transition now underway to a CE via CSCs. In sections 7.1, 7.2 and 7.3 we recommend specific further research in each part of A, S and D relating to CSC management. Section 7.4 takes a broader perspective by relating CSCs' A, S and D to the ReSOLVE framework for transitioning to a CE.

### 7.1. Returns acquisition

Fig. 7 depicts used product flows in a CSC. Real-life CSC implementations use both closed and open loop circularity (Batista et al., 2018; Genovese et al., 2017; A. Zhang et al., 2021). Current literature on returns acquisition focuses on CLSCs and primary markets from the viewpoint of OEMs. In a CSC, many returns stem from secondary markets and non-commercial channels, including charities (Batista et al., 2018). In the extant literature, returns forecasting is often based on new product sales in prior periods. Forecasting research should include patterns in returns from secondary markets, where players are diverse and have different relationship dynamics. New modelling assumptions and approaches are also needed in research into returns channels selection and acquisition incentives.

In open loop circularity, used products become feedstock to manufacturers in the same sector, other goods-producing sectors, or recycling and other waste management sectors (Farooque et al., 2019). For example, used clothes can be processed to manufacture building insulation. Returns acquisition research needs to venture into open loops, especially from the perspective of other goods-producing and waste management sectors, which are absent from the literature. Further research is needed on the impact of returns quality, timing, and take-back effort (exchange offer, trade-in, etc.) on channel choice.

### 7.2. Returns sorting

Pre- and post-acquisition product sorting pose trade-offs in costs and benefits for firms and consumers. Research is needed into the conditions in which pre- and post-acquisition sorting are suitable for organisations and customers. Sorting is prone to error. For example, the error rate at an electronics remanufacturer can reach 20% (Ferguson et al., 2009). Sorting inaccuracies may incur extra costs at acquisition and value-recovery, such as higher acquisition prices for products misassigned to a *superior* quality category. Also, contamination from mis-sorting can necessitate *disposal* by letting through products unfit for recovery (Method bins, 2020). More realistic future research should remedy the overwhelming, problematic assumption so far that sorting operation is error-free. More research is also needed to understand *physical* sorting: the conditions where customer, manual labour and/or automation are suitable.

Researchers mainly consider returns sorting as a tactical activity and neglect related decisions at strategic and operational levels, e.g., outsourcing vs in-house operations, sorting facility location and capacity, technology selection and investment, and staff planning. Research is largely silent on the common strategic practice of outsourcing waste management activities, including sorting. Current research on returns sorting also stops at the product level, overlooking component and material sorting (Fig. 8), perhaps because these can be part of disassembly. However, component sorting and material sorting may also be performed separately. That invites explicit treatment of them, as does the fact that successful CSC implementation must establish a restorative cycle for technical materials and a biological one for restorative materials (EMF & McKinsey, 2015).

### 7.3. Returns disposition

The waste hierarchy (Fig. 9) has been widely used to prioritise waste management options. Its many variations share the same logic. The best option is to rethink/redesign products and services to stop waste and pollution from being created in the first place. Second-best is to reduce consumption and environmental footprint. These two options align with the first CE principle: to design out waste and pollution. Reuse, remanufacture, and recycle support the second CE principle to keep products and materials in use. Compost and anaerobic digestion serve the third CE principle to regenerate nature systems. The least-favoured options are to *recover energy* from non-recyclable waste (often by incineration) for *landfill*.

The options most discussed by current research are *remanufacture*, *recycle*, and *dispose* (*landfill*). Future research needs to fill two gaps. One is the omission of biological materials for composting and/or anaerobic digestion, perhaps reflecting inattention to bio-based products in CSC research (A. Zhang et al., 2021). The other is a lack of joint decision-making between product design and returns management. Product design in a CSC must consider convenient value-recovery (e.g., design for disassembly, and design for circularity) from EOU and EOL products (Burke et al., 2021). Both industry and academia tend to isolate returns disposition from other supply chain functions – a critical shortcoming. Comparing the lifecycle impact of conventional versus circular products at the disposition stage may also be worthwhile.

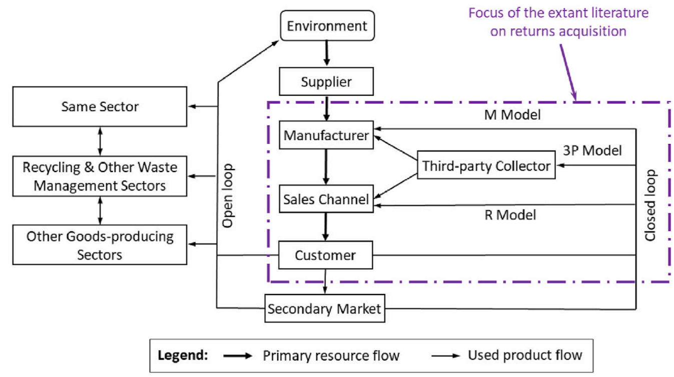


**Fig. 7.** Used product flows in a circular supply chain.
Source: Adapted from Batista et al. (2018) and Farooque et al. (2019).

