



Review

Perspectives in reverse logistics: A review

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ABSTRACT

This paper investigates the current development in research and practice in reverse logistics (RL) through content analysis of the published literature. We have used various web based search engines, books and conference proceedings to locate and review the literature. The review finds that research and practice in RL are focused on all aspects of RL—from collection of used products, their processing and finally to the outputs of processing, namely, recycled materials, spare parts, remanufactured products and waste material disposal. Many of the literature have also focused on case studies on various aspects of RL. The review also shows that mathematical modeling in RL research is mainly focused on deterministic methods and there are limited research papers considering stochastic demand for the remanufactured products and supply of used products by the customer. Also, it is found that the pricing models for acquiring used products are still developing. We believe that the characteristics of RL provided here can help the researchers/practitioners to advance their work in the future.

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1. Introduction

Reverse logistics (RL) has received considerable attention due to potentials of value recovery from the used products. Besides, legislations and directives, consumer awareness and social responsibilities towards environment are also the drivers for RL (Melnyk et al., 1999; Ferrer and Ayres, 2000; Bloemhof and van Nunen, 2005; Ravi and Shankar, 2005; Cooper, 1994; Yang, 1995; Boks et al., 1998; Castell et al., 2004). The growing importance of research in RL has also been highlighted by many authors (see for example, Jones, 1992; New, 1997; Ayres et al., 1997; Handfield and Nichols, 1999). The focus on RL is on waste management, material recovery (recycling), parts recovery or product recovery (through remanufacturing). However, as the recovered products face competition from the new products, the investment on product recovery becomes a risky venture (Horvath et al., 2005). The cost of recovered products can be reduced by optimal locations and allocations of facilities in RL (Ferrer and Whybark, 2000; Prallinski and Kocabasoglu, 2006).

Research on RL has been growing since the Sixties (see, for example, Zikmund and Stanton, 1971; Gilson, 1973; Scharj, 1977; Fuller, 1978). Research on strategies and models on RL can be seen in the publications in and after the Eighties. However, efforts to synthesize the research in an integrated broad-based body of knowledge have been limited. Most research focuses only on a small area of RL systems, such as network design, production planning or environmental issues. Fleischmann et al. (1997) studied RL from the perspectives of distribution planning, inventory control and production planning. Carter and Ellram (1998) focused on the transportation and packaging, purchasing and environmental aspects in their review of RL literature. Linton et al. (2007) studied the interactions between sustainability and supply chains by considering environmental issues regarding product design, product life extension and product recovery at end-of-life. Rubio et al. (2008) have also reviewed the literature on RL published between 1995 and 2005 by focusing on management of the recovery, distribution of end-of-life products, production planning and inventory management, and supply chain management issues. The review presented in this paper extends the review to consider important features of reverse logistics such as product acquisition, pricing, collection of used products, RL network structure vis-à-vis the integration of manufacturing, and remanufacturing facilities of location of facilities for inspection and consolidation activity. The literature review covers published research until 2008.

The rest of the paper is organized as follows. In the next section research methodology is discussed. In Section 3, the result of review is presented. Each section is divided further into subsections to highlight various factors that are important to this research. The paper ends with conclusions and some thoughts on further research.

2. Review methodology

We have adopted content analysis method for literature review. Content analysis is an observational research method that is used to systematically evaluate the symbolic content of all forms of recorded communication (Kolbe and Brunette, 1991). This method also helps to identify the literature in terms of various categories (Li and Cavusgil, 1995), thereby creating a realm of research opportunities (Berelson, 1952; Krippendorff, 1980; Kolbe and Brunette, 1991). Al-Mashari and Zairi (2000) used content analysis to analyze the implementation of SAP R/3 for re-engineering the supply chain using enterprise resource systems. Gallivan (2001) adopted content analysis methodology to examine case studies of open source software projects in the research on balance between trust and control in a virtual organization. Content analysis was also used by Byrd

and Davidson (2003) to examine the impact of information technology on supply chain; and by Ellinger et al. (2003) in their research on the transportation industry in the US. Recently, Marasco (2007) also used a similar method for review of literature on third party logistics.

