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A framework for closed-loop supply chains of reusable articles

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Abstract

Reuse practices contribute to the environmental and economical sustainability of production and distribution systems. Surprisingly, reuse closed-loop supply chains (CLSC) have not been widely researched for the moment. In this paper, we explore the scientific literature on reuse and we propose a framework for reusable articles. This conceptual structure includes a typology integrating under the reusable articles term different categories of articles (transportation items, packaging materials, tools) and addresses the management issues that arise in reuse CLSC. We ground our results in a set of case studies developed in real industrial settings, which have also been contrasted with cases available in existing literature.

Key words: Reverse logistics, Returns Management, Closed-loop supply chains, Case studies

1 Introduction

1.1 Background

Reverse Logistics (RL) and its natural extension, Closed-Loop Supply Chains (CLSC), are still in their infancy as academic disciplines, especially when compared with the enormous amount of scientific literature focusing on the forward supply chain. The academic community has been able to determine

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the kind of activities that are generally carried out when dealing with reverse flows (Thierry *et al.* 1995; Fleischmann *et al.* 2000; Guide and van Wassenhove 2001) and has applied or developed a number of quantitative models in order to support decision-making in networks including product returns (Dekker *et al.* 2004). However, the terms "reverse logistics" or "closed-loop supply chains" include a wide variety of return flow types: production-related returns (rework), distribution returns (reusable articles), commercial returns, repair-related returns, end-of-use returns or end-of-life returns (taxonomies of return flows are proposed in Flapper *et al.* (2005) and also in Krikke *et al.* (2004)). This diversity in return flows entails different levels of complexity and management importance. Much research has focused in the last few years in areas such as inventory control with product returns, remanufacturing issues or commercial returns aspects. However, other areas have received much less attention, even if their contribution to achieving sustainable industrial systems is not to be neglected. One of these areas is constituted by what we call *reusable articles* [1], which include products such as pallets, crates, refillable bottles, cylinders or tools. Hence, in this paper we focus on *reuse* closed-loop supply chains, in contrast to other recovery options such as repair, remanufacturing or recycling.

1.2 Motivation

Design and management of reusable articles systems are likely to be more important in the near future, as a result of the growing concern on natural resources' depletion. We cannot rule out that in medium-term, industries which currently are choosing disposable packaging elements or single use instrumentation (recycle), can reorient their policy towards reuse. As the new sustainability paradigm gains momentum, the need of switching our use-and-dispose model (one-way economy) to a closed-loop economic model, where a packaging element or a durable article can have multiple lives, will become more and more evident.

However, from the academic point of view, reusable articles have not been widely researched (see section 2). On the other hand, from practitioners' point of view, management of closed-loop systems of reusable articles is not straightforward (see section 5). In our interaction with organizations dealing with reusable elements, managers have reported difficulties in orchestrating these logistics systems. These operational challenges are also remarked in existing

[1] The term reusable articles is proposed in this paper to integrate under a single expression different types of items that are frequent in the context of reuse. A definition of the "reusable articles" term and a typology is introduced in subsection 3.1.

literature, where several authors point out that managing reusable articles systems can become trickier than expected (McKerrow 1996; Twede and Clarke 2005). The identification of the management difficulties arising in reusable articles systems constitutes a first step in order to avoid that these troubles become a hindering factor to the adoption of reusable articles when confronted with single use articles, thus contributing to a more sustainable (from the economic and environmental point of view) production and distribution system.

1.3 Objectives and methodology

The aim of this paper is to provide a general and comprehensive framework for the management of CLSC of reusable articles. To achieve this aim our objectives are:

- To define the reusable articles term and to build a typology for them, identifying similarities and differences between the different categories. Combining several classes under the same concept enables us to extend results obtained for one type of reusable articles to the other categories. This typology is also a proposal of standard terminology in the reusable articles field.
- To identify the main challenges that managers face when operating a CLSC of reusable articles. These management issues constitute further research opportunities for academics in the operations management area, as possible solutions to them can be addressed either through quantitative models or qualitative approaches.

Our contribution seeks to develop new theory useful for the operations management academic community and for industrial practitioners. Our methodological choice for building new theory is basically inductive: our results are grounded (Glaser and Strauss 1967; Strauss and Corbin 1990; Glaser 1992) in conceptualization on the different case studies (Eisenhardt 1989) we have carried out in real industrial settings, the knowledge we have acquired through these different research projects and the contrast with existing literature. For validating the emerging theory we used a deductive approach, using empirical evidence also coming from our case studies, validation by managers we interacted with during our field work and contrasting again with existing literature. Hence, the paper is conceptual and empirically supported by case studies.

The remainder of the paper is organized as follows. In section 2, we analyze previous academic literature related with reusable articles (RA). In section 3, we propose a typology for RA: we sharpen our definition of RA, we present the three different types of RA we have identified and we make clear which are the similarities and differences among them. Next, in section 4, we provide the empirical evidence supporting our statements (case studies). In section 5, we present a framework addressing the management issues that arise in RA systems. Finally, we present our conclusions, contributions of the paper and further research directions in section 6.

2 Literature review

Scientific literature on the topic of reusable articles is quite scarce. Fleischmann *et al.* (2000) point out that the number of references on the topic is limited. According to Kärkkäinen *et al.* (2004), the scarcity of literature on the management practices of reusable articles, given their increased importance, is startling. Johansson and Hellström (2007) also remark that empirical research on reusable articles management is surprisingly scarce.

Besides, most of the previous scientific literature has just dealt with some particular subclasses of reusable articles, such as some types of packaging, focusing either on returnable transportation items, on refillable containers, on reusable cameras, etc. To our knowledge, none of the current academic publications considers simultaneously different classes of reusable articles. In addition, terminology in the field of reusable articles is not always consistent. We found a multiplicity of terms to designate similar concepts depending on the author(s). This lack of an agreed-upon wording is sometimes misleading.

Kroon and Vrijens (1995), McKerrow (1996) and Twede and Clarke (2005) focus on the *organizational design* of returnable containers systems. The first paper explores different network design alternatives and proposes a MILP plant location model for deciding where container depots should be located. McKerrow (1996) focuses on the benefits of standardized reusable packaging and presents different ways of organizing an equipment pool network. Twede and Clarke (2005) identify the supply chain relationships that favour the introduction of reusable packaging systems.

Some firms substitute disposable for reusable packaging elements in order to obtain a more sustainable supply chain (waste reduction), among other reasons. Thus, much academic research concerning reusable packaging has focused on assessing the costs and savings to be considered when evaluating a potential shift from one-way to reusable distribution items. Flapper (1996), Dubiel (1996), Rosenau *et al.* (1996), Mollenkopf *et al.* (2005) and, also, Twede and Clarke (2005), propose cost evaluation models for supporting this *choice between reusable or disposable* packaging systems.

Another group of previous contributions focuses on operational aspects of reusable packaging systems and primarily, on techniques for *forecasting future article returns*. This topic is central in Goh and Varaprasad (1986); Kelle and Silver (1989a&b) and Toktay *et al.* (2000). Returns forecasting is closely related with the *value of item-level tracking information*. The two latter papers also deal with this topic. Besides, Van Dalen *et al.* (2005), Johansson and Hellström (2007) and De Brito and Van der Laan (2009) also contribute in this line. Regarding production and distribution planning and control considering a closed-loop system of refillable bottles we only found Del Castillo and Cochran (1996).

Most of the papers we reviewed allude to the *operational problems* that typically arise in particular subclasses of reusable articles. Specifically, Duhaime *et al.* (2001), Rudi *et al.* (2000), Young *et al.* (2002) or Breen (2006), deal respectively with the management challenges of postal monotainers, reusable medical devices (wheelchairs), chemical railcars or a diverse variety of distribution items (pallets, totes, trays, kegs, trolleys, bins).

For a more extensive literature review on this topic, we refer the reader to the Appendix I of this working paper, where we provide for each of the references cited in this section the topics dealt with, the main contribution of the paper and the subclasses of reusable articles specifically considered. As a result of our literature review, we conclude that knowledge on CLSC of reusable articles is fragmented, scattered and terminology in the field needs to be standardized. The analyzed papers deal with particular types of reusable articles or particular problems or issues related with them. To our knowledge there is no existing paper considering together different types of reusable articles and identifying with a holistic approach the management issues arising in the context of reuse. This motivates a conceptual paper that provides an empirical analysis of real case studies in this area.

3 Reusable articles: structuring the field

3.1 Defining reusable articles

The term reusable articles (RA) refers to products that are used *multiple times* by *different users*. This definition implies that the use by each user is of relatively short duration (compared with article lifetime) and does not deteriorate the product. It also implicitly states that RA require a reconditioning process which should remain short and simple, in order to enable quick utilization by the next user. We define *reconditioning*, in line with Guide and Van Wassenhove (2002), as the necessary processes required to bring a used RA to a condition in which it can be safely reused again. Another feature essential to RA is the fact of having multiple different users: so, articles have to go back to a reconditioning facility where they are made available for the next user. RA are returned and reintroduced in a closed-loop system to be reused in multiple use cycles.

Reusable packaging is a natural example of RA, but is not the only class that can be included under this term. Other articles also exhibit the same characteristics, as will be explained in the following paragraphs. Then, we put forward the following typology for RA, which is depicted in Figure 1:

- returnable transportation items (RTI),
- returnable packaging materials (RPM),
- reusable products (RP).