### 7.4. Overall transitioning to a circular economy

Having suggested more research within the three overarching areas of a CSC, we now discuss overall research directions for a CE using relevant levers from the ReSOLVE framework. We cover the implications of each lever as outlined in Fig. 10.

ASD research can explore *sharing* assets (e.g., warehouses, vehicles) for better resource use, thus cutting resource extractions and greenhouse gas emissions. Second-hand goods markets can facilitate reuse. To enable sharing, product life can be prolonged by design for durability and upgradability, repair, and maintenance. ASD research in the sharing economy may meet unconventional ownership issues and user behaviour, demanding expertise of empirical and modelling researchers. In returns management, the *optimise* lever may use material optimisation, emissions abatement, and smart technologies. Material optimisation reduces complexity in and demand for used product material recovery. Process optimisation may involve smart technologies, e.g., big data analytics, internet-of-things, robots, and AI (EMF, 2019). However, current optimisation research appears lagging in the use of robots and AI.

In terms of the *loop* lever, circular product design is a foundational step towards a CE as it enables effective and efficient value-recovery from used products (Burke et al., 2021). Besides the traditional disposition options, a CE considers options such as upcycle, upgrade and repurpose. For example, upcycling combines many products into one. Disposition decision models for such options will require new research. Cross-sector collaboration offers ample scope for both modelling and empirical studies at various supply chain/process stages. supply chain and cross-sector collaboration can be within the original supply chain, or in open loop CSCs (Farooque et al., 2019). A CE necessitates new acquisition channels such as partnerships with local authorities and charities (e.g., with used apparel), and industry collaboration among competing firms. Furthermore, a common disposition option in ASD

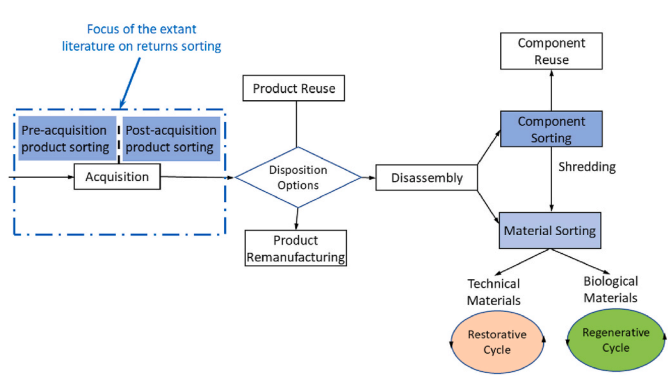


**Fig. 8.** Returns sorting at product, component, and material levels.

literature is disposal, which a zero-waste CE would argue must be replaced. A potential solution lies with *industrial symbiosis*, often realised in eco-industrial parks where one firm's disposed materials become another's inputs.

Supply chain digitisation is a key to *virtualising* utilities and increasingly discussed. Recommerce and the platform economy have grown fast. Academic research, policymaking and practice must keep up with the fast-changing landscape of online businesses to maximise their positive impact and minimise negative externalities. *Exchange* elicits new research problems. For example, 3D printing can produce spare parts on demand, eliminating obsolescence risk and take-back needs. Product-service systems (PSS) have been strongly advocated as a circular business model. PSS providers retain ownership, while consumers use the product and services. As the OEM owns the product, PSS business models mitigate returns uncertainty. Yet firms face practical complications in acquiring products due to the need for new capabilities beyond traditional producing and selling, and for managing consumer behaviour (Vezzoli et al., 2015). If OEMs have control over their products throughout their entire lifecycle from production to disposal, they will have a stronger motivation to design their products and processes in a way that allows for the reuse of materials and returns. Yet, if consumers take less care of products they do not own, used product quality will vary more. Such complexities suggest returns management in a PSS model warrants study.

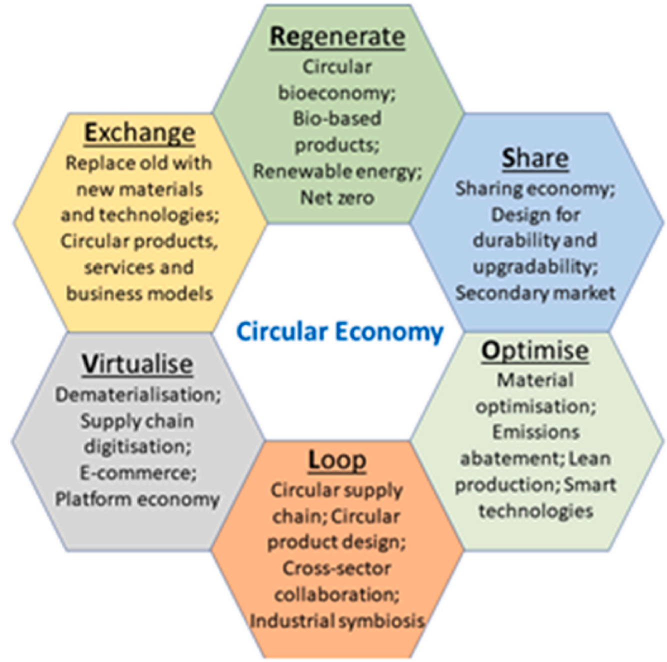


**Fig. 10.** Resolve framework-based CE transition.

## 8. Conclusion

A global CE is crucial for environmental reasons, and CE initiatives are often financially beneficial too. The decade 2012–2021 saw the transition now underway to a CE grow in practice, and literature on CE swell (MahmoumGonbadi et al., 2021). But with no review paper yet addressing all decision areas within A, S and D, the state of the art on used product ASD for CSC and ways to build on it as a key part of a CE has been unclear.

