

SURVEY OF REVERSE LOGISTICS: A LITERATURE REVIEW

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Survey of Reverse Logistics: A Literature Review

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Abstract

Reverse logistics is an important activity for all types of industry. It offers competitive advantages, the ability to build long-term relationships with customers, opportunities to reclaim value, and important environmental benefits. It also allows for a once linear product cycle to become a closed loop where a returned product can be reclaimed, recycled, or disposed of in an environmentally safe manner. Although reverse logistics requires considerable resource commitments and presents uniquely challenging management issues, it has the potential to deliver more value than cost. The intent of this paper is to find out why reverse logistics should be important for firms, what factors are driving its adoption, how reverse logistics works, and how best to manage it. This paper is intended as a survey of academic work surrounding reverse logistics and provides the necessary general conceptual framework for further in-depth study

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Introduction

Reverse logistics is an important activity for all types of industry. It offers competitive advantages, the ability to build long-term relationships with customers, opportunities to reclaim value, and important environmental benefits. It also allows for a once linear product cycle to become a closed loop where a returned product can be reclaimed, recycled, or disposed of in an environmentally safe manner. Although reverse logistics requires considerable resource commitments and presents uniquely challenging management issues, it has the potential to deliver more value than cost.

The intent of this paper is to find out why reverse logistics should be important for firms, what factors are driving its adoption, how reverse logistics works, and how best to manage it. This paper is intended as a survey of academic work surrounding reverse logistics and provides the necessary general conceptual framework for further in-depth study. Not intended to add any new insights into reverse logistics, this survey rather introduces a student to the general themes and concepts associated with a closed-loop supply chain and its reverse logistical flows. The paper provides a student with a general introduction to reverse logistics and aims to promote further study, and it does so through a review of reverse logistics literature.

The paper begins by asking what reverse logistics is and discusses various definitions. Then discussed are factors driving its adoption. Factors include competitive advantage to be gained, the ability to recapture value, social and environmental stewardship, and good customer relationship management. Key terms are then provided for understanding reverse logistics, terms such as end-of-life products, product residual value, producer responsibility organizations, and extended producer responsibility. Reverse logistics management is examined with discussions

on supply chain network design and network optimization. Finally, two examples of reverse logistics in practice are examined.

What is Reverse Logistics?

Reverse logistics (RL) can be defined as the logistical activities of retrieving materials or products to repair, re-sale, recycle, or to properly discard (Hsu, Tan & Zailani, 2016, p. 92). In its simplest form, RL is the opposite of logistics. Logistics is the process of planning, executing, and administering the efficient movement of materials, in-process inventory, and finished goods from a point of origin, say an original equipment manufacturer (OEM), to a point of consumption to meet a customer demand for a product. RL is like logistics in every respect except direction. RL is the process of planning, executing, and administering the efficient movement of materials, inventory, and finished goods from a point of consumption, to a point of origin, say a remanufacturer, to reclaim value or dispose of a product (Rogers & Tibben-Lembke, 1999, p. 2).

Another way of looking at RL is as a form of commercial and environmental efficiency. Carter & Ellram (1998) have two views of RL as commercial and environmental efficiency. First, “viewed narrowly, it can be thought of as the reverse distribution of materials among channel members.” In other words, value from returned products can be reclaimed up through the supply chain. Second, viewed more broadly, RL is the “reduction of materials in the forward system in such a way that fewer materials flow back, reuse of materials is possible, and recycling is facilitated” (p. 85). Put another way, less material is used to produce a product resulting in less to be disposed of at the end of a product’s life, or material is used more efficiently so that it can be reclaimed more easily.

Both of these two views of RL suggest a closed-loop supply chain (CLSC) where initial products sold to customers are reclaimed for reuse in a variety of ways. By viewing RL more broadly as a CLSC, which includes both forward and reverse logistical movements and activities, one can discern its full potential to add and create value. RL can support government mandated take-back of product waste, meeting a social or environmental responsibility need, or it can add profitability for a firm by “maximizing value creation over the entire life cycle of a product” (Govindan et al., 2014, pp. 603-604). Figure 1 provides a generic example of a CLSC and RL product flows:

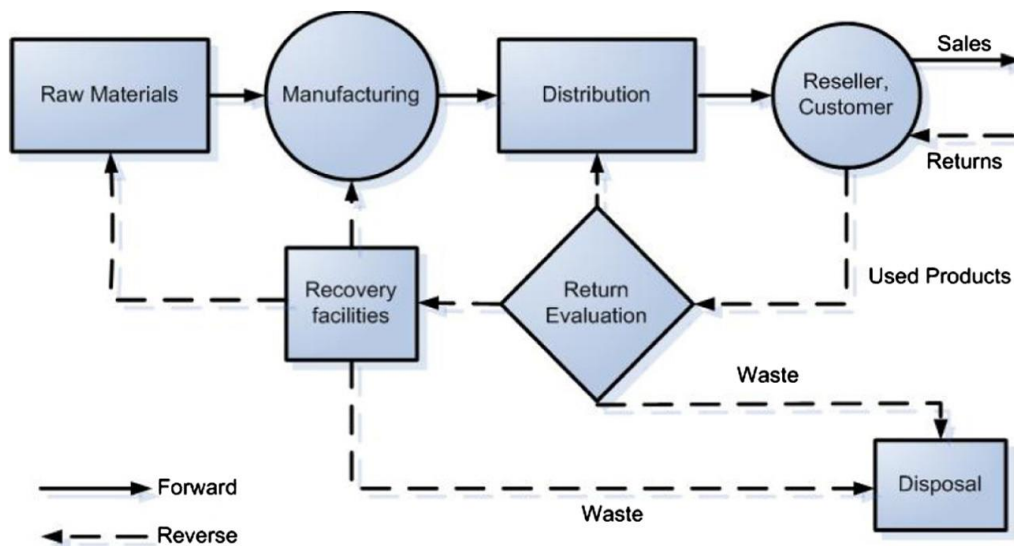


Figure 1. Generic Closed-Loop Supply Chain (Govindan et al., 2014, p. 604).

Factors for the Adoption of Reverse Logistics

Four factors are driving the adoption of RL across industries. First, RL offers companies a greater number of business opportunities or greater competitive advantage. Second, RL enables a company to gain additional profits by recapturing value from returned products. Third, environmental concerns are compelling firms to become good citizens through greater

responsibility for the ultimate disposal of their finished products rather than the consumers of their finished products (Dowlatshahi, 2000, p. 144). Finally, RL is crucial for customer relationship management (CRM) and requires systems and processes in place to ensure customers are satisfied when dealing with a product return (Smith, 2005, p. 180).

Competitive Advantage & Recapturing Value.

Jayaraman & Luo (2007) refer to the resource-based theory of the firm as a way of understanding the need for RL. With the resource-based theory of the firm, the source of a firm's competitive advantage comes from a collection of resources that actually makes up the firm. Through "value chain" strategies a firm's resources can be utilized not only for the primary activities of producing finished products but also utilized for the reclamation of products to gain "new tangible and intangible values." Jayaraman & Luo (2007) insist that RL should not be viewed as an expensive side job and stress that there is competitive advantage to be gained from returned products. The resources of a firm can not only create value through new products but can also create direct and indirect value from returned products (p. 57).

For Kapetanopoulou & Tagaras (2011), RL is all about the reclamation of product value at the end of life (EOL) of a product (p. 148). The competitive advantage associated with RL comes primarily through the recapturing of value by promoting alternate uses for products no longer wanted by consumers. In many cases, companies may be able to extend the normal lifecycles of products and in so doing find additional opportunities to make money. Refurbishing or remanufacturing products for alternate sales, sales in secondary markets, is one example of recapturing value. According to Jayaraman & Luo (2007), "elevating the returns process to a new marketing opportunity builds a loyal customer base and also attracts new ones" (p. 56).