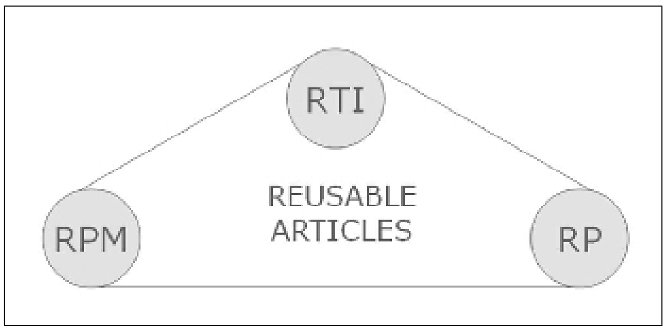

Fig. 1. Reusable Articles (RA): RTI, RPM and RP (own development).

The RTI acronym, coined by Johansson and Hellström (2007), is used in this paper to designate secondary and tertiary packaging materials (Stock 1992) which are used for assembling goods in material handling and transportation in the supply chain and then returned for further usage. RTI are not in direct contact with the product consumed by the end customer. Examples of RTIs include pallets, maritime containers (Crainic *et al.* 1993), railcars (Young *et al.* 2002), standardized vessels for fluids transportation, crates, totes, collapsible plastic boxes, trays (Duhaime *et al.* 2001), roll cages (Carrasco-Gallego and Ponce-Cueto 2009), barrels, trolleys, pallet collars, racks, lids, etc. Most RTI are used in B2B settings, although they can also appear in B2C contexts with elements such as supermarket trolleys, baggage trolleys in airports and train stations and wheeled bins arranged by local councils (Breen, 2006).

We use the RPM acronym, coined by Van Dalen *et al.* (2005), for denominating primary packaging materials designed to directly protect and hold the product that the end consumer really wants. Examples of RPM are refillable glass bottles for beverages (Goh and Varaprasad 1986; Del Castillo and Cochran 1996), gas cylinders (Kelle and Silver 1989a&b), kegs (Swinkels and Van Esch 1998), containers for chemicals, toner cartridges (Guide and Van Wassenhove 2003), single-use cameras (Toktay *et al.* 2000), medical equipment protection, windmill parts equipment protection or steel coils packaging (Rubio *et al.* 2009).

Finally, we use the reusable products (RP) term for a third category where products themselves are used multiple times. We refer, for instance, to sterilized surgery instruments, wheel chairs or other types of medical equipment lent by National Health Services to patients (Rudi *et al.* 2000), systems for borrowing of books, video tapes or sport equipment (Yuan and Cheung 1998) or the service tools (Vliegen and Van Houtum 2009) required to perform maintenance actions that are borrowed from a central unit. It is essential in the RP category to consider articles being utilized by different users. Rechargeable batteries, for instance, are excluded from this category because they are typically utilized by a single user. Batteries do not need to return to a reconditioning facility to make them available for the next user. It should be noted that reuse by different agents is related with the usage pattern of the article and not with the article itself. Consider for instance, books. Library books are included under the RP term while personal books are not, because they are not acquired with the intention of being reused by multiple different users.

The rationale for considering together these three types of items as reusable articles resides in the fact that the three categories share the same logistical characteristics (see subsection 3.2). Hence, the results obtained from the analysis of an individual class (RTI, RPM or RP) can be extended to all classes of reusable articles. This allows generalizing the results obtained in the RTI literature (which, although scarce, is the more abundant in the three types of reusable articles) to a wider number of situations in which reuse is involved. Our claim for generality also enables us to “learn” from other classes and transfer best practices developed for one particular category to the others. For instance, management models used for RTI can be extended to service tools or other types of RP.

When confronted with disposable articles, we find that reusable articles reduce purchase costs in the long run [2] and article disposal costs, if they exist. RA contribute to reduce firms’ ecological footprint through a reduction of the amount of waste they generate. On the other hand, RA add extra costs related with return transportation, reconditioning and management of the closed-loop of reusable articles. The latter cost element includes the administrative effort and the cost of acquiring the necessary information for effective management.

[2] Although the acquisition cost of one unit of a single-use article is usually lower than its reusable homologue, the cost per use is typically lower in the reusable version.

3.2 Characteristics of reusable articles networks

In this subsection, the objective is to identify and describe the features distinguishing reusable articles networks from other types of CLSC, such as rework, commercial returns, repairs and warranties, end-of-use returns or end-of-life returns. These features or contingency factors as they were coined by Woodward (1965) are summarized in Table 1.

Table 1. Features of reuse closed-loop supply chains

<table>
<tr><td colspan="2">(a)
New and reused products are treated as the same.</td><td colspan="2">(b)
Simple reconditioning activities.
Quick reintroduction in the forward supply chain</td><td colspan="2">(c)
The fraction of returned products is high.
(most demand is fulfilled with used products).</td></tr>
<tr><td colspan="3">(d)
Many units in circulation of low-medium unitary value each</td><td colspan="3">(e)
Main operational challenge: balancing demand and returns</td></tr>
</table>

(a) One of the main characteristics of RA when confronted with other types of CLSC is that users do not make a difference between brand new and reused articles. Both have the same cost for the end consumer and they provide the same functionality. New and used products are mixed in the logistic channel and serve the same markets.

(b) Simple reconditioning processes enable RA to be quickly reintroduced in the forward supply chain. This makes reuse CLSC different from other types of CLSCs, such as those involving repair, refurbishing or remanufacturing, which typically entail to some extent the disassembly of the used product. Reconditioning in reuse CLSC include activities such as inspection, testing, cleaning, minor repairs, filling, sterilization, etc. Reconditioning lead times are usually short (we do not include in this lead time the time articles spend in inventory waiting to be reconditioned or waiting to be shipped as new after reconditioning). Reconditioning does not entail a major cost compared with the acquisition cost of a new product (that is the rationale for reuse of many of these articles).

(c) When compared with other closed-loop flows, the volume of RA return flows is substantial. The fraction of returned articles is high, even if some articles would be lost or irreparably damaged in the logistic channel. However, quantifying exactly the percentage of reusable articles that effectively return is not straightforward, as will be explained in section 5. In general terms, it can be said that in CLSC of RA, most demand is fulfilled with previously used articles. The return percentage is usually above 80%.

(d) The number of units circulating in the system tends to be considerable, varying from large (RP) to very large (RTI, RPM). Hence, even when the unitary value of each article is limited, the complete fleet of RA should be considered assets, rather than expensed items. The relative inexpensiveness of each article sometimes leads to a lack of tight control over each unit.

(e) Despite the high return volumes, it is still a challenge in these systems to ensure equilibrium between demand and return rates. As some RA would have to be replaced due to leakages or permanent damages, even in the case of an even demand pattern, new articles have to be purchased from time to time. Even if the number of articles circulating in the CLSC is enough, it is still necessary to assure that the articles are returned and reconditioned at the right time in order to fulfil demand. Balancing demand and returns becomes even more complex when transhipments between depots are allowed, as articles need to be located in the right point of the supply chain in order to fulfil demand.

Next we present the characteristics of reusable articles return flow, which is depicted in Figure 2.

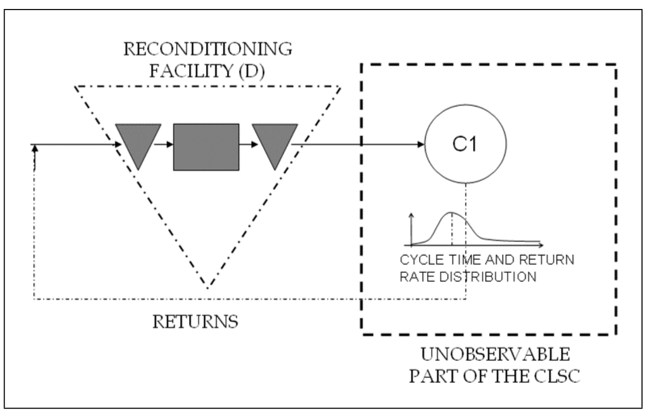

Fig. 2. Reusable articles CLSC: cycle time, return rate and unobservable part of the supply chain (own development).

RTI, RPM and RP have similar characteristics in their return flows. As in many other CLSC, the return flow features in reusable articles systems are conditioned by the past behaviour of sales (forward flow). RA are launched to the market and, after a certain unknown time they will return to the central facility to be reconditioned and, next, reused. This unknown time may be described by a statistical distribution, although a non-stationary description may be necessary. A number of RA will not return due to uncontrolled leakages (losses) or irreparable damage. Hence, the time from issue to return of each RA is a random variable with a distribution that includes a finite probability of never being returned (Kelle and Silver 1989a; Toktay *et al.* 2000).

In this paper, we use the term *cycle time* to designate this random variable. The same variable has been referred to in literature with different names such as turnaround time or trip duration (Goh and Varaprasad 1986), return delay (Toktay *et al.* 2000) sojourn time (Fleischmann *et al.* 2002), time until return (De Brito and Dekker 2003), lead time (Kiesmüller and Van der Laan 2001) or circulation time (Van Dalen *et al.* 2005). The probability of a sale yielding a return is the *return rate*. Note also that there is a part of the supply chain, when RA are at "customer-use" stage, which is unobservable for the organization in charge of RA reconditioning. During this phase, the central organization loses control over their assets. The return rates of RTI, RPM and RP are remarkably high when compared with other types of CLSC, such as remanufacturing or commercial returns. It can be said that return rates in the context of reuse tends to fluctuate between 80-99% (as most demand is fulfilled with used products). However, precise figures of return rates are usually not available, due to lack of visibility over the unobservable part of the supply chain.