The review is limited to the published literature including books, conference proceedings, and literature obtained from electronic sources. Search engines were used to explore Google Scholar, ScienceDirect, EmeraldInsight, and Inderscience databases for literature. Keywords such as 'recycling', 'remanufacturing', 'product returns', 'product recovery', 'reverse logistics', 'end-of-life products', 'closed-loop supply chains', 'green supply chain' were used to find related literature. Special issues on sustainable supply chains were also reviewed. The publications were found in the areas of logistics management, production and operations management and business logistics. The references cited in each relevant literature were examined to find out additional sources of information.

In this research, 7 books, 6 conference proceedings and 151 journal publications have been reviewed. The search shows that only 14 articles were published between 1971 and 1995 and 99 articles between 1996 and 2005. Fifty-one publications were published on or after 2006 because of special issues on sustainable supply chains in Omega (in 2006), Production and Operations Management (2 issues in 2006), International Journal of Production Research (in 2007), Journal of Operations Management (in 2007), Computers and Operations Research (2007), and International Journal of Production Economics (in 2008). This, in itself indicates the relevance and importance of this topic in supply chain research.

2.1. Literature content

An RL system is given in Fig. 1. The system contains inputs, processes and structure, and outputs. Therefore, research can be focused on each group of these contents separately. Inputs would refer to used products, recycled materials, used parts or new parts that go through RL processes. The nature of returned products can be stochastic in terms of quality and quantity. The returned items could be collected at designated centres or at the retailers and inspected for their quality. During inspection, used products can be segregated to different quality levels. The products can then be consolidated for disposal, or minor processing (or pre-processing for remanufacturing), or remanufacturing.

Processing for remanufacturing can be disassembly and separation of parts into different bins. Some of these parts can be sent to the spare parts market. As for remanufacturing, full set of parts or modules are required. Therefore, shortages, if any, can be fulfilled by acquiring new or used parts/modules.

The structure part of the system becomes a process optimization or a location-allocation optimization problem. Process optimization could be in terms of new processes to design disassembly and assembly, cost effective dismantling or assembly process, and yield management. The coordination in the RL system and the implication of product modularity on RL structure can also be studied.

The outcomes of RL system are wanted outputs in terms of remanufactured products and recycle materials and spare parts. Pricing of outputs could be an issue due to competition from suppliers of new products or materials.

The RL system is facilitated by the drivers such as legislations, and early producer responsibility (EPR) for green design and manufacturing. The RL system could be designed either for a single (or homogenous) product type or multiple product types.

3. Result of literature review

Major literature on the groups mentioned in Fig. 1 is discussed below.

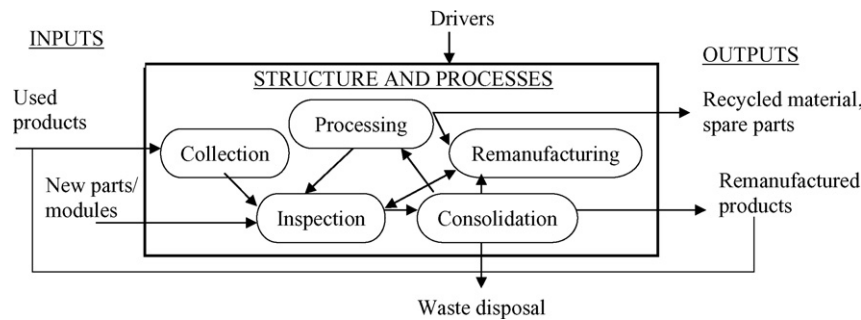


Fig. 1. Content categories for an RL system.

3.1. Inputs and collection

This section reviews the research done in developing product acquisition and collection systems. Inputs would refer to new or used products or parts, or recycled materials. The collection activity generally deals with locating collection points or developing strategy to collect used products through third party logistics providers. Literature reviewed for acquisition and collection of used products are given in Table 1.

3.1.1. Inputs

Kelle and Silver (1989) developed procedures to forecast the return of reusable containers. Guide and van Wassenhove (2001) and Aras et al. (2007) suggest offering attractive incentives to motivate the end-user to return the product to a designated place. Wojanowski et al. (2007) have assumed charging a refundable deposit to ensure product returns.