Jayaraman & Luo (2007) see firms gaining three strategic advantages from RL (p. 58). First, the value chain is not simply one-way but a closed loop that gains additional value from existing resources. These existing resources can be returned products that may be refurbished for re-sale or stripped for valuable components and materials, or they can be inputs like logistical containers that can be reused again and again without be replaced or simply discarded. Second, RL can gain more than just tangible value, but can gain intangible value in the form of knowledge. A returned product can provide information as to why it failed and why other like products are failing, and it can provide information about customers and their interaction with a product. Third, from a resource-based perspective the value gained from RL generates economic rent, or, put in simpler terms, revenues associated with RL can surpass the cost associated with RL—RL can pay for itself and then some.

Good Citizenship & Environmental Stewardship.

Sustainability and the need for environmentally beneficial practices are impacting every aspect of life today, and supply chain management is no exception. RL is a key supply chain function for promoting sustainability and green practices. The driving factors behind the adoption of green RL practices are government regulations, competitive pressures, customer expectations, and social responsibility (Hsu et al., 2013, pp. 663-666).

Government regulations around product disposal are becoming an increasingly influential factor for RL. Coercive pressure in the form of laws and regulations is a compelling force for firms to adapt good environmental practices (Hsu et al., 2013, p. 664). Even the threat of government regulations can be a compelling force. Carter & Ellram (1998) point out that “a reverse logistics program can proactively minimize the threat of government regulations” (p. 85). Competitive pressure can also drive the adoption of green RL practices. As mentioned earlier,

there are competitive advantages to adopting RL. So, a firm can adopt green RL practices and gain a competitive advantage over its rivals (Hsu et al., 2013, p.664). Lo (2014) finds that RL allows firms to not only dispose of components that cannot be remanufactured or recycled, but also reclaim and recycle product components for competitive gain (p. 105).

Customers are increasingly expecting firms to adopt environmentally sound practices. Customers are exerting pressure on firms “to take an environmentally conscious approach to product design to minimize adverse environmental impacts of the product throughout its life, and to promote recycling and reuse of the product and its packaging” (Hsu et al., 2013, p. 665). These increased expectations for more green initiatives are moving up the entire supply chain, from consumers wanting a product recycled at the end of its use to suppliers of final products wanting components and materials of returned products recycled or reclaimed by members of the supply chain (Hsu et al., 2013, p. 665). Firms may also take up green RL practices on a voluntary basis. Rather than coerced or compelled into taking up environmentally sound practices, a firm may take up such practices “to establish a socially acceptable image that is consistent with the obligations and values of the society” in which it functions (Hsu et al., 2013, p. 666). From a business ethics perspective there are compelling reasons for supporting the welfare of society. Moral obligation can have a significant effect on the decision to adopt green RL practices (Hsu et al., 2013, p. 666).

So, environmentally sound RL practices are becoming a part of a holistic effort at making supply chains sustainable from start to finish. According to Hsu et al. (2016), firms must “partner with members throughout their supply chains to improve energy efficiency while reducing natural resource usage, waste, and adverse environmental impacts, which together lead to a stronger bottom line” (p. 90). All supply chain activities need to consider the entire life

cycle of a product, so as to minimize negative impacts to the environment--from the upper portion of the supply chain, say the extraction of raw materials for a product, to the lower portion of the supply chain and the eventual consumption of a final product (Rao & Holt, 2005, p. 899). The lower portion of the supply chain, where RL comes into play (as can be seen in Figure 1), offers significant opportunities for gains in environmental sustainability, “because products generate most of their environmental emissions and waste during their use [and disposal], such that these detrimental impacts may exceed those generated during the manufacturing state” or upper portion of the supply chain (Hsu et al., 2016, p. 91).

Reverse Logistics as Customer Relationship Management.

Managing customer returns is critically important for companies, and a robust RL process is essential for managing returns and the customer relationships associated with them. Smith (2005) found that customers “felt that it is a company’s reverse logistics’ practices, policies, and procedures that sets a company apart from another and gives a company the competitive advantage over other companies” (p. 178). Without solid RL processes in place a company will not fully realize the potential of its products and ignores a sound investment in customer relationship management (CRM) (Smith, 2005, p. 179). High quality RL service, or, from a customer perspective, the good handling of a return, is linked with the ability of a company to establish longer-term relationships with customers (Smith, 2005, p. 173). So regardless the costs of RL, it is essential that a company build a robust RL process.

Although RL is a cost that companies cannot avoid, the key benefit from the management of returned products is informational. Every product has a life cycle and each phase of this life cycle provides information on the existing state of the product, its sales and returns, and on the

future development of new products (Smith, 2005, pp. 168-169). There are six product life cycle phases, and each has RL implications:

1. The “development phase” can introduce a “non-defective” defective phenomenon where customers could potentially return a product because they may not understand how the product works—essentially the customer is poorly informed of how to use the product. During the development phase, thought must go into how customers will react to the design and functionality of a product so as to limit the potential of a non-defective defective return (Smith, 2005, pp. 169-170).
2. During the “introductory phase” is when a product will have the most defects, real or imagined. If the product’s form varies significantly from previous iterations or is entirely new, then customers may struggle with adopting it and returns may suffer for it. Significant design changes, changes in product form, may also come with a greater defect rate and again affect the return rate (Smith, 2005, p. 170).
3. With the “growth phase” RL return centers will begin to provide valuable feedback on product defects and customer concerns. Also, during this phase, sales of returned or refurbished product can be leveraged to increase the value to be had from RL (Smith, 2005, p. 170).
4. The “maturity phase” of the product should come with mature, fully developed RL processes that will ensure quick processing of returns either to return to the actual customer or to added to a re-sale inventory. During the maturity phase a company will gain the greatest cost-benefit from RL (Smith, 2005, pp. 170-171).
5. During the “decline phase” of the product, a company will need to look at its return policy and will need to begin considering when the last sale of the product

will occur. As a product begins to show less interest in the market then a company will need to start to consider how it will limit returns and the resulting returns inventory that will have less and less potential for valuable sales (Smith, 2005, p. 171).

6. The “cancellation phase” of the product life cycle exposes a company to returns and inventory that will provide little or no benefit. Customers that return the product may not want it returned or exchanged, and with newer and better products in the market any refurbished inventory may have no demand. With the cancellation phase, the company may not even be able to give returned product away (Smith, 2005, p. 171).

Obviously, companies need to concentrate on reducing the number of product returns, whether it be through knowledge of customers issues with the product that result in technical fixes or better communication with the customer. That said, Smith (2005) found that convenient return policies and processes for customers underpinned by a robust RL system provides significant benefits for companies (p. 173).

Key Terms for Understanding Reverse Logistics

Before diving into the particulars of managing RL its important to understand some key terms used in the literature surrounding RL. The following terms are essential for making RL decisions and managing RL supply chain networks.

Product Cores

Frequently within the literature on RL, particularly the literature associated with the automobile industry, product “cores” refer to the recoverable components of a single product formally used by a consumer. These cores can be such things as a car alternator or transmission.

RL supports value retrieval processes like remanufacturing and material recycling, and cores are the product retrieved for additional use (Ostlin et al., 2009, p. 999). A core product can be refurbished and sold again in a secondary market, or it can be stripped for parts that can be used elsewhere.

End-of-Life (EOL) & End-of-Use (EOU) Products

All products have a useful lifespan and a returned product is either at the end of its useful life or at the end of its use with a particular consumer. Kongar et al. (2015) define an end-of-life (EOL) product as having “completed its service lifetime and has reached the end of its useful life” (p. 51). Put another way, an EOL product has reached a point in its lifespan where it either has limited functionality, simply doesn’t work anymore, systematically made invalid by newer products with greater functionality, or is technologically obsolete. With EOL products there is little or no economic value gained, or the physical condition of the product precludes any further usefulness other than value recovered through materials recycling. Through RL, products at the end of their life are either recovered to extract any residual value or recovered because of legal obligations to dispose of properly (Ostlin et al., 2009, p. 1000).