3.3 Differences between RTI, RPM and RP

Although RTI, RPM and RP share many logistical characteristics, there are also differences between them that led us to establish three different categories. In this subsection we will point out these differences in order to establish boundaries for the generalization of results between categories.

The main difference between RTI (secondary and tertiary packaging) and RPM (primary packaging) is that the latter are in direct contact with the product the end customer really wants. As a result, while RTI tend to be standardized, RPM are less. Many well-known operational benefits can be derived from standard material handling units: more efficient cube utilization, enabler for material handling automation (unique dimensions for material handling equipment), potential productivity improvements in handling operations, enhanced product protection, etc. The direct contact of the RPM element and the "real" product makes it more difficult to achieve the standardization of RPM, mainly because of marketing or technical reasons. For instance, beverage manufacturers maintain different glass bottles for different brands: bottles constitute a means to differentiate each brand product from its competitors and are a very important marketing element. Industrial gas cylinder connections are gas-specific (for security reasons) and sometimes even installation-specific (a given instrumentation requiring a special type of cylinder). Packaging protecting products entailing special dimensions (medical equipment, windmill parts, steel coils) is difficult to standardize. These are examples of technical reasons hindering standardization of RPM. In addition, RPM's reconditioning tends to be more difficult than RTI's, because of the direct contact of the product. More thorough cleaning is usually required for RPM.

The main difference between RP (tools, instrumentation, etc.) and the two previous RA categories is that RTI or RPM are somehow a packaging holding the product that the end customer will consume (gas, ink, photo film, ...) while in this latter category what is reused is the product itself. RP are rarely standardized and their reconditioning operations complexity varies from very simple activities (e.g. library books) to more somewhat complex actions (e.g. sterile surgery instruments).

Standardization (articles interchangeability) is a necessary condition for the management of RA in pool[3] systems. Hence, while RTI pools are relatively frequent, this organizational design is less common for RPM or RP.

3.4 Types of reusable articles networks: star systems vs. multi-depot systems

Depending on the configuration of the physical flows involved, logistics networks entailing reusable articles returns can be broadly classified in two categories: star systems and multi-depot systems. Figure 3 depicts the difference between the two network models. In star systems, RA return to the same plant or depot from where they were originally issued once they have been used. In multi-depot systems, it is not compulsory for RA to return to the issuing depot.

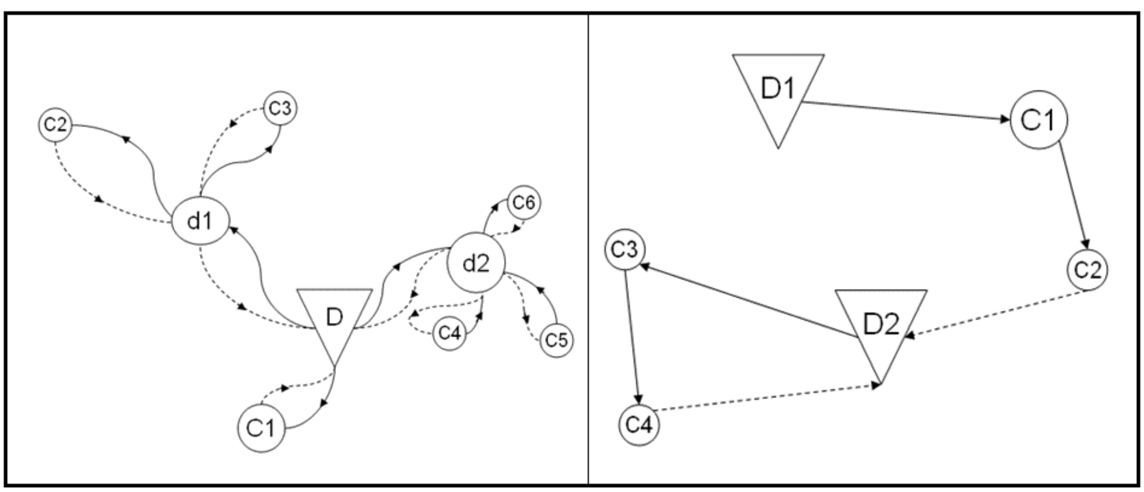

Fig. 3. Star network vs. multi-depot network (own development).

[3] In pool systems, a group of suppliers and/or customers agree to participate in an exchange program, where the same collection of interchangeable RTI -the pool- is used by them all. The pool can be jointly owned by the pool participants (i.e., Dutch flower auctions) or can be owned by an independent third party (i.e., Chep pallet pool).

In star systems, the central facility D can directly supply end customers (C1) or use intermediate distributors (d1, d2) that serve the end customers in a given region (C2 to C6). Even if the network comprises several tiers, RA always return to the same central facility D (the filling plant, the sterilization unit, etc.) where they receive specialized reconditioning operations (filling, sterilization, etc).

In multi-depot systems, RA can be utilized by different agents of the supply chain (C1, C2) before returning to a depot that can be different from the original sender. Only eventually will RA return to their original sender (D2). In the multi-depot network, all depots must be able to perform the reconditioning tasks necessary to bring RA into a usable condition again. Thus, the simpler the reconditioning activities, the more favoured is a multi-depot structure. This is usually the case of RTI, whose reconditioning tends to include only inspection, cleaning and minor repairs.

In literature, the difference between the two network models has been suggested but not clearly established. Kroon and Vrijens (1995) underscore the differences between transfer systems, depot systems and switch pool systems. Dubiel (1996) distinguishes between individual exchanges, multilateral exchanges and pool systems. Twede and Clarke (2005) use the terms closed-loop applications and supply chain system-wide applications.

4 Empirical evidence: case studies

The statements presented in section 3 are supported by a set of ten case studies. Six of them have been developed by the authors in real industrial settings. An extensive description for each of them is provided in Appendix II of this working paper. The other four cases are available in scientific literature. They were selected because they have been described extensively in previous papers. We check each feature discussed in subsection 3.2 ((a) new and reused products are treated as the same, (b) simple reconditioning, ...) within each case study. This analysis is summarized in Table 2.

Our first case study (MedGas) concerns the Spanish subsidiary of a multinational company that produces and distributes gases for the industrial and medical sectors, such as oxygen, nitrogen or carbon dioxide. More precisely, we interacted with the healthcare branch of the firm. For small consumption levels, gases are compressed and distributed by means of cylinders. Inside the cylinder, gas is compressed and packaging has to withstand pressures of around 200 bars, so cylinders are typically manufactured in steel or aluminium alloys. A standard 50 l cylinder has an estimated unitary cost of €100, making cylinder reuse the only economically viable option.

Table 2. Features of reuse CLSC. Contrast with case studies

	OWN CASE STUDIES						LITERATURE CASE STUDIES			
	MedGas	LPG	Erasmus MC	Service Tools	Shopping Carts	Flora Holland	Heineken	Arla Foods	IKEA	Automotive
New / used	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reconditioning	Inspect, clean, fill.	Inspect, clean, fill.	Sterilize, complete net.	Test, substitute consu-. mables	Clean	Clean	Inspect, clean, fill.	Clean	Clean, (dis) assembly.	Clean
Return Volume is High	+90%	+ 90%	+90%	+90%	+90%	+90%	+90%	+ 90% loss:10%	+90% loss:10%	+90% loss: 5%
Many units in circulation	20,000 units, €100 per unit.	30 million units, €20 per unit.	Millions of €in inventory, €100 per tool €10,000 per net.	Millions of €in inventory.	200-400 units, €174 per unit.	50,000 units, €500-600 per unit.	Total RPM: €550 m Crates: 3,57m, €3,5 per unit.	120,000 units, €120 per unit.	16,000 units, €250 per unit.	$16.7m-$35m in inventory, $100-600 per unit.
Type of nework	Star	Star	Star	Star	Star/MD	MD	Star	Star	Star	Star/MD
Balance demand and returns	X	X	X	X	X	X	X	X	X	X

Medical oxygen is distributed in the so-called compact cylinders. The company owns an estimated fleet of compact cylinders for this particular product of roughly 20,000 units (€2 million investment). When they return to oxygen filling plants, cylinders have to be checked in order to determine if they can be safely reused. If the hydraulic test [4] has expired for a particular cylinder, it is put aside in order to be taken to a special testing facility. If the cylinder is suitable for reuse, it enters an automated circuit where it is cleaned and refilled with oxygen. Physical flows in the medical oxygen supply chain are organized following a star model, as cylinders return to the originally issuing filling plant. Regarding losses, the company controls the number of cylinders that are scrapped due to their bad condition and these assets are retired from the account balance. Nevertheless, there is a lack of control over the cylinders that are lost in the unobservable part of the supply chain.

