

A management model for closed-loop supply chains of reusable articles: proposing solutions

Ruth Carrasco-Gallego, Eva Ponce-Cueto

Escuela Técnica Superior de Ingenieros Industriales. Universidad Politécnica de Madrid (UPM). C/ José Gutiérrez Abascal, 2. 28006 Madrid, Spain. ruth.carrasco@upm.es, eva.ponce@upm.es

Abstract

In this manuscript we describe, analyze and propose solutions to several management issues arising in the context of closed-loop supply chains of reusable articles. More specifically, we study how recovery incentives and users' accountability can be used as control strategies for preventing fleet shrinkage and promoting rotation in reusable articles systems. A methodology for fleet size calculation under two different informational levels is also presented.

Keywords: reverse logistics, closed-loop supply chains, reuse, sustainable SCM

1. Introduction

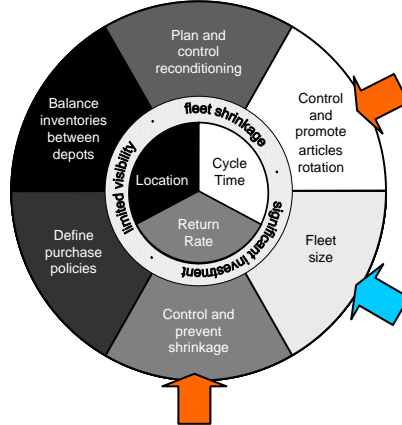
This manuscript is framed in a wider-scope research project aiming at exploring the characteristics of reuse closed-loop supply chains (CLSC). The first part of this research has resulted in a conceptual model (framework) for the management of reusable articles (RA), which has been presented in another paper submitted to this conference. Our conceptual model (Figure 1) comprises three building blocks summarizing (a) the common problems found in reuse CLSC, (b) the basic information which is required to control operations in the context of reuse, and (c) the main management issues that practitioners have to focus on when dealing with RA systems.

The following typology for reusable articles (RA) will be used throughout the text:

- (a) *Returnable Transport Items* (RTI) term designates secondary or tertiary packaging materials which are not in direct contact with the real product used by the customer (e.g. pallets, crates),
- (b) *Reusable Packaging Materials* (RPM) term refers to primary packaging materials that are in direct contact with the “real” product (e.g. glass bottles, cylinders, barrels for chemicals),
- (c) *Reusable Products* (RP) term is used for the cases where the article reused is directly the “real” product (e.g. maintenance tools, surgical equipment).

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Figure 1. A management model for reuse CLSC (own development).



2. Objectives and methodology

In this paper we present the results corresponding to the second part of our research. We develop some solutions to the six management issues identified in the first part of the research (framework). More precisely, the objectives in this paper are:

- To propose and analyze a set of control strategies aiming at the prevention of fleet shrinkage and the promotion of rotation in reusable articles systems.
- To propose a methodology for fleet size calculation.

The empirical support for the whole research, including the framework and the solutions presented in this paper, are six case studies (cases #1 to #6) we have carried out in real industrial settings and four additional case studies that other authors have reported with enough detail in the academic literature (case #7 is described in Van Dalen et al. (2005), cases #8 and #9 in Hellström (2009), and case #10 in Roseneau et al. (1996)). The ten case studies are summarized in Table 1. We also support our statements in the general literature review about reuse CLSC that we have carried out simultaneously.

Table 1. Industrial case studies empirically supporting this research.

Nb.	Name	Reusable article type	Nb.	Name	Reusable article type
1	MedGas	RPM - Oxygen cylinders	6	<i>Stapelwagen</i>	RTI - Flower roll cages
2	LPG	RPM - LPG cylinders	7	Heineken	RPM – Beer crates
3	Erasmus MC	RP - Surgical tools	8	Arla Foods	RTI – Roll Containers
4	Service tools	RP - Service tools	9	Ikea	RTI - Steel containers
5	Shopping carts	RTI - Shopping Carts	10	Automotive	RTI - Racks

3. Solutions proposal: control strategies

Reusable articles constitute a shared resource in the supply network: they travel beyond the boundaries of the organization and their control involves several supply chain partners having different objectives and incentives. In order to obtain the desired behaviour from supply chain partners, reusable articles' owners can use a variety of control strategies. The objective of the control strategies should be twofold: (a) Control and prevent fleet shrinkage and (b) Promote articles rotation. Control strategies simultaneously address two management issues, as depicted in Figure 1 (orange arrows).

In turn, we explain and analyze different alternatives of control strategies that are used in real industrial practice. We classify the collection of control strategies in three categories: (a)

Economical recovery incentives: deposit, rental, account management; (b) Non economical recovery incentives: equal exchanges, repacking; (c) User accountability.