Ostlin et al. (2009) defines end-of-use (EOU) product returns as “those situations where the user has a return opportunity at a certain life stage of the product” (pp. 999-1000). Sometimes treated synonymous to EOL products in the RL literature, EOU products are very different and require differing strategies when recovered through an RL process. Unlike an EOL product, an EOU product is not at the end of its useful life. Typically returned in a reasonably good state, EOU products can be sold again in a refurbished or secondary market (Ostlin et al., 2009, p. 1000). EOU product can also be reusable assets, assets returned after use and used

again and again. Such assets can be returnable containers like bottles or transportation packaging.

Remaining Useful Life & Product Residual Value

When returned, products receive a residual value or quotient of remaining useful life (RUL). John et al. (2018) define RUL as the length of time from the actual return of a product or asset to the end of its useful life (p. 313). RUL is important for maximizing the useful life and the revenue potential of an EOL or EOU product. Another way of defining RUL is a product's residual value or PRV. A product with a high PRV can potentially be remanufactured and put in a secondary market to capture revenue. Components and materials recovered to capture revenue through recycling have a low PRV (Gobbi, 2011, p. 772).

Producer Responsibility Organizations (PRO)

A producer responsibility organization (PRO) is an industrial cooperative, typically a not-for-profit, that allows for collective action to meet extended producer responsibility (EPR) regulatory obligations. A PRO enables its member companies to share in operational and financial responsibility for the proper disposal of EOL products. The PRO manages the financing, collection, transportation, and regulatory compliance and control of EOL products (Khetriwal et al., 2009, p. 156).

Product-Service System (PSS)

Sometimes referred to as “servicizing”, a product-service system (PSS) combines products and services. With PSS schemes “consumers may no longer purchase the product itself, but the function (or service) that the product provides” (EPA, 2009, p. ES-2). PSSs come in three categories (EPA, 2009, p. ES-2):

- Product-oriented PSSs involve the sales of products with additional services that add an additional source of value—extended warranties, maintenance programs, and EOL management. The consumer holds product ownership.
- Use-oriented PSSs are a form of product leasing or rental where the consumer has access to the product and its function but do not own the product. A leasing company takes back the product once the consumer has no use for its function.
- Results-oriented PSSs involve consumers having access to the function of a product, but not direct access to the product. Consumers purchase the function of a product as a service rather than the product itself.

Extended Producer Responsibility (EPR)

Extended producer responsibility (EPR) is a policy that attempts to make firms responsible for their products not only at the beginning of their life cycle, the initial development and production, but also at the end, at their disposal. Having to take back a product at the end of its life cycle compels a firm to think about disposal costs and creates incentives for the firm to design its product with its EOL in mind (OECD, 2001, pp. 9-10). These incentives vary with the type of producer responsibility, of which there are two. Individual producer responsibility (IPR) involves individual OEMs being responsible for the take back of their products. Generally seen as a more effective, IPR makes producers responsible for their products and does so particularly when it comes to design for recoverability in an RL process. Collective producer responsibility (CPR) involves the collective responsibility of producers to be responsible for the take back of their products. Seen as less effective than IPR because of the lack of individual incentives, CPR take back does not distinguish product by producer. Products taken back under CPR go through

the same RL process together regardless of how well they are individually designed for recoverability (Atasu & Subramanian, 2012, p. 1043).

Traditionally, environmental regulation has focused on pollution emissions and material use in production rather than the produced products' waste contribution at the end of its life (Klausner & Hendrickson, 2000, pp.156-157). In the early 1990s Germany and Sweden were the first countries to propose EPR policies. According to Lifset et al. (2013), the hope was to create incentives for more eco-friendly designs of packaging and products while “leveraging private sector expertise to achieve public goals, internalizing the costs of waste management into product prices, and shifting the financial burden of waste management from municipalities and taxpayers to firms and consumers” (p. 162). The intent of these incentives was to create products that are design for product recovery (DfR), designed and built from the start for ease of disassembly and recyclability (Atasu & Subramanian, 2012, p. 1043).

Wherever attempted, EPR policies have had four principle goals (OECD, 2001, p. 29):

1. Source reduction—natural resource conservation and material conservation
2. Waste prevention and reduction
3. Design of more environmentally compatible products
4. Closure of material loops to promote sustainable development

When pursued, EPR polices have used four approaches, as shown below in Table 1 which includes examples (Khetriwal et al., 2009, p. 155; OECD, 2001, p. 29):

Table 1

EPR Approaches

EPR Approach	Examples of Types of Approach	Examples of EPR
Product take-back	Mandatory programs	Packaging—German law, German Packaging Act 2019 (https://verpackungsgesetz-info.de/en/)
Regulatory approaches	Minimum product standards	Plastic containers—California state law, Assembly Bill #341 (http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201120120AB341)
	Disposal bans	Electrical & electronic equipment (EEE) disposal—Switzerland law, VREG 814.620 (https://www.admin.ch/opc/de/classified-compilation/19980114/index.html)
Voluntary industry practices	Voluntary codes of practice	Packaging—German industrial association, Arbeitsgemeinschaft Verpackung und Umwelt (AGVU) (http://www.agvu.de/en/)
	“Servicizing” or Product-Service System (PSS)	Photocopiers & printing services—industry example, Xerox (https://www.office.xerox.com)
Economic instruments	Deposit/refund schemes	Beverage containers—California Public Resources Code 14501-14599 (http://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=PRC&sectionNum=14501)
	Advance recycling fees	Participation in a Producer Responsibility Organization (PRO)—Swiss Foundation for Waste Management (https://www.erecycling.ch/en/)

Managing Reverse Logistics

Clearly, RL can allow firms to reduce costs, gain greater profits, encourage more customer satisfaction, and benefit the environment. Returned products either go back into inventory for resale, or broken down into constituent parts for remanufacture, recycling, or disposal. All these steps can reduce costs, increase profits, reduce environmental impacts, minimize liabilities, and create a greater bond with customers. For this to happen effectively, there needs to be clear resource commitments to RL. These commitments not only support activities at the end of a product's lifecycle but must also be pushed up the product lifecycle to the very beginning of a product's life (Hsu et al., 2016, p. 95).

According to Ghosh & Fedorowicz (2008), supply chain governance structures (SCGS) enable a company to create and sustain value through the operational performance of delivering products to a customer at a minimum cost and on time (p. 453). For Aitken & Harrison (2013), RL governance structures enable the reverse flow of product as well as any information related to the return of product (p. 745). For companies to take advantage of RL for competitive advantage, recapturing value, fostering better CRM, or meeting environmental demands, they must invest in the development of effective governance or management RL systems.

Effective RL management systems are dependent on three variables: the complexity of transactions, the codifiability of transactions, and the capabilities of the RL supplier or member (Aitken & Harrison, 2013, pp. 746-747). RL transactions are complex in that returned products are not all alike, the demand for returned products varies, and the information and knowledge necessary to support the actual RL transaction is high. Effective RL transactions or operations require codification and standardization to reduce risk. Standardized, industry endorsed part codes allow for the reduction of risk by creating a codified or common language for

understanding how to recover parts (Aitken & Harrison, 2013, p.755). To share this common language, the original producers of products need to share information with RL supply chain members. A company whose products are involved in a RL cycle needs to ensure the same levels of service of a forward logistics process as when managing a complicated return transaction, and to do this it needs to create or leverage collaborative systems. Developing informational and technological shared capabilities enables the simplification of RL transactions (p.758-759).