Guide et al. (2003) proposed a method to calculate the optimal acquisition price and the optimal selling price for remanufactured products. Similar analyses for calculating the optimal acquisition price are also developed by Choi et al. (2004) and Yalabik et al. (2005). Similarly, Liang et al. (2007) proposed option pricing for used products of different quality.

3.1.2. Collection

Authors have also discussed the problem of collection of used products. Bloemhof-Ruwaard et al. (1999) mentioned the problems of locating collection points for returned used products. Other authors have proposed either combining retail activities with the collection of used products (Wojanowski et al., 2007) or outsourcing of RL activities (Gooley, 1998; Krumwiede and Sheu, 2002; Meade and Sarkis, 2002; Murphy and Poist, 2003; Spicer and Johnson, 2004). Serrato et al. (2007) also suggest outsourcing RL activities when the returns are more variable.

Table 1
Literature on RL inputs and collection.

Content	Literature
Inputs	Guide and van Wassenhove (2001), Guide et al. (2003), Choi et al. (2004), Yalabik et al. (2005), Liang et al. (2007), Morana and Seuring (2007)
Collection	Kelle and Silver (1989), Gooley (1998), Bloemhof-Ruwaard et al. (1999), Krumwiede and Sheu (2002), Meade and Sarkis (2002), Murphy and Poist (2003), Savaskan et al. (2004), Spicer and Johnson (2004), Hameri and Paatela (2005), Richey et al. (2005), Karakayali et al. (2007), Aras et al. (2007), Biehl et al. (2007), Ko and Evans (2007), Serrato et al. (2007), Webster and Mitra (2007), Wojanowski et al. (2007)

3.2. RL structure

Majority of studies in RL structure are related to location and allocation problems, identification of supply chain system, inventory control, coordination and the use of RL system for modular structure. The groupings of literature for structure are given in Table 2 and content of some of the literature is discussed below.

3.2.1. General

This section reviews the literature pertaining to strategic planning of RL systems. Development of RL networks has been discussed by several authors (Fleischmann et al., 2000, 2003; Goggin et al., 2000; Fleischmann, 2003; Steven, 2004; Ravi et al., 2005). Locating facilities close to the sources of used products, availability of resources for reprocessing, proximity to disposal sites or even customers are some of the strategies suggested by researchers in establishing RL systems (Dowlatsahi, 2000; Realff et al., 2000; Krikke et al., 2001; Knemeyer et al., 2002; Tibben-Lembke and Rogers, 2002; De Brito and de Koster, 2003; Dowlatsahi, 2005; Ravi and Shankar, 2005). Presley et al. (2007) proposed a framework to

Table 2
Literature content on RL structure.

Content	Literature
General	Bowersox and Closs (1996), Dowlatsahi (2000), Fleischmann et al. (2000), Goggin et al. (2000), Realff et al. (2000), Ferrer and Whybark (2001), Krikke et al. (2001), Knemeyer et al. (2002), Nakashima et al. (2002), De Brito and de Koster (2003), Fleischmann (2003), Kekre et al. (2003), Blackburn et al. (2004), Bufardi et al. (2004), Savaskan et al. (2004), Steven (2004), Dowlatsahi (2005), Nagurney and Toyasaki (2005), Ravi and Shankar (2005), Ravi et al. (2005), Wells and Seitz (2005), Aras et al. (2007), Mitra (2007), Presley et al. (2007), Srivastava (2007), Kusumastuti et al. (2008), Neto et al. (2008)
Inspection and consolidation	Gooley (1998), Bloemhof-Ruwaard et al. (1999), Guide and van Wassenhove (2001), Krumwiede and Sheu (2002), Meade and Sarkis (2002), Murphy and Poist (2003), Spicer and Johnson (2004), Galbreth and Blackburn (2006), Savaskan and van Wassenhove (2006), Biehl et al. (2007), Webster and Mitra (2007),
Integrating manufacturing and remanufacturing	Ferrer and Ayres (2000), Goggin et al. (2000), Guide and van Wassenhove (2001, 2002), De Koster et al. (2002), Nakashima et al. (2002), Chouinard et al. (2005), Wells and Seitz (2005), Kocabasoglu et al. (2007), Fuente et al. (2008)
Product modularity	Krikke et al. (2004), Kusumastuti et al. (2004), Fernandez and Kekale (2005), Mukhopadhyay and Setoputro (2005), Mutha and Pokharel (2007), Xu et al. (2007)

incorporate environment, economy and social concerns and applied it to make decision on RL outsourcing.