The second case study was developed within a Spanish oil company that delivers Liquified Petroleum Gases (LPG), mainly butane and propane, to households and industrial customers. The firm holds a fleet of 30 million LPG cylinders for supplying the Spanish market. Assuming a unitary price of €20 per cylinder, this represents a value of €600 million. Cylinders have a very long technical life, so much of the cylinder fleet financial value has been written down a long time ago. However, LPG in Spain is a declining market and management acknowledges that their cylinder fleet size is now overdimensioned for their current operational needs. Maintaining such a big fleet of cylinders has financial and economic consequences, not only in terms of space and handling, but also in terms of maintenance and opportunity costs (see complete case in Appendix II). Regarding losses, the firm just controls the cylinders scrapped due to their bad condition. They cannot control the losses happening in the unobservable part of the supply chain. Physical flows are organized around a star network: end customers are assigned to a particular distributor. Distributors are assigned to a particular filling plant. Therefore, cylinders return to the filling plant from where they were originally issued.

Our third case study concerns the central sterilization department (CSD) of Erasmus MC, an important clinical institution in the Netherlands. The hospital holds a stock of durable surgical instruments that are sent to sterilization to the CSD after each use. CSD management could not quantify exactly the amount invested in the total instrument inventory, but they established the magnitude order in millions of euros. Typical figures dealt with in the case were €100 per single instrument and €10,000 for a complete surgical net comprising around a hundred instruments. The reconditioning of surgical instrumentation involves checking the completeness of the net, replacing the missing

[4] A periodical test that cylinders pass every 2, 5 or 10 years in order to check if they can resist high working pressures (testing pressure is at least 1.5 times cylinder working pressure).

or defective instruments in case it is needed, and instruments sterilization in autoclaves. All sterilization operations in the hospital are done in the CSD, so the physical flows follow a star model necessarily.

The fourth case study is related with service tools used for maintenance purposes. Typically, Original Equipment Manufacturers (OEMs) hold local inventories of expensive service tools that are required for assuring customers' equipment maintenance in a given region. Service engineers borrow these tools from the warehouse when needed. After use, tools are taken back to the warehouse for further use. Before reintegrating the tools stock, instruments are checked and consumable parts (welding material, for instance) are replaced. Lateral transhipments between tool warehouses are allowed in case of emergency, but tools always return to the original issuing warehouse, so physical flows follow the star model. The amount invested in service tools inventories could not be exactly quantified but the firm participating in this case study estimated it in the millions of euros for each warehouse. The percentage of lost tools because of misplacement or irreparable damage is considered to be very low by OEM management.

Our fifth case study concerns the shopping carts of a retailer in the Netherlands. The trolley inventory for a typical medium-size retailing surface in this country varies between 200 and 400 units. The price of each cart fluctuates between €152 and €174. In small retail centres, where there is only one service point where customers retrieve and take back the carts, physical flows follow a star model. Big retailing surfaces typically have several service points (depots) and in that case, physical flows follow the multi-depot model: carts can be returned at any available depot. Management issues in this context include determining the required cart fleet size in order to provide the right service level even in intense-demand periods (weekends), preventing trolley losses (3 per cent of the fleet is lost or irreparably damaged annually) and rebalancing cart inventory between locations when the retailing surface has more than one trolley service point. Note that the term "fleet size" refers to the total number of RA in circulation in the system. It includes, for instance, RA stocked in the reconditioning facilities, RA stocked in other parts of the supply chain and also RA in transit.

In our last case study, we have analyzed the use of *stapelwagen* or metal carts in the cut flowers and plants supply chain within Flora Holland, a Dutch company in charge of flower auction houses in the Netherlands. Metal carts are used by all the agents of the floricultural supply chain (growers, auction houses, buyers) in order to reduce unnecessary product handling. Carts are property of Flora Holland and growers and buyers rent them for supplying/retrieving products to/from the auction house. Once they have been used, metal carts can return to any of the six auction houses that Flora Holland runs in the Netherlands. Carts just require very simple reconditioning operations (mainly cleaning) and are available to be reused very quickly. Physical flows follow a multi-depot model, so rebalancing carts inventory levels among auction houses is an issue in this case. The total inventory levels of carts are estimated by Flora Holland in roughly 50,000 units, with a unitary price of €500-600 per cart (involving an investment of around €30 million).

Our analysis also includes four relevant case studies described in the academic literature. We have selected case studies concerning four different industries utilizing reusable articles: a brewery (Van Dalen *et al.* 2005), a dairy producer (Johansson and Hellström 2007), a furniture retailer (Hellström 2009) and the automotive industry (Roseneau *et al.* 1996).

The Heineken case (Van Dalen *et al.* 2005) describes the closed-loop supply chain of reusable packaging used in a Heineken brewery, which includes RPM such as glass bottles, crates and kegs. The total replacement value of RPM (kegs, bottles, crates) within Heineken Europe is estimated at €550 million. The inventory of crates in one particular brewery is estimated at 3.57 million crates, each of them having a unitary cost of €3.5. In the case, a tracking experiment on crates is described, and authors conclude that return percentages on crates are very high, close to 100%. However, an exact return percentage for crates is not provided in the case. Periodically, a certain amount of crates, bottles and kegs are replaced because their image is no longer acceptable from the marketing point of view. In the case it is acknowledged that Heineken maintains large amounts of RPM in stock in order to avoid disruptions in the bottling processes. The firm's investments on new RPM have been traditionally based on experience and simple calculations. Physical flows in the analyzed brewery considered in the case are organized around a star network: all the crates labelled with that particular brand return to the same central facility.

In the Arla Food case, Johansson and Hellström (2007) describe the operations of a Swedish diary producer that distributes their products to retailers using different types of RTI, such as roll containers. The firm experiences difficulties in managing and controlling RTI. The information concerning how many units of RTI are in circulation or how much inventory is available in each location does not exist. Management estimates that they own roughly 120,000 units of RTI and that 10 per cent of the RTI fleet is lost annually due to theft and misplacement. €2 million are invested annually in order to substitute the lost RTIs. Each roll container has an estimated unitary cost of €120. Their reconditioning is simple as they just require inspection, cleaning and in some cases, minor repairs. Regarding physical flows, roll containers are exchanged between the dairy distribution centres and the retailers following the star model.

Ikea (Hellström 2009) uses steel containers for delivering products directly home to end-consumers. Steel containers consist of two components: a platform and side bars. Depending on the products to be delivered, different side bars are placed in different positions on a platform. The steel containers loaded with products are issued from IKEA distribution centres (DC) to the logistics hubs of the third-party logistic providers (3PLs). Then, 3PLs deliver the products to the end-customers and return the empty containers to the original IKEA's DC (star network). Reconditioning in this case consists of cleaning and assembly / disassembly of platforms and side bars. The fleet of platforms and side bars for one DC comprises 16,000 and 64,000 units, respectively. The estimated value of each component is €170 for a platform and €20 for a side bar. The total investment on RTI fleet for one DC is around €4 million. Roughly 10 per cent of the steel containers are lost annually.

Finally, we consider a case study on the use of returnable containers in the automotive industry (Roseneau *et al.* 1996). Ten vehicle assembly companies participated in the study. The assembly companies receive parts from their components suppliers in returnable containers built of steel (racks) or of plastic, high-density polyethylene. Each individual container is relatively inexpensive ($100-$600) but the amounts invested in the complete fleet for one single assembly plant are astounding. The authors give figures of $16.3 million and $35 million for two different assembly plants. Containers are designed to resist harsh industrial environments and their reconditioning usually requires simply cleaning. Regarding the return rate, it is assumed in the automotive industry (Mollenkopf *et al.* 2005) that 5% of the container fleet will have to be replaced due to loss and damage every year. Management difficulties with reusable containers systems are acknowledged. As remarked by Twede and Clarke (2005): *"Companies that excel at inbound and outbound logistical arrangements, such as the US automobile manufacturers, have not been so successful when it comes to managing their container fleets. Containers are routinely misdirected, inappropriately reused or lost and they are rarely tracked in system-wide information systems. [...]The automotive industry's frustration with container control [...] led to outsourcing it to a third party"*. Regarding the organization of the physical flows, both star and multi-depot networks are possible in the automotive industry.

The three types of RA arise in this analysis. Shopping carts, Flora Holland, Arla Foods, Ikea and the automotive case studies deal with RTI. MedGas, LPG and Heineken cases concern RPM. Erasmus MC and service tools cases involve RP. In the ten cases, we deal with durable articles, designed for sustainability. Articles are used during short times, compared with their lifetime, enabling multiple use cycles. End users do not make distinctions between brand new and reused articles. Depending on the article being considered, reconditioning operations require different levels of complexity, but they remain simple when compared with repair, remanufacturing or recycling, as dissasembly of the RA is not required in any case. RTI´s reconditioning tends to be simpler than RPM's. RP's reconditioning complexity varies depending on the article type. Firms assume that the volume of articles returning is very high (typically above 90%), as most of the demand is fulfilled with used articles. However, it is very difficult for the companies to provide precise quantifications of the return rates. Usually, only losses due to damage are controlled (because they fall under the observable part of the supply chain) while losses due to misplacement or alternative use of RA by other supply chain agents are not controlled (these losses take place in the unobservable part of the supply chain). In all the cases, new articles have to be bought from time to time in order to replace misplaced, lost or irreparably damaged articles.The RA fleet is constituted by many units of relatively inexpensive articles. Nonetheless, the amounts invested in RA fleets are remarkable in the ten cases. Besides, all the organizations we analyzed were dissatisfied with their performance when it came to management of RA. In order to avoid problems to make demand and returns of RA meet, many firms tie-up large amounts of capital in high inventories of RA.