3.1. Economical recovery incentives

3.1.1. Deposits

Within this control strategy, the quantity paid as a deposit acts as a guarantee that customers will meet their obligation of returning back the RA to the owner. Many examples of deposit use can be found in B2C settings such as deposits for beverage packaging (case # 7: Heineken), for LPG cylinders (case # 2) or the €1 deposit for using trolleys at supermarkets (case # 5).

The deposit system has the advantage that, in case of loss, the owning organization gets at least partially compensated. However, especially in B2B settings, the deposit system can be perceived as a sign of mistrust between the parties and an opportunity for the owner to make cash. Deposit customer acceptance decreases in the case of a high deposit in relation to a low product price. The extra administrative effort related with the deposit system management has also to be taken into account. The effect of deposits on cycle time control is limited because the only penalty for excessive customer holding time is deposit depreciation.

3.1.2. Rental

The customer has to pay a daily rent for each RA the customer has in use. Rental systems are typical in maritime containers (Kärkkäinen et al., 2004) or railcar fleets (Young et al., 2002).

Using rental as a control strategy constitute an effective way of speeding up cycle time in reuse CLSC, as customers would tend to return the RA as soon as they do not need it anymore. However, not all industries and products can suit to such a recovery strategy: rental requires articles to be serialized (and item-level tracked) and therefore, is typically only applied in reusable articles with a high unitary value.

3.1.3. Account management with periodical payments

Account management with periodical payments can be used as a substitute of rentals when item-level tracking information is not available (e.g. oxygen cylinders, case # 1). Incoming and outgoing RA quantities from the customer have to be carefully registered in the information system of the company. Then, it is possible to re-build the inventory at the customer at any given time and charge a daily fee depending on the number of RA in inventory each day. The payment is done at the end of a pre-agreed period, such as the month.

The main shortcoming with account management systems is that any transactional error in the incoming or outgoing quantities leads to inaccuracies in the customer inventory record (Heese (2007) show how inventory discrepancies between “information system” and “physical” inventory arise in the operations of many organizations). The application of this control strategy requires periodical inventory audits in order to correct discrepancies.

As rental systems, reliable account management systems also constitute an effective way of speeding up cycle time in RA CLSC, as customers have an incentive to return the articles as soon as possible in order to decrease their daily inventory.

3.2. Non-economical recovery incentives

3.2.1. Equal exchanges

Equal exchanges consist in the following rule to be observed by supply chain partners: the supplier will hand over n full RA only if the customer is able to give back exactly n empty units at the moment of delivery. This equal exchange of full-for-empty (or new-for-old) is a

quite extended control mechanism in reuse CLSC. We found this strategy in many case studies (cases #1, #2, #6, #8: Medgas cylinders, LPG cylinders, flower roll cages, roll containers) and also in other studies published in academic literature (Del Castillo and Cochran, 1996; Roseneau et al., 1996; Twede and Clarke, 2004; Karkkäinen et al., 2004; Breen, 2006).

This control strategy results advantageous because it constitutes a simple mechanism for preventing losses (no administrative efforts are required) and also because its application simplifies transport organization integrating forward and reverse flows. Vehicle routing is done attending to forward flows and articles for reconditioning (old, empties) are returned in the backhauls of delivery routes. Nevertheless, the equal exchanges policy doesn't have any positive effect in cycle time, and in fact, it can even have a negative effect. Using equal exchanges implies that return flows pass through all the stages (echelons) of the forward supply chain. By-passing some stages for the return flow would lead to shorter cycle times. Moreover, in the case of seasonal products, the use of this control strategy requires a wider fleet size than the strictly necessary. Other disadvantages include the exceptions that have to be done the first and last time a customer is delivered.

3.2.2. Repacking

The repacking control strategy can only be applied to secondary or tertiary packaging materials used for material handling and transportation (RTI type). It is used, for instance, with the racks used for engine transportation in the automotive sector. This strategy consists in immediately removing the delivered goods, so that material handling element can be taken back by the transporter right away. It constitutes a very simple mechanism for preventing losses and achieving fast circulation of RTIs, but on the other hand, requires extra handling and extra waiting time for the delivering vehicle.

RPM (primary packaging) or RP always require some time at the customer while the article (contents or directly the product) is in use. Some specific cases of RTI, such as the display pallets used in retail surfaces, present the same limitation. Hence, the immediate return of the RA to its owner is not possible.

3.3. User accountability

In some cases, the structure of the supply chain (in terms of product type and partners relationships) advice against introducing neither economical incentives nor equal exchange policies. The RA owner has to rely in the goodwill of the supply chain partners for recovering the articles. In such a context, where no return incentives are applied, the only action that owners can undertake for keeping fleet shrinkage under control is making users accountable for the articles they handle.

Monitoring reusable articles in the "customer-use" stage of the CLSC is a necessary condition for implementing users' accountability policies. RA tracking can be done manually (even with pen and paper or with a spreadsheet), but the use of Auto-ID technologies (such as bar codes or RFID), renders this task less-labour intensive and the information obtained is less prone to human error. Tracking information enables to point out which partners or customers are accountable for article losses or longer cycle times. Just the communication of this information to non-compliant partners seems to have positive effects in return rates and cycle times (Hellström, 2009). If required, penalties can be introduced in contracts or verbal arrangements in B2B settings.