Perspectives on used product ASD have been evolving. Insofar as it concerned a CSC, initially, the literature considered ASD's various aspects as silos, each affecting environmental sustainability. Then, over 2012–2021, ASD was considered part of CLSC, focusing on remanufacturing, and economic optimisation. As the world continues to transition to a CE, ASD research should expand into a fuller CSC, which envisions materials in circulation through both open and closed loop circularity in various primary and secondary markets, with the ultimate goal of eliminating waste (A. Zhang et al., 2021). This paper addresses the gap to review 131 articles in leading academic journals. Our review is not only more recent that others but has only a small overlap. It clarifies and critiques the state of the art and points ways forward to better research on ASD both in itself and as enabling fuller transition to a CSC by incorporating CE principles.

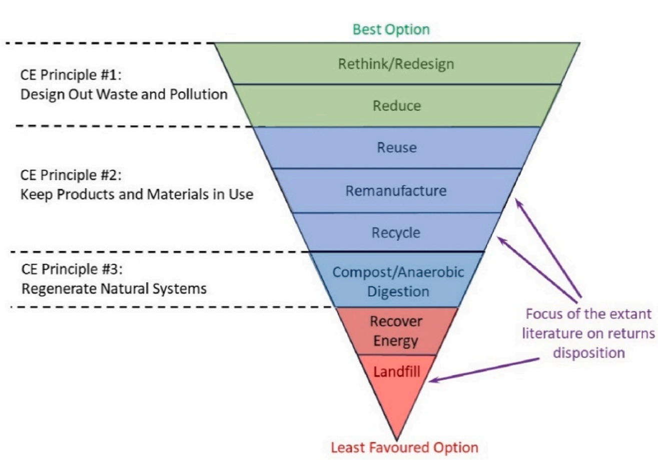


**Fig. 9.** Waste hierarchy and returns disposition.
Source: adapted from Kirchherr et al. (2017) and EMF (2019).

The review makes several contributions to ASD literature in general and for ASD oriented towards a transition to a CE. First, we uniquely combine all three of A, S and D. Second, the analysis of literature goes beyond traditional thinking of CLSCs to encompass CSCs extending the boundaries of value-recovery to external loops. Third and uniquely, we systematically analyse behavioural aspects in ASD literature, which many researchers and practitioners accept as important but which are underspecified at individual actor level in studies. Finally, we characterise each of the articles reviewed, under methods, decision areas, circularity archetypes and five important research considerations, to shed light on knowledge gaps, flaws, and limitations. Remedying these, and the analysis specifically from the point of view of what is needed for a CSC, just as the latter becomes more critical, identify important future directions for researchers, practitioners, and policymakers.

We highlight several future research directions. For an overall transition to a CE, ASD research may require more investigation into applying CSC dimensions beyond a CLSC. Anticipating inflows from open loop circularity applications is especially applicable to acquisition, while understanding the conditions for pre- and post-sorting and how sorting errors can be mitigated may prove worthwhile for take-back efficiency. Regarding disposition, the decisions may benefit from integrating decisions for product design and end-of-use product value-recovery. As far as the research considerations are concerned, legislation is central in levelling the playing field for A, S and D for businesses. How it can be employed is open for research, especially in regards to its impact on individual behaviours for acquisition and as a whole for sorting and disposition. We recommend considering the impact of legislation on all supply chain stages rather than focusing on separate steps of material flow when incorporating it for research. Despite technology being a crucial driver for the transition to a CSC, the way in which it helps ASD lacks research attention. Furthermore, consumers are the critical link to ensure the return flow of materials in a CSC, and their behaviour is not always driven by perfectly rational decision-making. Therefore, including behavioural operations in ASD may be of value.

In general, there should be more empirical studies to provide a predictive and descriptive understanding of ASD in its current state. Academic literature should also move outside conceptual models to assist practitioners with practical applications and case studies. Currently, ASD studies mainly focus on economic objectives. Research and practice will benefit from exploring environmental and social imperatives more. Additionally, ASD research needs to expand to low-value items from its current focus on high-value ones.

We also acknowledge several limitations in this review. To control quality of the reviewed literature, we focus on academic journals and omit publications in conference proceedings, books and grey literature. By restricting to the Scopus database and utilising a journal quality criterion, we may also overlook some relevant articles. Non-English publications are also excluded from this review. In addition, the scope of this review is restricted to CSC studies that directly deal with or impact ASD decisions. Future review work may expand the scope to consider a wider range of relevant factors.

## Data availability

Data will be made available on request.

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