Retailers, as a supplier or member of an RL cycle, face some of the most challenging of RL management issues. For many retailers, an effective product return process is a competitive advantage and essential to retaining customers. However, managing returns is a costly process for retailers and, without effective RL capabilities, unsustainable. Jack et al. (2010) find there are four antecedents or precursory factors that affect the development of sustainable and cost effective RL capabilities:

1. High levels of resource commitment in information technology and the technical human resources that go with it are crucial to developing sustainable and cost effective RL capabilities (pp.232, 240).
2. Partnerships in the RL process with well-defined contractual obligations are also crucial to developing sustainable and cost effective RL capabilities (pp.233, 240).
3. Although essential for retailers to retain customers, customers are opportunists who will show a willingness to fully exploit product return policies. Retailers consider returns as a cost of doing business, but customer opportunism can have a negative effect on sustainable and cost effective RL capabilities (pp.232, 240).

4. Since retailers cannot escape the need of accepting returns, they must develop internal processes to effectively implement and manage RL processes (pp.233, 240).

Managing RL clearly requires dedicated resource commitments towards governance structures to manage the complexity of return transactions as well as the volume and variability of returns. Additionally, a good portion of RL management is sorting and processing product returns that are either in a good state or bad state. Put simply, the demands associated with sorting good from bad is one of the principle concerns of RL. As De Brito & Dekker (2003) point out, products in good condition “can be put again in inventory after a short period of inspection, sorting, possible testing and repackaging” (p. 226). This is typical of many retail or e-commerce returns. By contrast, products returned to their point of origin, whether it be the retailer or the OEM, in bad condition or that are obsolete usually end up sold to another market for remanufacture, component material recycle, or disposal (De Brito & Dekker 2003, p. 226).

Reverse Logistics Network Design & Elements

Network design is crucially important for an effective RL regime. John et al. (2018) provides a general RL network structure, as shown in Figure 2 (p. 315). Network design involves the selection of the number and location of RL processing centers. In general terms, these facilities can serve as centers for collection, dismantlement, remanufacturing, repair, or recycling. The networking of these centers presents problems of material flow and of cost and create an added burden to an existing supply chain management system (John et al., 2018, p. 312).

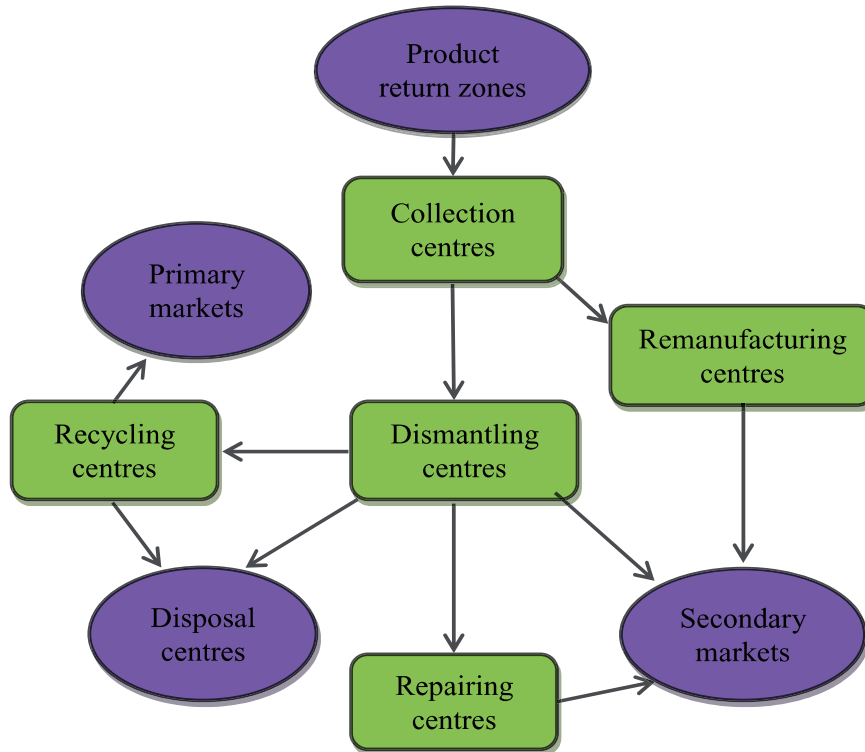


Figure 2. Generic Reverse Logistics Network Design (John, Sridharan, Kumar, & Krishnamoorthy, 2018, p. 315).

The RL network cycle begins with return zones, examples of which are retail location drop boxes or municipal waste collection sites. The products at the return zones eventually end up at collection centers where the products are classified as either having a high remaining useful life (RUL), reached a point of initial end-of-use (EOU), or having a low RUL, essentially reached an end-of-life (EOL) state. Products that have a high RUL can be refurbished or remanufactured and sold again on a secondary market as essentially a new product. Such products typically go to remanufacturing centers. Products with a low RUL cannot be remanufactured and are broken down into constituent components and materials. Individual components and materials can either be repaired or refurbished and used in new products, or they can be recycled or simply disposed of (John et al., 2018, p. 314).

The complexity of the RL network cycle grows as the particulars of product recovery and the management of returned inventory are examined. Sasikumar and Kannan (2008) review in detail the product recovery and inventory management processes of RL and some of the challenges facing those processes. Figure 3 below is another conceptualization of a network cycle or framework for RL supply chain movements, specifically, in this case, for the management of an EOL product. The framework helps conceptualize each step of product recovery in a RL network and suggests areas where inventory management challenges can occur at each step (Sasikumar & Kannan, 2008, p. 155).

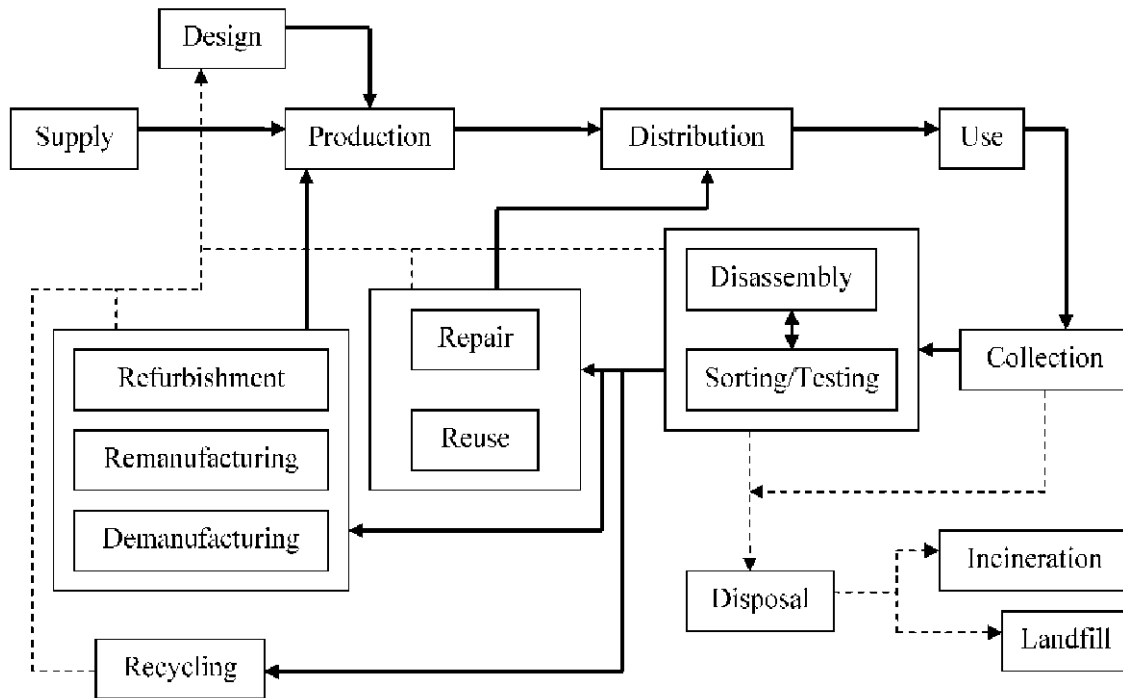


Figure 3. A Reverse Logistics Supply Chain Network for End-of-Life Product (Sasikumar & Kannan, 2008, p. 155).