3.2.2. Inspection and consolidation

Some authors have considered integration of collection, inspection and consolidation of used products with forward logistics activities (Flapper, 1995; Guide, 2000; Savaskan and van Wassenhove, 2006) while others have proposed outsourcing of collection and consolidation (Gooley, 1998; Autry et al., 2000; Krumwiede and Sheu, 2002; Meade and Sarkis, 2002; Murphy and Poist, 2003; Spicer and Johnson, 2004). Some researchers have also suggested categorizing the returns on the basis of quality (Aras et al., 2004).

3.2.3. Integrating manufacturing and remanufacturing

Researchers have mentioned that integration of manufacturing and remanufacturing operations can be an option but this may require realignment of the manufacturing process, information systems and handling of returns for remanufacturing (Flapper, 1995; Goggin et al., 2000; Guide et al., 2000; Chouinard et al., 2005; Wells and Seitz, 2005). De Koster et al. (2002) discussed the issues in combining and separating inbound and outbound flows for food retailers, non-food store chains and mail order companies. Researchers have also analyzed the issues of integrating product design, product take back and supply chain incentives (Guide and van Wassenhove, 2001, 2002) and the problem of inventory control in an integrated system (Nakashima et al., 2002).

3.2.4. Product modularity

Some studies (Kusumastuti et al., 2004; Krikke et al., 2004; Fernandez and Kekale, 2005; Mutha and Pokharel, 2006, 2007) reflect on the need to look at RL with modularity in product structure. Krikke et al. (2004) have discussed the implications of product modularity on closed-loop supply chains. Modeling of handling multiple products in a RL system is proposed by Mutha and Pokharel (2007).

3.3. RL processes

The groupings of literature under RL processes are given in Table 3. The RL process includes disassembly, remanufacturing, supply chain planning, coordinating, inventory control, and after-sales services.

3.3.1. Disassembly

Processing of used products for easy disassembly is also discussed by the authors (Mok et al., 1998; Gungor and Gupta, 1998; Guide and Srivastava, 1998; Guide et al., 1999b; Lambert, 2002). Researchers have also proposed disassembly release mechanisms to assist in better coordination in planning and controlling the remanufacturing process (Guide et al., 1997c; Veerakamolmal and Gupta, 2000). Mazhar et al. (2007) assess the mean life of components to analyze the degradation and condition of used products.

3.3.2. Coordination

Coordination in RL is also discussed by the authors. Some authors have discussed the importance of communication to help in quick and early disposition of returned products and also assisting in remanufacturing planning (Hess and Meyhew, 1997; Autry et al., 2000; Fleischmann et al., 2000, 2001; Yalabik et al., 2005). Some authors have suggested the use of information support systems to assist in coordination (Chouinard et al., 2005; Daugherty et al., 2005).

Table 3
Literature on RL processes.

Content	Literature
Disassembly	Mok et al. (1998), Guide and Srivastava (1998), Gungor and Gupta (1998), Guide et al. (1999b), Lambert (2002), Teunter (2006), Lambert (2006), Kim et al. (2007), Mazhar et al. (2007), McGovern and Gupta (2007), Shimizu et al. (2007), Barba-Gutierrez et al. (2008)
Coordination	Fleischmann et al. (2000, 2001), Fleischmann (2003), Hess and Meyhew (1997), Chouinard et al. (2005), Daugherty et al. (2005), Yalabik et al. (2005), Aras et al. (2006), Atasu and Cetinkaya (2006), Ketzenberg et al. (2006), Kongar and Gupta (2006)
Supply chain	Guide et al. (1997a,b), Bras and McIntosh (1999), Guide (2000), Veerakamolmal and Gupta (2000), Inderfurth and Teunter (2001), Choi et al. (2004), Kim et al. (2006), Reimer et al. (2006), Bakal and Akcali (2006), Debo et al. (2006), Georgiadis et al. (2006), Tang and Teunter (2006)
Inventory	Van der Laan et al. (1996, 1999), Richter (1997), Guide et al. (1997c, 1999a), Teunter et al. (2000), Toktay et al. (2000), Inderfurth et al. (2001), Nakashima et al. (2002), Fleischmann et al. (2002, 2003), Vlachos and Dekker (2003), Inderfurth (2004, 2005), Hwang et al. (2005), Bayindir et al. (2006), Zhou et al. (2006)
Repair and after-sales	Blumberg (1999), Murthy et al. (2004), Amini et al. (2005), Du and Evans (2007)