5 Management issues in CLSC of reusable articles

Our own case studies and cases from scientific literature confirm that management of closed-loop systems of RA is not a simplistic task. Depots need to assure that they are able to fulfil demand depending heavily on returned articles (return volumes are typically over 90% and most demand is fulfilled with reused articles). In order to balance demand and return rates of RTI, RPM or RP, firms deal with the challenges listed and explained below. Note that our focus is on the management aspects (tactical and operational issues) in a system that is already in place. Design aspects of the system, such as network design, actors involved in the supply chain, relations and cost allocation between these agents, etc. remain out of the scope of this framework.

Issue 1. Define the fleet size dimension.

Depots need to determine the number of RA in circulation in the network required to keep operations running smoothly. The purchase of the initial RA fleet generally constitutes an important initial investment. An overdimensioned RA fleet unnecessarily ties up capital and adds holding costs. On the other hand, an undersized RA fleet will cause unsatisfied demands..

The fleet size is a function of two variables: demand and cycle time. Neither demand nor cycle time take deterministic values: both are random variables subject to stochasticity. Safety factors are then needed in order to cope with the inherent dispersion of demand and cycle time. Besides, when demand or cycle time values are subject to structural trends or effects such as seasonality, fleet size needs to be redefined. Demand is usually a well controlled variable in most organizations and plenty of information is typically available. Unfortunately, this is not characteristically the case with cycle time. Lack of information about cycle time values and its evolution through time renders the calculation of the required fleet a complicated task.

Issue 2. Control and prevent fleet shrinkage. Promote articles rotation.

The fleet of RA will shrink through time due to losses in the system. These losses can be classified in quality losses, incidental losses and structural losses. *Quality losses* refer to RA which are irreparably damaged or their reconditioning for reuse is not economically viable anymore. *Incidental losses* refer to fortuitous misplacement or loss of some RA by customers or other supply chain agents. *Structural losses* refer to losses due to deliberate fraud to the owner: theft, alternative usage of RA, resale, etc.

Our case studies indicate that firms have more control over quality losses because damaged articles are rejected in the observable part of the supply chain. Incidental and structural losses are more complex to be tracked and, as a result, obtaining precise quantifications of the global return rate (which includes quality, incidental and structural losses) is not straightforward.

In order to prevent fleet shrinkage, firms can use a variety of *recovery incentives* such as deposits, rentals, account management with periodical payments, equal exchanges, etc. For further details on these policies, we refer the reader to Flapper (1996), Kärkkäinen *et al.* (2004), De Brito *et al.* (2005), and Breen (2006). The objective of these control mechanisms is not only to prevent leakages in the system (maintain and, if possible, improve the return rate), but also to encourage RA rotation in the system. Achieving a short cycle time, and thus a high utilization rate per unit, is directly related with economical efficiency of the RA system.

Issue 3. Define purchase policies for new articles.

Fleet shrinkage has consequences both in the finance and operations functions. Lost assets have to be written off from the balance sheet. New articles have to be purchased from time to time in order to substitute lost or irreparable RA. Therefore, even in the case of an even demand pattern or a stable cycle time, purchasing polices for new articles have to be defined.

New articles also have to be purchased when the fleet size has to be redefined due to structural changes in demand or cycle time (an increase in RA demand or an enlargement of cycle time motivated for instance, by longer travelling distances, require more units of RA in circulation).

Issue 4. Plan and control reconditioning activities.

Even if the number of RA in circulation in the network is accurate, depots need to assure that articles are returned and reconditioned at the right time in order to fulfil demand. Planning and controlling reconditioning activities involves forecasting the expected demand and the expected returns in a given time period. If the forecasted demand and return rates do not match, some course of action has to be taken: buy new reusable articles, accelerate reconditioning activities, promote rotation in the system in order to reduce cycle times, etc.

Issue 5. Balance inventory between depots.

This challenge only concerns multi-depot networks, where RA do not have to return to originally issuing depot. In this case, periodical rebalancing of the number of RA among facilities is required, so that the inventory in each depot is sufficient to cope with its demand. Rebalancing involves transhipments between depots from time to time.

Interesting research opportunities arise from these five issues for the operations management academic community. Issue 1 can be addressed through stochastic inventory control models. Obtaining information about cycle time distribution is critical for these purposes. Issue 2 calls for methodologies for return rate quantification and for analyzing the effect that different recovery policies (deposits, rental, equal exchanges, etc.) have on fleet shrinkage prevention and on articles' cycle time. Issue 3 points out a need for defining optimal purchasing policies for new articles. Issue 4 calls for developing techniques for forecasting future returns under different levels of information availability. Issue 5 can be addressed by linear programming models providing norms for carrying out inventory rebalancing between depots.

6 Conclusions, contributions and future research directions

In this paper we have provided a conceptual structure for deepening our understanding of CLSC of reusable articles. After exploring the literature related with this topic, we concluded that empirical research on reusable articles management is quite scarce. Knowledge on reuse CLSC is fragmented and scattered and only considers some particular situations in which reuse is involved, such as some types of packaging. We have proposed a definition and a typology for RA, which integrates three different categories of RA (RTI, RPM and RP) and proposes a standard terminology in the field. Our framework highlights the similarities and differences between the three categories. We have also defined two different models for physical flows configuration in RA networks (star and multi-depot models).We claim that the commonalities found between RTI, RPM and RP's logistics characteristics enable us to generalize results and best practices obtained for one particular category of RA to the others. Our claim is grounded on a set of 10 case studies comprising different industrial situations in which reuse is involved.

This paper contributes to scientific literature by defining RA term, by integrating the view of RTI, RPM and RP and also by identifying the main management issues that companies must face when dealing with reuse CLSC. Interesting research opportunities emerge from these issues. We intend to tackle some of them in further developments of this study. As our case studies indicate, reusable articles involve management difficulties that do not arise in supply chains utilizing single-use articles. But on the other hand, reusable articles contribute to natural resources preservation by reducing the amount of waste that firms generate. When well managed, RA also provide interesting cost reductions. Mitigation of the management difficulties related with RA contributes to facilitate the shift from a use-and-dispose model to a reuse one.

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Appendix I - Literature review: Extensions

Table 1: Literature review

PAPER	TOPIC	MAIN CONTRIBUTION	WHICH RA?	TYPE
Kroon and Vrijens, 1995	Organization of RA systems.	Explore different design alternatives for returnable containers (RTI) systems. They focus in a case study analyzing secondary packaging alternatives to cardboxes in the Netherlands. Propose a MILP plant location model for deciding where container depots should be located.	Collapsible returnable containers.	RTI
McKerrow, 1996	Organization of RA systems.	Introduces some of the benefits of using standardized reusable packaging elements, presents different types of equipment pool networks depending on their convergent or divergent characteristics and on the ownership of pool assets and identifies some control problems inherent to equipment pools. At the time of paper publication, the author was Director of Business Development at Chep Europe.	Pallets, plastic crates.	RTI
Del Castillo and Cochran, 1996	Production and distribution planning and control in closed-loop systems.	Make use of aggregate planning concept to provide an optimal weekly master plan for production and distribution in a soft drink plant reusing glass bottles. Restrictions in the model consider the availability of empty bottles to be filled. The number of full containers delivered to a given depot in a day must coincide with the number of bottles returned in the same day from that depot.	Glass bottles for the soft drink industry.	RPM
Goh and Varaprasad, 1986	Returns forecasting.	Propose a transfer function forecasting model (Box and Jenkins approach) for forecasting the timing and quantity of future returns and apply it to the case of soft drinks bottles of a filling plant in Southeast Asia. Using only data on container issues and returns they obtain important parameters of container life cycle such as trippage, trip duration, loss rate and expected useful life	Glass bottles for the soft drink industry.	RPM

Table 1: Literature review (cont.)

PAPER	TOPIC	MAIN CONTRIBUTION	WHICH RA?	TYPE
Van Dalen et al., 2005	Returns forecasting. Value of information.	Present a case study concerning Heineken beer crates. A tracking technology was introduced in order to get insights in crates circulation times in the supply chain (1.4% of the whole population of crates was individually identified). Information about total circulation times and about the time crates spend in the market is relevant for long-term decisions about RPM investments as well as for short-term forecasts of the RPM returns to the brewery.	Plastic crates in the beer industry[1].	RPM
Kelle and Silver, 1989a&b	Returns forecasting. Value of information.	They put forward four methods for estimating the expected returns during the replenishment lead time for new containers and their variability. The four methods represent different informational levels, from just average container behaviour to individual tracking of each container. Knowing the expected net demand of containers (demand minus returns) during the lead time and its variability, it is possible to establish the reorder point for purchasing new containers. Departing from these results, in the second paper they determine the optimal purchasing policies for new reusable containers (as some containers are lost or irreparably damaged, even under a level demand pattern new containers have to be purchased from time to time). They minimize total purchasing and expected holding costs, given a specified service level.	Cylinders, kegs, glass bottles.	RPM

[1] Beer crates in this particular context are a handling element intended for end-customer use. Thus, a marketing component is generally important in this type of handling element so we include them under RPM type, although regular crates are usually included in RTI category.

Table 1: Literature review (cont.)