Sasikumar and Kannan (2008) define product recovery as “the set of activities designed to reclaim value from a product at the end of its useful life” (p. 157). Product recovery is necessary

for three reasons, one, because of government regulations, two, the market or customer expectations requires it, and three, there is hidden economic value to be had from the recovered product. Product recovery comes in four forms (Sasiumar & Kannan, 2008, pp. 157-159):

- Repair—when products that have failed or been damaged while in use are returned and brought back into working order. These repaired products are either returned to the original users or returned to a refurbished inventory to be sold as pre-owned products (p. 159).
- Direct Reuse—the recovered products can simply be cleaned and reintroduced to a usable inventory. Examples of reuse products are reusable containers like bottles or shipping containers (Sasiumar & Kannan, 2008, p. 157).
- Remanufacturing/Refurbishment/Demanufacturing—when products are dismantled for their constituent parts which are then used to manufacture the same products or different products. The intent of remanufacturing is to bring a product back into a nearly new condition through any necessary disassembly and overhaul, or by supplying parts for other products being refurbished. Remanufacturing can occur alongside the production of newly manufactured products. Examples of remanufactured products include automobiles, electronic and electrical products, and tires (Sasiumar & Kannan, 2008, pp. 158-159).
- Recycling—when the constituent materials making up products are recovered and converted back into a raw material. Examples of recycled products are metals, plastics, and wood pulp products like paper (Sasiumar & Kannan, 2008, pp. 157-158).

For any of these product recovery activities there are three issues that the RL network will need to address, namely the collection of returned products, sorting and testing the products, and disassembly. Collection begins the product recovery process. It involves the collection or acquisition of products and transporting them to a location for sorting and processing. A customer's site, a retail location, or another drop-off location (recycle bins, hazardous material drop-off sites, etc.) serve as a collection point. A deposit-refund system, like that used to promote the return of such items as bottles or car batteries, can influence the quantity, timing, and the quality of collection (Sasiumar & Kannan, 2008, p. 160).

Sorting and testing, sometimes referred to as the "grading" of recovered product, follows collection (Aydin et al. p. 4403). Grading allows for the determination of whether or not a product is reusable and to what extent. This process of grading, of inspecting and separating, can involve specialized functional testing of a product, disassembly, shredding or demolishing, and storage. Disassembly is a systematic process of breaking a product down into its constituent components. The grading and disassembly processes can require significant scheduling and allocation of resources as well as facilities to support the processes. Supporting bills of materials (BOMs) are also necessary for grading the constituent parts as well as understanding how to disassemble a product (Sasiumar & Kannan, 2008, p. 160-161).

The disassembly of a product generates a variety of components that can either be directly reusable, are faulty, or consist of recyclable or disposable items. Repaired and directly reusable products and components go into secondary markets, and recycled component material go to primary markets as raw materials for new products. Disposable products/components are no longer usable and are therefore either non-recyclable or are hazardous. Depending on the

nature of the disposed product, it is either sent to a landfill or to an incinerator (John et al., 2018, p. 314).

RL allows a firm to manage the fabrication of new products using not only a new component inventory to produce products but also leverage the use of overhauled or recycled components to support the production. Firms need to be able to manage the inventories of externally source components, “new” components, but also must be able to support the inventory management of internally sourced components, components recovered from the RL loop of the closed-loop supply chain (CLSC). As Sasiumar & Kannan (2008) put it, “the objective of inventory management is to control external component orders and the internal component recovery process to guarantee a required service level and to minimize fixed and variable costs (p. 162).

Reverse Logistics Network Optimization

The key to managing all of these recovery processes is, according to John et al. (2018) “to decide the location and the quantum of flow of products/components between pairs of facilities so as to maximize the revenues and minimize the total cost of setting up the facilities and other costs such as collection, processing, disposal, and transportation” (p. 314). Yu & Solvang (2018) note that network planning for RL involves strategically important decisions on the number and locations of processing facilities, identification of modes of transport, and the establishment of distribution channels for both EOL and EOU products (p. 286). When considering the RL supply chain design for the EOL product in Figure 3 the complexity of an RL networks is evident. There are three reasons for this complexity. First, RL involves a wide range of activities, from collection, transport, disassembly, repair, distribution, remanufacturing, and recycling. Second, within those RL activities are many uncertainties in terms of what

quantity of product a return cycle will generate and the quality of the products returned. These uncertainties are compounded by market fluctuations in the potential price of recovered products. Finally, remanufacturing facilities are typically handling a heterogeneous collection of products, which creates trade-offs between efficiency and flexibility. With these trade-offs comes variation in cost (Yu & Solvang, 2018, p. 286).

To manage these complexities the literature on RL points to solutions in a variety of mathematical optimization models. In general, the objective of optimization models is to minimize the total cost of a RL system—the sum of taking back products, the collection and transportation of them, any remanufacturing, recycling or disposing of them, and any inventory costs associated with holding the products for any given time (Aydin et al. p. 4403). Yu & Solvang (2018) review recent research into optimization for RL networks and concluded there are principally three models for optimization (pp. 289-291):

- Mixed integer modelling is a decision-making technique for determining the location of RL processing facilities (collection, remanufacturing, recycling, etc.) and the allocation of products to those facilities. In this model there are two decision variables. The first is the binary integer variable, which provides a yes or no decision to a candidate location for a facility, and the second is the continuous variable, which provides decisions for facility operations and transportation strategy.
- Multi-objective modelling is a decision-making technique for analyzing trade-offs between multiple objectives. With several objectives in conflict with each other this technique will balance the trade-offs between them.

- Two-stage stochastic modelling is a decision-making technique that controls uncertainty across a two stage decision. In the first stage a decision is made after which, in the second stage, a random or uncertain event occurs that impacts the first stage. A first stage decision might be the choice of location for a remanufacturing facility, a decision with long-term impact of an RL network, and the second stage decision might be uncertainty in the quantity of product collected for remanufacturing. A two-stage stochastic model helps in deciding where to locate a remanufacturing facility and the second stage account for may be designed to accommodate an optimal value of product to remanufacture.

Reverse Logistics in Practice

What follows is an examination of academic work surrounding two industries and their RL in practices. First examined are the RL practices of electrical and electronic equipment OEMs and regulatory requirements. With e-waste a growing problem, the Europeans are putting significant restrictions on it and requiring OEMs to reclaim it. but RL provides avenues for dealing with it. Similarly, the automotive industry also faces significant regulatory drivers for RL and CLSCs. Although the automotive industry claims to have had a long-standing remanufacturing industry and accompanying RL, the environmental concerns of waste are driving further expansion of remanufacturing and other reclamation processes.

Waste Electrical and Electronic Equipment (WEEE)

As the use of electronic products has expanded over the years, the need to manage e-waste has become increasingly important. E-waste or waste electrical and electronic equipment (WEEE) is any electrically powered appliance or device that has reached its EOL. This can include 'white' goods, typically large domestic appliances like refrigerators and washing

machines, or 'brown' goods, typically goods like computers, cell phones or household audio-visual equipment (Khetriwal et al., 2009, p. 154). To manage WEEE many governments have enacted EPR take-back laws, most notably in Europe. The European Union (EU) initially established take-back regulations for e-waste with "WEEE Directive 2002/96/EC".