3.3.3. Supply chain

An understanding of reverse supply chain is also explored by the authors. Scheduling arrivals of new modules, storing or disposing excess recovered modules are some of the factors analyzed by researchers (Guide et al., 1997a; Bras and McIntosh, 1999; Guide, 2000). Research is also carried to analyze capacity planning techniques and material planning systems in a remanufacturing environment (Guide et al., 1997b; Ferrer and Whybark, 2001). A few authors have also discussed the aspect of supply planning by considering the modular structure of products (Guide et al., 1997a; Choi et al., 2004; Kim et al., 2006).

3.3.4. Inventory

Handling heterogeneous parts (new, remanufactured and substitutable) for production; and handling variety of inventories (used parts, new parts, spare parts, finished goods and work-in-progress) is an important issue in RL for which researchers have suggested alternative procurement and inventory control strategies (Van der Laan et al., 1996, 1999; Toktay et al., 2000; Nakashima et al., 2002; Fleischmann et al., 2002, 2003; Inderfurth, 2005). Authors have also determined inventory policies in a hybrid manufacturing system in which new products are downgraded and sold in case of shortage of remanufactured products (Inderfurth, 2004). Various inventory control policies to handle demand and supply of used products are discussed by Inderfurth et al. (2001) and Fleischmann et al. (2002).

3.3.5. Repair and after-sales service

Ability to provide repair and after sales service can also enhance a company's ability to market its product. Therefore, researchers have also analyzed these issues (Blumberg, 1999; Amini et al., 2005; Du and Evans, 2007). Murthy et al. (2004) discussed issues in location of warehouses and service centres in warranty logistics.

3.4. RL outputs

Pricing the remanufactured product for sale is a complex and challenging issue (Liang et al., 2007) due to stochastic returns and demands. This makes it difficult to determine the price of a remanufactured product vis-à-vis new products. The groupings of literature under RL outputs are given in Table 4.

Table 4

Literature on RL outputs.

Content	Literature
Product pricing and competition	Purohit (1992), Purohit and Staelin (1994), Majumder and Groenevelt (2001), Guide et al. (2003), Choi et al. (2004), Bayindir et al. (2005), Ferguson and Toktay (2005), Debo et al. (2005), Yalabik et al. (2005), Yao et al. (2005), Bhattacharya et al. (2006), Ferrer and Swaminathan (2006), Vorasayan and Ryan (2006), Karakayali et al. (2007), Mitra (2007), Vadde et al. (2007) <i>Competition:</i> Porter and van der Linde (1995), Shrivastava (1995), Newman and Hanna (1996), Russo and Fouts (1997), Marien (1998), Goldsby and Stank (2000), Majumder and Groenevelt (2001), Sahay et al. (2003), Richey et al. (2004), Ferguson and Toktay (2005), Heese et al. (2005), Ferrer and Swaminathan (2006), Savaskan and van Wassenhove (2006), Webster and Mitra (2007)
Customer relation	Fuller et al. (1993), Turner et al. (1994), Amini and Retzlaff-Roberts (1999), Wise and Baumgartner (1999), Daugherty et al. (2003), Sarkis et al. (2004), Daugherty et al. (2005), Mollenkopf et al. (2007), Srivastava (2007)

3.4.1. Pricing and competition

Researchers have studied the relationship between markets for new and remanufactured products (Purohit, 1992; Purohit and Staelin, 1994) and developed models to determine the optimum selling price for remanufactured products and parts (Guide et al., 2003; Karakayali et al., 2007; Mitra, 2007; Vadde et al., 2007).