PAPER	TOPIC	MAIN CONTRIBUTION	WHICH RA?	TYPE
Toktay et al., 2000	Returns Forecasting. Value of information.	They build a closed queuing network to model camera reuse supply chain and investigate the consequences of the unobservability of the customer-use portion of the supply chain. They asses the value of information relating return flows (return probability, return delay and unobservable inventory) through two informational structures (trackable and untrackable case) and the simulation of five different inventory control policies.	Single-use Kodak cameras (reuse of circuit board, plastic body and lens aperture).	RPM
Johansson and Hellström, 2007	Value of information.	Through a combined methodology of case study and discrete-event simulation, they explore the impact of asset visibility on the management of RTI fleet. They conclude that asset visibility has a considerable potential to lower the operating and investment costs of RTI systems, mainly through the reduction in asset shrinkage.	Stackable roll containers.	RTI
Mollenkopf et al., 2005	Choice between reusable and disposable RTI.	Propose a general cost model for comparing the relative cost of an expendable container system to the cost of a reusable container system (enable "what if" simulations). They also evaluate the relative influence of the cost factors incorporated in the model (simulation and multivariate regression analysis).	Returnable shipping containers.	RTI
Twede and Clarke, 2005	Choice between reusable and disposable RTI. Organization of RA systems.	They identify the supply chain relationships that favour reusable packaging, through two case studies, one in the US automotive industry and the second one in the UK grocery retailers. They also analyze how packaging performance issues, such as durability or ergonomics, affect the cost and operations of a reusable packaging system. They also review the cost factors to include when considering an investment in reusable packaging for substitution of disposable packaging.	Metal racks, plastic pallets, plastic bins, plastic crates.	RTI
Rosenau et al., 1996	Choice between reusable and disposable RTI.	Explore financial evaluation methods used for investment decision in returnable containers systems. Propose a framework for such decision, identifying positive and negative cash flows for such systems. The framework proposed is based on a case study in the US automotive industry, with 10 firms participating.	Returnable shipping containers.[2]	RTI

[2] Secondary packaging alternative to corrugated fibreboard boxes and shipping containers

Table 1: Literature review (cont.)

PAPER	TOPIC	MAIN CONTRIBUTION	WHICH RA?	TYPE
Dubiel, 1996.	Choice between reusable and disposable RTI. Organization of RA systems.	Identify the cost factors arising in reusable packaging systems and compares them with the costs of a one-way packaging systems. Advocates for taking into consideration an holistic approach when choosing between both types of packaging systems, taking in to account all the relevant factors (waste generation, transportation, systems management,Ě) rather than on concentrating in the unit cost of each packaging element	Reusable containers and pallets.	RTI
Duhaime et al., 2001	Management challenges of reusable articles.	Deal with a case study on Canada Post, where monotainers shortage caused major production problems in the mechanized postal handling plants. Through a minimum-cost flow model, it is shown that the number of monotainers in circulation in the system was enough to meet demand requirements. Recommended actions aim at reducing monotainers cycle time in the network and at balancing monotainers inventory among the regions so that they are available where they are actually needed.	Postal monotainers.	RTI
Rudi et al., 2000	Management challenges of reusable articles.	Describe a case study in the National Health Service of Norway, where devices such as wheelchairs, hearing aids or speech synthesizers are supplied to handicapped or eldery people from the governmental Technical Aid Centers (TACs). After use, devices are returned and the Technical Center has to decide whether to scrap or reuse the unit (after a reconditioning process).	Reusable medical devices.	RA
Young et al., 2002	Management challenges of reusable articles.	Presents an exploratory study identifying the underlying factors behind one of the main problems affecting railcar fleet operators: the excessive customer holding time of the railcars in chemicals and plastic industries. Expert panel methodology was used to identify causes of customers holding cars too long and to suggest some possible solutions.	Railcars.	RTI

Table 1: Literature review (cont.)

PAPER	TOPIC	MAIN CONTRIBUTION	WHICH RA?	TYPE
Breen, 2006	Management challenges of reusable articles.	Explores the financial and operational impact of customer non-compliance in returning distribution equipment back to the sender, in both B2B and B2C relationships, through a qualitative study involving interviews and questionnaires to organizations in the UK dealing with this type of assets. Identifies several policies that facilitate effective returns behaviour in B2B and B2C relationships.	Pallets, tote boxes, trays, beer kegs, supermarket trolleys, baggage trolleys, local council wheeled bins.	RTI and RPM

Appendix II - Case studies description

Case studies description is organized as follows. After a short introduction to the context in which each case study has been developed, we address the reusable articles' characteristics (special features, reconditioning process, etc.), the dimensions of the RA fleet size in each case, the organizational design of the RA system, issues related with RA losses (fleet shrinkage) and the more relevant management challenges within each case.

Case 1. Gas cylinders in a multinational chemical company (MedGas)

Context. The first case concerns a multinational company producing and distributing industrial and medical gases. Our interaction took place with the Spanish subsidiary of this corporation. The firm's main productive process consists in liquefying and then distilling atmospheric air in order to obtain oxygen, nitrogen and some noble gases (argon, helium). Through a different chemical process, carbon dioxide and hydrogen are also obtained. All this gases have multiple applications in industry and healthcare and can be delivered to the final customer by different means: pipelines, bulk (using cryogenic tank trucks) or cylinders.

Reusable article's characteristics. Inside the cylinder, gases are compressed and the vessel reaches an internal pressure of around 200 bars. Cylinders are designed to resist high pressures: typically manufactured in steel or aluminium alloys, a standard 50 l cylinder has an estimated unitary cost of €100, making cylinder reuse the only economically viable option. Vessel owner is legally responsible to test them every 2, 5 or 10 years, depending on the physical-chemical characteristics of the gas contained. These periodic tests include an hydraulic test (in which the cylinder shall withstand a given test pressure, which is usually 1,5 times the working pressure) and eventually, some complementary tests, such as ultrasonic inspection. This periodic test requires specific instrumentation and needs to be carried out in a focused facility.

The focus of this case study is on the healthcare branch of the company, where the more important cylinder-delivered gas product is medical oxygen compressed in the so-called compact cylinders. This product presents a marked seasonality, as consumption during winter months is around a 50% higher than in the low season (summer), due to the higher incidence of respiratory diseases in winter.

Fleet size. Cylinders are owned by the gas company. The compact cylinder fleet size is estimated in roughly 20,000 units for serving the Spanish market.

This represents an investment of €2 million only for this particular product. Each individual cylinder does not represent an important investment, but the enormous amount of them in circulation make that, collectively, cylinders constitute a relevant amount of tied-up capital. This calls for considering the cylinder fleet an asset.

Investments in cylinders are gas specific: filling a vessel prepared for oxygen with a different gas is not allowed, due to security reasons. Therefore, unfortunately, sharing the same cylinder fleet for different gas products is not possible.

Organizational design. The structure of the closed-loop process followed by medical oxygen cylinders is depicted in Figure 4. The solid grey coloured elements in the upper part of the figure represent the full cylinders, whereas the stripped ones in the lower part represent the empties. The four agents participating in the closed-loop system are depicted in columns (filling plants, distributors, customers and testing centers).

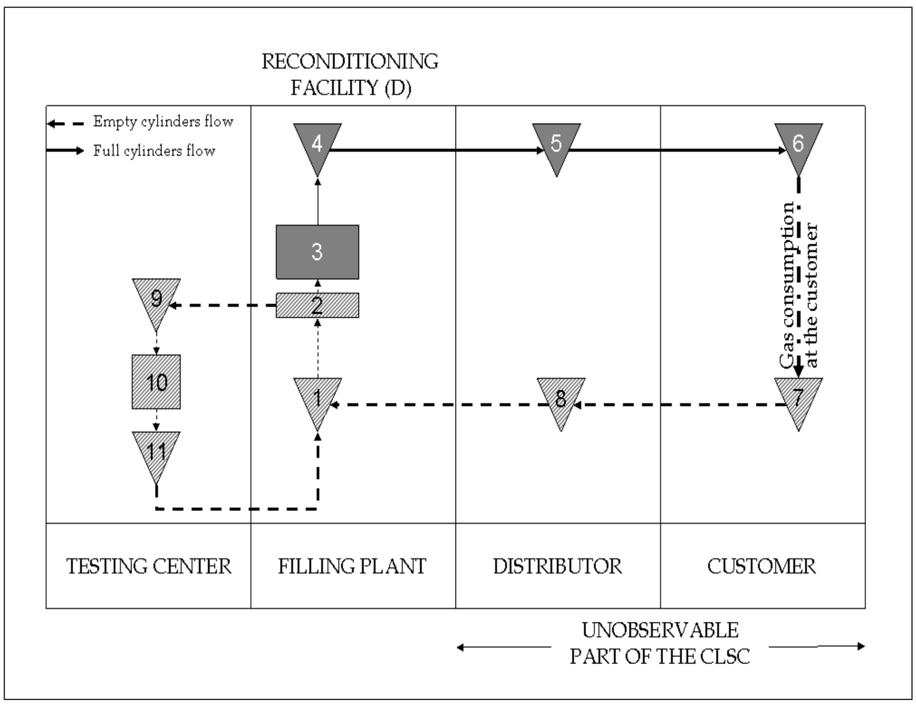

Fig. 4. Closed-loop supply chain of medical oxygen cylinders.