Article 4 of the WEEE Directive 2002/96/EC highlights the rationale behind ERP policies: "Member States shall encourage the design and production of electrical and electronic equipment which take into account and facilitate dismantling and recovery, in particular the reuse and recycling of WEEE, their components and materials" (European Community, 2003, p. 27). The subsequent amendment to this directive, "Directive 2012/19/EU", maintains the original intent of 2002. WEEE Directive 2002/96/EC seeks to prevent WEEE generation in the first place. It seeks to supplant disposal with reuse, recycling, and the recovery (Ylä-Mella et al., 2014, p. 2). In addition to trying to compel industry to reduce and even eliminate waste, the regulation also makes manufacturers of electrical & electronic equipment (EEE) jointly responsible for the recovery and recycling of future products after 2002. The so-called collective producer responsibility (CPR) implementation of the WEEE directive requires manufacturers to be collectively responsible for collection and recycling as well as share in the associated costs of such a recovery regime.

Finland provides a good example of how a WEEE recovery system works in the EU. The majority of EEE products sold in Finland are imported and, therefore, producers have transferred their CPR to a set of five producer responsibility organizations or PROs that organize the collection and processing of WEEE (Ylä-Mella et al., 2014, p. 6). Figure 4 below illustrates the principle stages of Finland's RL supply chain (Ylä-Mella et al., 2014, p. 7):

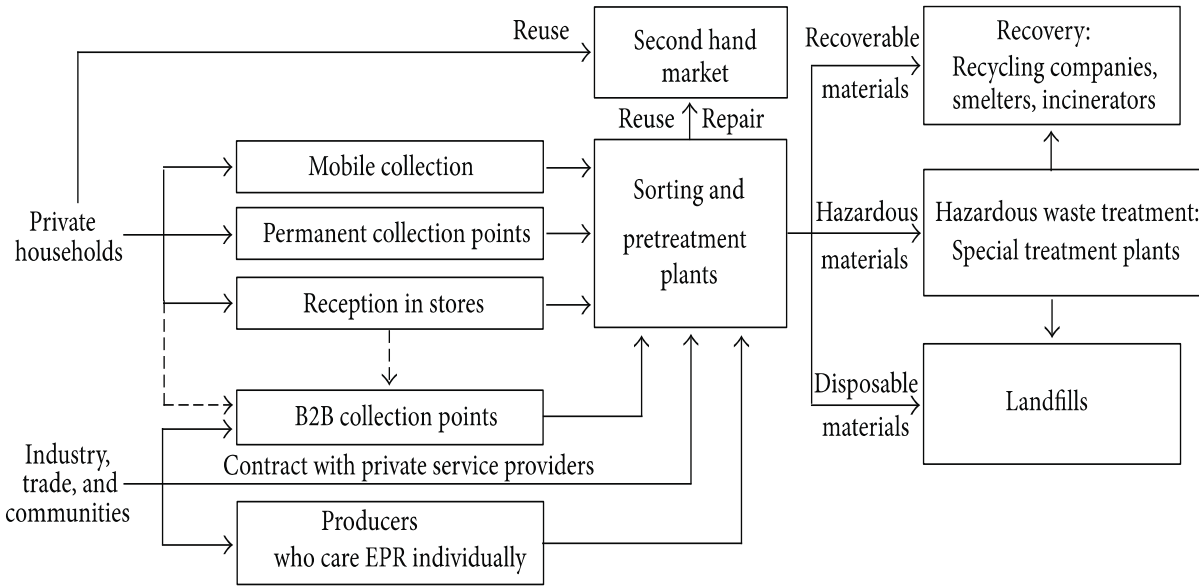


Figure 4. The Principle Stages of Finland’s Reverse Logistics Supply Chain (Ylä-Mella et al., 2014, p. 7).

Collection and transportation are usually the most expensive steps in any product recovery regime and WEEE recovery is no exception. Finland orchestrates collection in three ways: through municipal programs, through in-store retailer take-back, and through take-back organized by PROs. The methods of collection in Finland include drop-off programs, as is the case with retail in-store and municipal drop-off points, pick-up programs, performed by municipal waste management or contractors working for PROs, and distance collection through postal service facilitated by PROs or government. The collection of EOL consumer products is free of charge for both private individuals and businesses. PROs and individual EEE producers use business-to-business (B2B) collection points and contracted collection to handle physically large WEEE and bulk quantities (Ylä-Mella et al., 2014, p. 7).

From points of collection, PROs use contract transport to deliver the WEEE to sorting and pre-treatment plants. These plants sort WEEE by hand into distinct product lines, each sorted line is then weighed, and then each line gets sorted again for EOU and EOL

conditionality. A secondary market receives appropriate EOU products and EOL products go on for pre-treatment. Pre-treatment begins with the manual disassembly of any WEEE containing hazardous materials like lead, mercury, cadmium, or chlorofluorocarbons. Such WEEE are typically things like LCD monitors, batteries, or printed circuit boards. With hazardous materials removed, treatment typically continues with mechanical crushing and sifting of WEEE into metal, glass, and plastic constituent parts. Smelters receive metals and glass for recycling, currently incinerators create energy from plastics, and hazardous waste goes through appropriate special treatment. Finally, a landfill receives treated waste and any non-recyclable materials (Ylä-Mella et al., 2014, p. 8).

Before the EU had established an ERP initiative for WEEE with its Directive 2002/96/EC, Switzerland in 1998 had introduced an ordinance for “The Return, the Taking Back and the Disposal of Electrical and Electronic Equipment (ORDEE)”. Even before the enactment of this ordinance, Switzerland already had voluntary industry initiatives to set up PROs that would manage WEEE. The two combined, both legislative and industry initiatives, has created a CPR-based EPR system that has remarkably well-defined roles and responsibilities for all the actors involved (Khetriwal et al., 2009, pp. 155-156). Table 2 below outlines those responsibilities (actual ORDEE mandates shown in italics) (taken from Khetriwal et al., 2009, p. 156):

Table 2

Actors/Stakeholders and Responsibilities for WEEE Management in Switzerland

Actor	Roles and Responsibilities
Government	The federal government plays the role of an overseer, framing the basic guidelines and legislation. Cantonal authorities play a part in the overall control and monitoring in their capacity as the licensing authority for recyclers.
Manufacturers/Importers PROs	Importers carry the economic and physical responsibilities of their products. <i>Have the role of managing the day-to-day operations of the system, including setting the recycling fees, as well as licensing and auditing recyclers.</i>
Distributors & Retailers	Bear a part of the physical and informational responsibilities of the product. Are obligated to take back products in categories they have on sale, irrespective of where the product was sold by them, or whether the consumer purchases a similar product as replacement. <i>Are responsible for clearly mentioning the amount of the ARF in the consumer invoice.</i>
Consumers	Are responsible, and obligated by law, to return discarded appliances to retailers or designated collection points. <i>Bear the final financial responsibility through the recycling fee on new product purchases.</i>
Collection Points	<i>Collect all kinds of WEEE free of charge and ensure the safety of the disposal products to prevent pilferage or illegal exports.</i>
Recyclers	Must adhere to minimum standards on emissions and take adequate safety measures concerning employee health. Need authorization to operate a recycling facility from the cantonal government, <i>as well as a license from the PROs.</i>

The Swiss experience with WEEE EPR policy and the RL involved in facilitating it seems to reflect the worldwide experience with such policies. Notably is the Swiss experience with the CPR portion of ERP policy. To share costs mutually, Switzerland's PROs all buy into a CPR logistics regime, a system where take-back does not differentiate between different brands of a product type. The cost sharing is based on a manufacturer's sales volume, but some

manufacturers see the CPR regime as creating free-riding opportunities where some manufacturers are contributing more to the reduction of product recovery costs than competing producers. Without individual producer responsibility (IPR) the idea is that there are no incentives for design for product recovery (DfR), the primary intent of the EU WEEE Directive and all other e-waste ERP policies. From the perspective of some producers, CPR regimes “force an unfair sharing of product recovery costs among competing manufacturers and do not reward product designs that facilitate product recovery, thus diminishing the incentives” for DfR (Atasu & Subramanian, 2012, p. 1043). An IPR recovery regime would require that each manufacturer be responsible for recovering its own products and, therefore, more incentivized to design products for recovery.