The competition between original equipment manufacturers (OEMs) and local remanufacturers not only affect the supply of used products but also the price of the remanufactured product (Majumder and Groenevelt, 2001; Debo et al., 2005; Ferrer and Swaminathan, 2006; Webster and Mitra, 2007). They found that OEMs are in a better position to offer remanufactured products at a lower price than those offered by local remanufacturers. Ferguson and Toktay (2006) have discussed strategies used by OEMs to deter the entry of independent remanufacturers. Substitution of new products by remanufactured products is discussed by Bayindir et al. (2005).

Researchers have also recommended early entry of OEMs in RL to gain first mover advantages (Marien, 1998; Sahay et al., 2003; Richey et al., 2004; Heese et al., 2005) and to learn significant engineering capabilities and product disassembly knowledge (Shrivastava, 1995; Newman and Hanna, 1996; Russo and Fouts, 1997).

3.4.2. Customer relation

The benefits of RL on customer relationship such as improved customer retention and customer satisfaction through liberalized returns policies is analyzed by Fuller et al. (1993), Turner et al. (1994), Wise and Baumgartner (1999), Sarkis et al. (2004), and Mollenkopf et al. (2007). Amini and Retzlaff-Roberts (1999) suggest reduction in cycle time of providing refunds and exchanges to customers as a way of enhancing customer service quality. Daugherty et al. (2005) suggest the use of information technology for better customer relations and enhanced service quality.

4. Conclusions and discussion

The above discussion shows that research in RL is multifaceted and distinguishes itself from forward logistics. The review also

shows that research publication on RL is increasing specially after 2005 and therefore it shows the growing recognition of RL as a driver of supply chain and logistics.

We have used content analysis method to show a holistic perspectives of reverse logistics system from inputs to outputs and then to inputs again. The main perspectives that needs to be covered in a RL situation includes not only networking and inventory analysis but also collection of used products, their pricing, use, resale, and remanufacturing through an established system. The review also shows that research is also focusing on devising pricing policies to attract used products from the customers. Therefore, the challenge to the decision makers in RL business is not only to set up an economically efficient network but also to design systems in such a way that used products are received at the expected time, at expected price and at expected quantities. At the same time, remanufacturing can be done more efficiently, economically and environmentally compared to the production of new products. This will require a change in the design of product from design to market to design to disassembly and design to remanufacture and reuse. Therefore, larger the extended life of the product, smaller would be the use of new resources.

The review presents RL from a systems perspective. It can assist the decision maker in key operational and strategic decision making, for example, integrating manufacturing and remanufacturing operations, evaluating end-of-life options for returned products, or setting up a returns policy. RL involves a paradigm shift in terms of product, that is, from “cradle-to-grave” to “cradle to cradle”.

Arising from the above, we propose some important directions in RL research. We have found that the research can be strengthened in assessing the stochastic nature of supply and demand and the yield from a remanufacturing process. More generic models have to be developed to tackle this type of situation so that better networks can be designed to facilitate RL.

The second direction of research should be in terms of pricing of products based on quality of the returned products. Good quality products require less number of processes in terms of inspection, and less number of new parts for remanufacturing; this can possibly lead to higher value extraction to the remanufacturer. Therefore, designing a good pricing policy for the acquisition of used products should be strengthened. Liang et al. (2007) have proposed an option theory method for acquisition pricing based on anticipated demand. However, the authors do not explicitly consider network design and the remanufacturing process. Therefore, integration of models from acquisition of used products to the sale of remanufactured products should be considered. Further, as supply quantities would not be known in advance, such a pricing policy need to be dynamic and should be revised as quickly as possible. However, frequent changes in pricing of used products may not entice the consumers to return their product as soon as possible thereby leading the remanufacturer to a worst case remanufacturing decision and reducing the value recovery.

The third direction of research could be to incorporate product obsolescence and pricing of used and remanufactured products. This becomes a challenge especially to those products which have a short shelf life. With changes in the models of the products, the pricing, demand patterns and the remanufacturing process might have to be frequently adjusted.

The fourth area of research could be in terms of management of collection centres. These centres should be attracted to work with the remanufacturers on a long term basis. This requires multi-period transactions between the suppliers and the remanufacturers. Zou et al. (2008) have considered a two period model for this type of supply management in forward logistics. The challenge would be to use similar concepts by incorporating obsolescence and lead times in a RL situation.

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