Stock number 1 represents the stock of empty cylinders at the filling plant. At their arrival, cylinders are visually inspected (2) in order to separate those for which the hydraulic test has expired and need to be sent to retest (9,10,11). Cylinders found suitable for refilling go into the automatic filling installation (3) and enter the stock of full cylinders (4), from which customers orders are retrieved. Depending on their size and geographical proximity to the filling plant, end customers are served from an intermediate distributor (5) or directly from the filling plant (in that case, stocks 5 and 8 do not apply). Once the contents of the cylinder is used up (7), the vessel can return to the filling plant using the same logistic circuit used for delivering full units (7-8-1). Empty cylinder recovery takes place at the same moment of full cylinders delivery. Typically, customers are delivered only as many full cylinders as empty units they can give in exchange. The company call this practice *full-for-empty swapping* or *equal exchanges* policy. As the same logistic circuit is used for deliveries and returns, empty cylinders always return to the same filling plant, so the physical flows in this case follow a star model. Integrating in the same vehicle forward and reverse flows of cylinders enables the company to obtain transportation cost savings by using the backhauls of the delivery routes.

Fleet shrinkage. Regarding losses, the company controls the number of cylinders that are scrapped due to their bad condition and these assets are retired from the account balance. Nevertheless, the control over cylinders lost in the unobservable part of the supply chain (customers, distributors) is very limited. In order to ensure cylinder recovery, the firm only relies on incentives aiming at inducing the desired behaviour in supply chain partners. Two control mechanisms are applied in this supply chain. First, the above mentioned equal exchanges of full-for-empty swapping policy (a). Second, account management with periodical payments (b). The (b) control mechanism consists in registering in the information system (ERP) the incoming and outgoing cylinder quantitites from a given customer. This information, which is available in the delivery notes, enables us to re-build the RA inventory at the customer at any given time. Then a dialy rental is charged to the customer depending on the number of RA in inventory each day. The payment for this daily rental is reclaimed at the end of each invoicing period (the month).

These control policies are useful for preventing cylinder losses ((a) and (b)) and enhancing cylinder rotation (only (b)), but they do not provide any information about the number of cylinders lost outside the filling plant. Hence, the return rate is not known with accuracy. Besides, the two control policies are not always applied. Some big customers, such as hospitals, have a greater bargaining power and do not accept clauses in their contracts involving payments for cylinder tenancy. In such cases, management has reported a worse behaviour of cylinders in terms of return rate (more cylinders are lost by these customers) and cycle time (these customers do not have any incentive to return cylinders as soon as they are used up).

Management challenges. Operations management department executives acknowledge that uncertainty about the cylinders returns (timing, quantity, quality) makes difficult to match oxygen demand with empty cylinders returns. The balance between demand and returns is ensured by mantaining large amounts of cylinders in stock.

The role of the high inventory levels of cylinders in RA systems is shown up in this case study. When new governmental regulations classified medical oxygen as a medicament, additional requirements were introduced regarding quality assurance and traceability for medical oxygen filling and distribution. Top management decision was then to separate industrial and medical oxygen flows, and concentrate medical oxygen filling in a set of new facilities especially conceived for fulfilling the new legal requirements. This meant a complete reorganization of the logistics flows for medical oxygen, which introduced extra travelling distances between the reconditioning facilities (the filling plants) and the customers. Cylinder's cycle times increased (in general) in the new scenario. The number of required cylinders in the new situation (a new fleet size dimension) was not, however, reconsidered in the redesign of the logistical system. When the new system went live, multiple operational troubles were encountered because of the lack of cylinders. Availability of empty cylinders to be refilled became a major bottleneck which had to be solved by adding extra production shifts or by delivering and collecting at customers more frequently. In the long term, investments in new cylinders had to be done. The larger cycle times called for a larger cylinder fleet. As new investments in cylinders were not foreseen in the new medical logistic system, the cylinder inventory level was not sufficient to mitigate the lack of information about cylinders returns. This experience shows the existence of an industrial need for deepening in the understanding of design and management of reusable articles systems.

Case 2. LPG cylinders in a petrochemical company

Context. The second case concerns Repsol GLP, the liquefied petroleum gas (LPG) division of Repsol group. The LPG division has operations in Spain (where it holds a market share of roughly 80%) and the neighbouring countries (France, Portugal) and several iberoamerican countries (Ecuador, Peru, Argentina, Chile and Brazil). While LPG consumption grows in the developing countries, in the advanced economies LPG is a very mature or even declining market, where domestic use of LPG is being strongly substituted by safer or cleaner alternatives such as natural gas or renewable energies.

Reusable article's characteristics. In this case study we focus in LPG for domestic uses delivered in cylinders. LPG cylinders are similar to the vessels described in the previous case (MedGas), but their security specifications are less demanding. The pressures inside the LPG vessel do not exceed 20 bars (propane and butane are liquefied inside the cylinder), so the constructive steel of the LPG cylinder do not need to be as resistant as in the previous case. Therefore, the value of the LPG cylinders is lower than the value of oxygen cylinders. The unitary price of each LPG cylinder is estimated in €20. LPG cylinders are also periodically tested in order to check the vessel's resistance to working pressure's stress. Like in the previous case, the hydraulic test for

LPG cylinders takes place in specialized plants. Then, regular empty cylinder transfers between filling and testing plants are required.

Fleet size. For serving the Spanish LPG market, Repsol holds a fleet of 30 million cylinders. Assuming a unitary price of €20 per cylinder (estimated figure provided by Repsol management), this represents a value of €600 million. Of course, as cylinders technical life is very long, much of the cylinder fleet book value has been written down in the balance sheet a long time ago. LPG in Spain is a declining market and new investments in cylinders are not expected for this market. Repsol management acknowledges that their cylinder fleet size is currently overdimensioned for the company's operational needs. Maintaining such a big fleet of cylinders has financial-economic consequences, not only in terms of space and handling, but also in terms of maintenance. As LPG cylinders need to pass their hydraulic test every 10 years, every year some 3 or 3.5 million cylinder are sent to the testing plants in order to receive specialized maintenance (hydraulic test and painting). After this maintenance, the cylinder is as new, and in fact a new serial number is engraved in the body of the cylinder. Maintenance has an estimated cost of €3 per cylinder, so the maintenance invoice roughly represents annually around €9 million. A smaller fleet would require fewer units to be sent to maintenance. There is also an opportunity cost, as the exceeding fleet could be scrapped and then recover the value of the constructive material (steel). Cylinders can also be sold to countries where LPG is a growing market, such as for instance, the Indian market or the markets in other developing economies. With annual growth rate figures of up to 9% for LPG, companies operating in these countries need to invest in new cylinders for covering the growing demand.

Organizational design. The logistical scheme used for distributing Repsol LPG cylinders is very similar to the one depicted in Figure 4 for the previous case. The agents in the supply chain are again the filling plant, its distributors, the end customers and the testing center. In this case, the filling plant do not directly deliver any end customer, distributors are always used instead, so stocks (5) and (8) always apply.

As in the previous case, empty cylinder recovery follows the same logistic circuit used for full cylinders delivery. The *full-for-empty swapping* or *equal exchanges* policy also applies in this case for cylinder exchanges between filling plants / distributors and distributors / end-customers. The same vehicle route delivers full LPG cylinders and recovers the empty ones. As cylinders are heavy packaging elements, is important to achieve transportation cost reductions by using the equal exchanges policy. Cylinders always return to the same filling plant, so the physical flows are organized following a star model.

Regarding the exchanges with the testing center, empty cylinders that need to be tested (expired hydraulic test) are put aside in the filling plant. When a sufficient transportation lot size is achieved, a vehicle is shipped to the testing center. Tested cylinders ready to enter the filling circuit are sent in the return leg of this trip.

Fleet shrinkage. Cylinders are scrapped when their repair is not economical anymore. This decision is taken in the filling plant. Scrapped cylinders (assets) are written down of the balance sheet. However, cylinders are also lost at the distributor and end customer stages, but these leakages in the unobservable part of the channel are not controlled. The exact LPG cylinder return rate is then unknown.

Control mechanisms are also introduced in this case in order to incentivate cylinders returns from end-customers and distributors. First, the equal exchanges policy, that has already been explained. Second, the use of deposits. The first time a customer is delivered with LPG a certain amount (between €10-€20) has to be paid to the distributor for each of the cylinders delivered. Customers can reclaim the deposit once they do not need to use LPG anymore. Deposits only apply in the distributor / end-customer exchanges.

Management challenges. The cylinder fleet owned by Repsol is currently oversized for the LPG demand in the Spanish market. Thanks to this large cylinder inventory, Repsol filling operations run quite smoothly, even in the peak demand periods of the year (winter). Management is concerned with the financial-economical consequences of mantaining such a huge amount of cylinder inventory in the system, not only in terms of space and handling, but also in terms of manteinance. However, in order to reduce their cylinder fleet size, Repsol needs to define the number of cylinders that suits their current demand and operational requisites. Management affirm that the lack of a methodology for determining the cylinder fleet size dimension (and also the lack of information on cylinders' life-cycle parameters) are the main factors hindering the readjustment of the cylinder fleet size.