However, in the case of Switzerland the collective route has two important advantages. First, since Switzerland is a small country there are economies of scale, its more efficient logistically and more cost effective to have a collective system. Second, and most important of all, a collective system allows consumers to only have to go to one place to drop off their WEEE rather than have to search out collection points for distinct brands. According to Khatriwal et al. (2009), “consumers tend to think in terms of types of waste—of small electronic goods or large household appliances—and not in terms of brands when disposing old equipment” (p. 160).

In their study of individual and collective producer responsibility, Atasu & Subramanian (2012) found that CPR policies do indeed lower the incentives for producers to design for recovery, that CPR creates free-riders who are subsidized by those manufacturers that contribute more to the reduction in average recovery costs (p. 1047). Those producers that have higher incentives for DfR, typically those with the largest market share in a product type and consequently larger waste volume, will drive down the average recovery cost. The

manufacturers with smaller market share can then minimize costs by limiting DfR choices and as a result produce a cheaper more competitive product. This free riding then undermines the competitive equilibrium with consumers taking advantage of lower prices. As a result, market share eventually shifts to the OEM producing the product that has fewer DfR improvements. The end result is the non-recoverable elements of a product type will increase as the market share shifts between manufacturers. For Atasu & Subramanian (2012), it's clear from their analysis that IPR achieves the greatest product recovery cost reduction because the actual cost of recovery forces OEM to make superior DfR choices (Atasu & Subramanian, 2012, p. 1053). However, the practicality of CPR policies trumps the optimal choice of IPR. As in the case of Finland and Switzerland, a collective regime has operational cost-efficiencies.

The take-back of power tools in Germany provides a specific example of WEEE management as well as the pitfalls and potential of a reverse supply chain. Starting in 1993, acting in response to the drafting of legislation at the time, domestic and foreign power tool manufacturers selling in Germany agreed to develop a voluntary take-back initiative (p. 157). The reuse of certain power tool components, like electric motor parts, is appealing because of an inherent absence of any real technological obsolescence. But Klausner & Hendrickson (2000) found that costs associated with product take-back do not necessarily make remanufacturing of components or even the recycling of component materials a profitable initiative. They concluded that a market for remanufactured power tools requires a high take-back rate of used tools to be competitive. (p. 158).

According to Klausner & Hendrickson (2000), even simply reclaiming and recycling plastic and metal materials from power tools results in a net loss per tool after factoring in the logistical cost of recovering the product and the cost of processing the materials (p. 157).

Furthermore, they found that a facility specializing in power tool reclamation and remanufacturing requires a continuous flow of EOL product to be profitable (p. 158). To achieve a continuous flow of EOL power tools, Klausner & Hendrickson (2000) conclude that a carefully managed and budgeted buy-back program is necessary. They also suggest newly produced power tools have an Electronic Data Log (EDL) installed to track use so as to estimate the degradation of components and therefore their viability for re-manufacturability (p. 160). An EDL enables the remanufacturer to understand the remaining useful life (RUL) of a power tool motor and as such helps in defining a product's residual value (PRV).

Automotive Industry

According to the International Organization of Motor Vehicle Manufacturers (OICA), between 2005 and 2018 commercial and passenger vehicle sales grew by 44% (OICA, 2019, http://www.oica.net/wp-content/uploads/total_sales_2018.xlsx). Increasingly, this has prompted nearly all the major automotive markets to look at how to manage end-of-life vehicles or ELVs. The EU has required all vehicle bodies built since 2002 to be recycled at EOL (Kumar & Yamaoka, 2007, p. 115). According to the Automotive Parts Remanufacturers Association (APRA), automotive remanufacturing in the U.S. saved 8.2 million gallons of crude oil from steel manufacturing, 51,500 tons of mined iron ore, and 6,000 tons of mined copper and other metals (APRA, 2019, <https://apra.org/page/Remanufacturing>). And by 2020 China expects to scrap 14 million cars a year but doing so without the kind of remanufacturing or recycling implementation that Europe and the U.S. has thus far achieved (Zhou et al., 2018, p. 808). Clearly, there are economic and potentially significant environmental advantages to be had from vehicle remanufacturing and recycling.

Automotive RL, like any other reverse supply chain, consists of product collection activities and transportation of recovered product to a processing center. The supply chain consists of a set of intermediaries involved in moving used products from a customer or end-user through to a remanufacturer or some other processor. The intermediary organizations can be car dealerships, auto repair shops, core/component suppliers, and scrap yards. Like other industries using RL, it's crucial to limit uncertainties in quantity, quality and the timing of what Sundin & Dunback (2013) call "core acquisition" (p. 3). A remanufacturer may work with a wide variety of core suppliers, each having its own requirements for core acquisition. In order to limit uncertainties in supply and control costs, the methods of acquisition used by disparate suppliers require homogenization wherever possible. In the case of a remanufacturer, the firm may want to limit core acquisition to one method. Sundin & Dunback (2013) provide five methods of core acquisition (pp. 3-4):

- Direct-Order: acquisition for complex products like engines and transmissions the supplier/customer, in most cases an actual end-user of the product, sends the used product/core to the remanufacturer who then sends it back upon completing work.
- Reman-Contract: similar to Direct-Order but involving larger quantities over a much longer time-period and the supplier/customer is an OEM of the product.
- Deposit-Based: an acquisition/exchange scheme where the customer buys a remanufactured product, say brake calipers, and returns a similar used product/core to the remanufacturer.
- Credit-Based: an acquisition/exchange scheme where the customer returns a core and receives a credit or discount to purchase a remanufactured product.

- Buy-Back: an acquisition where the remanufacturer purchases the core from an end-user, core broker or scrap yard, or another supplier.

Much of the automotive industry has long utilized remanufactured parts, parts like engines, transmissions, brake components, and pumps. These parts or cores are collected for remanufacturing through an RL process. The collection of automotive core parts provides an example of the challenges of supply in RL—the lack of control over the quantity, quality, and timing of returns. Sundin & Dunback (2013) ascribe this lack of control over supply to three causes (p. 2):

- The uncertain lifespan of a product
- At what point a product is in its life cycle and the undermining of a product's life-cycle by technological change
- Stochastic or random product return patterns

These three issues affect an automotive remanufacturer's ability to maximize profits by either limiting the supply necessary to support demand or by creating inventory that exceeds demand. Research shows that most companies cannot adequately manage the uncertainties in the supply of returned automotive cores, that most companies do not even try to anticipate supply and demand and balance return inventories accordingly. In many cases, remanufacturing companies dispose of excess returned inventory due to the cost of maintaining the inventory. Uncertainties in quantity, quality and the timing of returns also affects the automotive remanufacturing process itself. Uncertainty in anticipating quantity makes production planning difficult, and uncertainty in quality means that returned products or cores will result in varied remanufactured yields (Sundin & Dunback, 2013, pp. 2-3).

Gonzalez-Torre et al. (2010) provides a good outline of the general barriers that all major automotive markets face in adopting remanufacturing and what she and her co-authors call environmentally oriented reverse logistics practices (EORLP) (p. 890). The barriers come in two groups: industry specific barriers and organizational barriers. Industry specific barriers begin with the high capital costs associated with adapting the technologies and programs necessary to facilitate RL. Returns from RL capital expenditures do not typically provide immediately apparent returns on investment (ROI), thus managers do not see such expenditures as immediately important. Uncertainty of the ROI has led to deficit investment in the necessary industry wide RL infrastructure. Small and medium size suppliers and remanufacturers make up the bulk of the automotive industry, and the lack of RL infrastructure creates barriers of entry for these companies. An emphasis on short-term ROI has also led organizations to not even consider the strategic advantages of RL. Culturally, organizations may not put much stock in environmentally sustainable practices, in investing in RL to promote the reduction, reuse, and recycling of automotive components (Gonzalez-Torre et al, 2010, pp. 890-892). In their study of Spanish automotive suppliers, Gonzalez-Torre et al. (2010) find that there is a consensus among firms that without efficient environmental regulations to provide necessary coercive pressure and collective industry wide action then creating a more CLSC will continue to encounter barriers (p. 901).