Case 3. Surgical material at Erasmus MC

Context and reusable article's characteristics. Erasmus MC is a large academic hospital in the Netherlands. As many other clinical institutions, Erasmus MC holds a stock of durable surgical instruments that are sent to sterilization after each use. A closed-loop flow is established between the operating theatres and central sterilization department of the hospital, who manages the inventory of used and sterilized instrumentation and is in charge of performing all the reconditioning operations required to leave instrumentation ready for the next use. Surgical instruments are typically grouped in the so-called "nets", a set of tools specific for a particular type of surgery.

In this case we are not considering a reusable packaging element but an article itself that is reused by multiple different users (RP).

Fleet size. Although Erasmus MC central sterilization department could not provide exact figures, they acknowledge that the amount invested in the total instrument inventory has a magnitude order of millions of euros. Approximate values we worked with in this case were €100 per single instrument and then €10,000 per a complete net with 100 items.

Organizational design. The sterilization cycle comprises the following phases. The sterile instruments/nets are stored near the operating theatres. Some time before every operation (as prescribed in the corresponding protocol) the required instruments are retrieved from the sterile inventory and brought to the operating theatre. After the operation, the used instruments are placed in a non-sterile inventory from which they are collected and brought to the central sterilization department (CSD). Upon receipt, the instruments are registered in the information system and then washed and disinfected in autoclaves. Before going to sterilization, the nets are checked for completeness. Any missing or defective instrument is replaced or repaired at the CSD. When nets are complete and sterile they are registered in the information system and finally taken to the sterile storage near the operating theatres. Being the CSD the only sterilization unit in the hospital, the physical flows for the surgical instruments follow a star model.

Fleet shrinkage. Along this cycle some tools can get lost or result irreparably damaged. Although the percentage of losses could not be exactly determined by CSD management, they do not consider instruments leakage as a problematic issue; annual losses are estimated to be below 5% of the total inventory.

Management challenges. Even if instrument losses do not seem problematic, CSD management is not satisfied with their current performance regarding the management of instrument inventory. For some types of instruments there are substantial under- stock (and hence, a serious need for additional instruments) while for other instruments types there are serious over-stock. Many sterilization orders are placed as rush orders, which are five times more costly than regular orders.

Case 4. Service tools

Context. This case study is framed in the context of the Service Logistics Forum (SLF, 2009), a knowledge platform in the Netherlands comprising several Original Equipment Manufacturers (OEMs) and some Dutch universities. The aim of the SLF is to develop and share knowledge on Service Logistics topics.

OEMs perform preventive and corrective maintenance actions in order to fulfil the service contracts agreed upon with their customers. In order to carry out these maintenance actions, firms need spare parts, service engineers and service tools. The OEM has to decide the stock levels of spare parts and service tools at each service location, as well as how many service engineers have to be hired, in order to meet the service target while the systems costs are minimized.

In the context of this case, the analyzed firm stored service tools in local warehouses near the customer factories. Each of these warehouses gives service to several machines installed in a region. When tools are needed, they are taken from this local warehouse and sent to the factory needing a maintenance action. After use, the service tools are returned to the warehouse.

Reusable article's characteristics. Service tools collection includes a wide variety of instruments of heterogeneous characteristics. The complexity of the reconditioning operations depends on the type of tool considered. Many tools just require cleaning while others, such as welding equipment, need to have their consumables replaced. The price of service tools is also variable and ranges from very cheap to very expensive. Cheap tools that are demanded very often are usually available in the standard tool boxes service engineers carry with them(one single user). Hence, these cheap tools cannot be considered RP as we defined them in section 3.1. More expensive tools are stocked in the local warehouses from where they are lent to multiple different service engineers. The focus of our case is then on this borrowing system, which fulfills the requisites to be included under the RP category.

Fleet size. If service tools stock levels in the local warehousesare are not optimized, they may lead to large investments for the OEM. The amount invested in service tools inventories is estimated in the millions of euros, but it could not be exactly quantified by OEM management. The inventories of service tools have traditionally received little managerial attention and information about them is scarce and not always reliable.

Organizational design. Each customer location is assigned to a service tools local warehouse. When manteinance is needed, service engineers borrow the required instruments from the corresponding local warehouse. After use, the service tools are returned to the issuing warehouse. Obtaining service tools from other warehouses (emergency supply) is also possible but, after use, service tools return to the warehouse they belong to. Then, the physical flows of service tools are organized in this case following a star network.

Fleet shrinkage. Eventually, some service tools may return damaged after a manteinance action. Local warehouse personnel decides if damaged tools can be repaired or they are discarded (quality losses). Discarded tools are written off and replaced. Some tools are lost because of misplacement or opportunistic usage by other parties. All in all, the percentage of lost tools is very small and OEM mangement did not find it a burdensome aspect.

Management challenges. OEMs participating in the SLF consider that service tools inventories have received much less attention than other parts of the business, such as the inventories of spare parts. Given the large amounts invested in service tools inventories, managers have expressed their interest in developing models and methods for determining the optimal "fixed circulation stock level" for each service tool With this term, we refer to the total inventory of service tools (either on stock at the warehouse or at the machine for repair purposes) required for providing a given service level.

Case 5. Shopping carts in retail shops

Context. This case study was developed after our interaction with a large retailing chain in the Netherlands.

Reusable article's characteristics. Trolleys used in retail shops constitute one of the few examples of RTI use in B2C settings. The recovery incentive typically used in this case is a deposit that the customer recovers once the shopping cart is back in one of the service points (the "depots"). When taken back to the service points by customers, carts are "reconditioned" and ready for the next use. Cleaning operations and minor repairs are carried out periodically by the retail shop personnel, too.

Fleet size. The unitary price of a shopping cart in the Netherlands varies between €152 and €175, depending on the model. A trolley fleet size between 200 and 400 units is considered within the regular limits for a medium-size retailing surface in this country.

Organizational design. Small retail shops generally have only one service point for retrieving and taking back the carts. In this case, trolleys physical flows follow a star model. In big retail centres, where more than one trolley service point is available, carts are managed in a multi-depot network, as they can be returned at any available depot.

Fleet shrinkage. In this particular case, involving a retailer in the Netherlands, roughly 3 per cent of the cart fleet is lost annually. This figure includes not only quality losses (which are controlled by the retailer and correspond to the carts taken out of the system because of irreparable damage), but also incidental and structural losses. These two latter losses types remain out of retailer's control and include cart misplacement, alternative usage by customers, etc. In other markets, trolley fleet shrinkage may represent a more problematic aspect: Breen (2006) reports that UK retailers lose 16-18 per cent of their trolley fleet every year.

Management challenges. Retailer management highlighted three main questions related to the operation of the trolley system. First, how can trolley losses be prevented. Second, how to assure that the number of shopping carts in the depots is sufficient to meet cart demand. In other words, management needs to define the required cart fleet size. Note that demand in this case presents weekly seasonality, with peak periods on weekends. Trolley fleet size has to be adjusted to these intense-demand periods. Finally, a last issue arising, particular of the multi-depot trolley networks, is the need for rebalancing shopping carts between locations so that the inventory level in all the depots is sufficient to meet cart demand in each of them.

Case 6. Flora Holland

Context. Flora Holland is a Dutch firm operating flower auctions in the Netherlands. Given the predominant role the Netherlands play in the horticultural sector at international level, Flora Holland has become the leading matchmaker and intermediary between worldwide demand and supply of cut flowers and plants.

Flora Holland runs six auction houses where growers supply their production and buyers bid in the so-called auction clocks (which follow the reverse auction or Dutch auction bidding system). In order to reduce the number of handling operations that such delicate products as cut flowers and plants have to undergo during the horticultural supply chain, growers, buyers and transporters use an industry-wide packaging standard. The use of standard RTIs avoid unnecessary repackaging operations when product ownership changes. As the central actor of the flower supply chain, Flora Holland is in charge of managing the pool of RTIs for the floricultural industry. Growers and buyers rent the packaging equipment they need from Flora Holland.

Reusable article's characteristics. The *stapelwagen* (aluminium metal cart) constitute the most important logistical carrier for plants and flowers within the floricultural sector and has positioned itself as a industry-wide standard. These metal carts are specially designed for the transportation and storage needs of the floricultural industry. The *stapelwagen* has three moveable shelves which the user may position at various heights. Its reconditioning operations are very simple, requiring just cleaning and sometimes minor repairs.

Fleet size. Each cart has an approximate price of €500-€600 and Flora Holland owns a stock of roughly 50 thousand carts (involving an investment of around

30 million €).

Organizational design. Flower and plant growers supply their products to one of the six auction houses already packed in *stapelwagens.* When received, products are exhibited to potential buyers in clock conveyors constituted by chains of these metal carts. Once the *stapelwagen* has a new owner, it is sent the buyers address. The buyer can return the empty *stapelwagen* to any of the six auction houses Flora Holland operates. Growers rent the empty *stapelwagens* from their nearest auction house. Hence, the physical flows in this closed-loop supply chain are organized following the multi-depot model.

Fleet shrinkage. When *stapelwagens* are irreparably damaged they are retired from the circuit and replaced by new units. Other types of losses are not tightly controlled, but Flora Holland management do not consider them problematic neither in the grower's part of the supply chain nor in the buyers' side. The *stapelwagen* return rate is not known with exactitude.

Management challenges. Regular rebalancing shipments have to be carried out between auction houses so that the *stapelwagens* inventory levels correspond to demand in each auction house. Linear programming models can be used to determine the intensity and sense of rebalancing flows among auction houses.