Even though the automotive industry extensively utilizes remanufactured parts, it still has a long way to go to create a more CLSC that will increase environmental benefits (Gonzalez-Torre et al, 2010, p. 890). China is particularly interested in fostering a more sustainable, CLSC that will enable the reduction, reuse, and recycling (3R) of materials used in its automotive industry, yet it faces significant barriers. The first such barrier is a nascent recycling system and

still relatively small remanufacturing industry. Another is a legal system that actually makes many remanufacturing activities illegal. Finally, like in many other large markets, consumers follow a consumption culture that promotes short-term and one-time use of products (Xiang & Ming, 2011, p. 682). Like the EU, with Directive 2000/53/EC, China is also beginning to embrace the idea of EPR policies to manage vehicle waste. However, those Chinese EPR policies, thus far promulgated, lack enforcement mechanisms or are not fully implemented (Zhou et al., 2018, p. 808).

Directive 2000/53/EC was formulated “with a view to the design of vehicles for recycling and recovery, to the requirements for collection and treatment facilities, and to the attainment of...targets for reuse, recycling and recovery, taking into account the principle of subsidiarity and the polluter-pays principle” (European Community, 2000, p. 34). Like most ERP policies, Directive 2000/53/EC makes the responsibility of recovering EOL products the OEM and it also sets general core and material recovery targets. Table 3 below summarizes the recovery/reuse targets that the directive calls for and the expected attainment date for those targets (Mansour & Zarei, 2008, p. 765; European Community, 2000, p. 38).

Table 3

Recovery/Reuse Targets Required by EU Directive 2000/53/EC

Vehicle Type	Attainment Date	Recovery/Reuse Target	Recycling/Reuse Target
All ELVs	January 1 st , 2006	85%	80%
ELVs produced prior to 1980	January 1 st , 2006	75%	70%
All ELVs	January 1 st , 2015	95%	85%

Clearly, the recovery/reuse targets set by Directive 2000/53/EC are not insubstantial and are undoubtedly placing significant burdens on automobile OEMs. Recovering the actual ELVs and then recovering core products/materials, the RL implications of the directive, each generate additional costs to producers. Recovery begins with the collection of ELVs from partners like dealerships and scrap yards with ELVs then delivered to suitable dismantlement and treatment facilities (Mansour & Zarei, 2008, p. 766). In Figure 5, Zarei et al. (2010) provides an outline of the network and relationships required to recover ELVs (Zarei et al., 2010, p. 5).

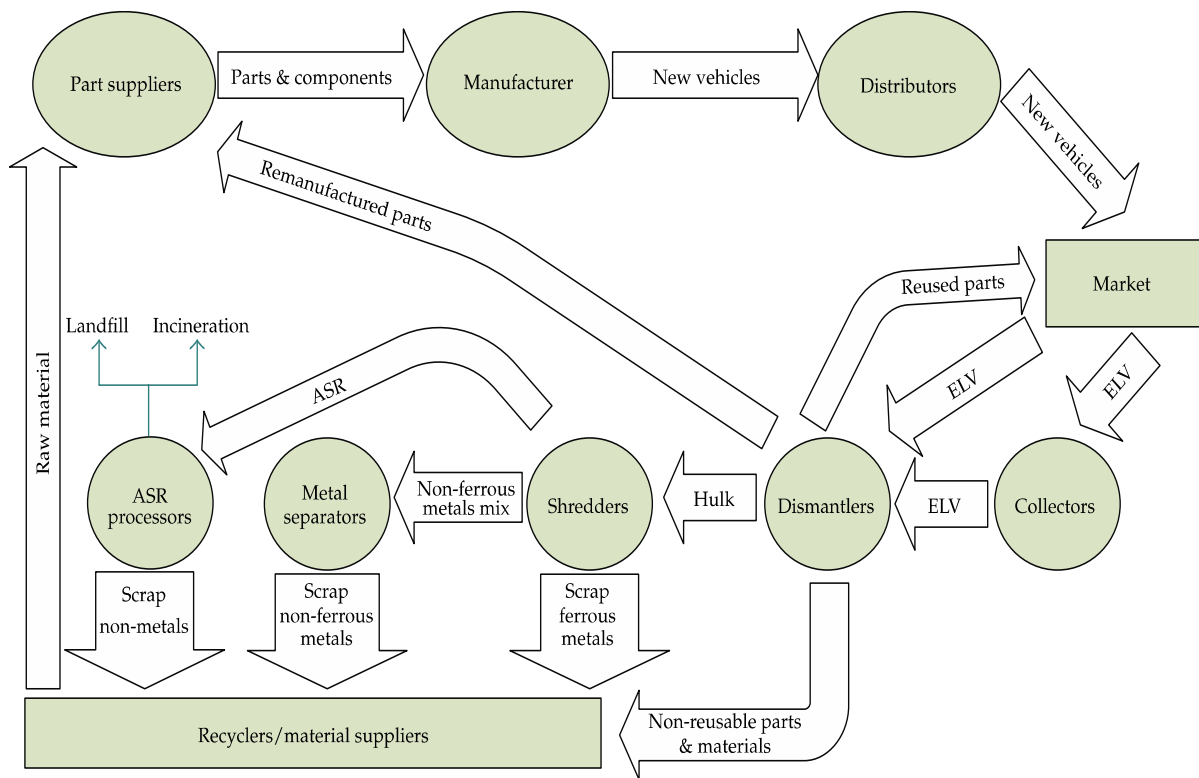


Figure 5. A Reverse Logistics Network for End of Life Vehicles (ELVs) (Zarei et al., 2010, p. 5).

Once collected and upon arrival at a dismantler, an ELV is stripped of its environmentally hazardous materials, such as batteries and fluids, and those cores that can be reused or remanufactured. With the removal of these items, the “hulk” left over goes to a

shredder for separation of ferrous and non-ferrous metals, as well as automobile shredder residues (ASR). A recycler then takes the ferrous metals and separated non-ferrous metals. ASRs or the non-metal portion of the hulk goes to a landfill or incinerator (Mansour & Zarei, 2008, p. 767). As with the management of WEEE, producers contract with PROs and other “authorized treatment facilities” (ATFs) to manage the free take-back and collection of ELVs, their dismantlement, and the logistics for delivering the hulk to separators and recyclers. Edwards et al. (2005) outline how in the United Kingdom (UK) the producers through ATFs do not have to manage the collection and dismantlement of ELVs, and do not pay for the associate RL costs. Rather, the ATFs managing the collection and dismantlement offset the associate costs through the sales of recyclable metals (p. 1214).

Summary & Conclusions

Although there are compelling reasons to take up RL practices for profit, customer relationship management, and environmental sustainability, many companies will still be reluctant or find it challenging to build a RL process. The challenges to building a RL process are significant and the resource commitments not insubstantial. However, there are compelling reasons for firms to build an RL process. RL offers a firm the ability to gain competitive advantage over competitors and allows for the recapture of value. It provides a mechanism for reducing product waste at the end of products lives and enables firms to establish social responsibility bona fides. And RL allows firms to build better relationships with their customers.

Managing RL is all about managing uncertainty, uncertainty in quantity, quality, and the timing of reclaiming products. RL supply chains must be optimized to manage a range of complex activities, from collection, transport, product disposition, remanufacturing, recycling, and disposal. In practice, government regulations drive the adoption of RL practices.

Regulations requires producers to be responsible for product EOL reclamation and disposal.

ERP regulations compel producers to design products to be more easily reclaimed and disposed of at EOL. The management of e-waste and ELVs are prime examples of ERP and RL practices.

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