It should be emphasized that the introduction of tracking technologies in itself is a necessary condition, but not sufficient, to establish user accountability as a control strategy. Continuous

management attention (making users really “accountable” for their losses) is required to obtain benefits in terms of reduced shrinkage and cycle time acceleration. RFID or bar codes just provide data about articles status and whereabouts, but firms need to know how to use this data for undertaking the proper managerial actions (Johansson and Helstrom, 2007).

4. Solutions proposal: a methodology for calculating the fleet size

Another central issue in reuse CLSC management is determining how many articles should be circulating in the network so that operations run smoothly (blue arrow in Figure 1). During our involvement in the six case studies we have developed, practitioners have remarked the importance of this issue. However, there is not a clear methodology in industry for defining the required fleet size. Investments in RA are usually based in experience and simple calculations (Van Dalen et al. 2005; Hellström, 2009). This situation calls for clarifying which are the variables of interest in fleet size calculations and for proposing a methodology for its computation.

There are two variables that determine the fleet size: *demand* and *cycle time*. The total number of RA required in circulation in the system is the number of expected uses in a given time horizon (demand) divided by the number of uses each RA is given in the same time horizon. However, neither demand nor cycle time take deterministic values: both are random variables subject to stochasticity. Therefore, we put forward the following yardstick (1) for fleet size calculation:

$$N = \frac{D}{T} \left(+ S_d \right) \left(+ S_t \right) \quad (1)$$

Where N represents the fleet size dimension, D is the average demand (in units of RA) during time period t, T is the average number of times a RA is used during time t, and S_d and S_t are safety factors for protecting the system against demand and cycle time inherent variability.

Note that in the above expression, the function of the safety factors is to “protect” against unpredictable changes in demand or cycle time in a stationary situation. Structural trends in the values of the variables, such as seasonality in demand or in cycle time, have to be addressed in a different way.

Demand is a well-controlled variable in most organizations, but this is not characteristically the case of cycle time. Then, the methodology we propose aims at obtaining the basic data requirements for cycle time distribution characterization under different information levels (account management or item-level tracking). Figure 2 depicts the steps we propose to follow for fleet size calculation.

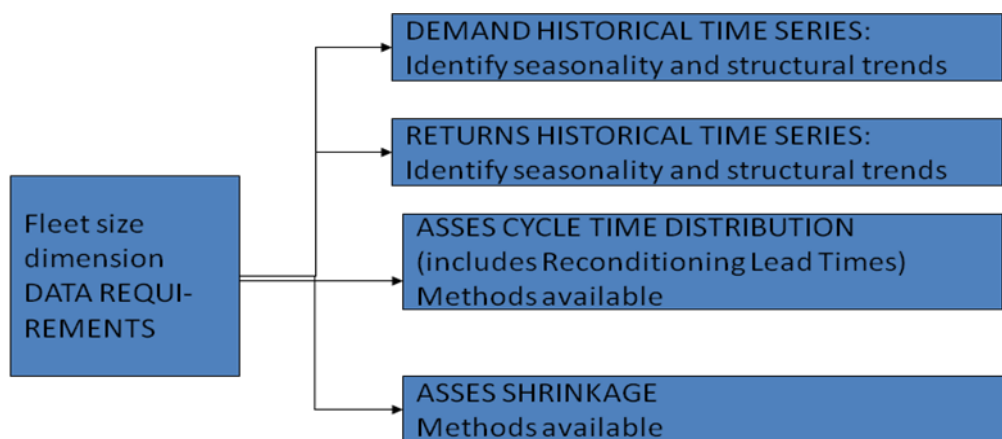


Figure 2. A methodology for determining fleet size in reuse CLSC (own development).

A previous step is to identify the data structure available (what is registered). We consider two possible informational levels: account management (only aggregate issues and returns are registered) or item-level tracking (each article is serialized and monitored univocally). Outlying observations due to measurement or transactional errors need to be identified and excluded if possible.

First step consist in representing the demand time series. This would allow identifying seasonal patterns in demand (more sales in winter (Medgas, LPG) or in summer (beer kegs)) and structural trends, such as an increasing or decreasing tendency in sales for the reusable article itself or the real products (contents) associated with it (LPG). Second step involves carrying out the same time series analysis over returns historical data. The objective of the two first steps is to identify nonstationarity in demand and returns, in case it exists. Faster cycle times are expected in high-demand seasons, for instance. Thus, cycle time distribution might be nonstationary if there is seasonality, trends or cycles in returns.

Third and fourth step consist in trying to assess the return rate (shrinkage) and cycle time distribution. Depending on the informational level available, different methods can be used. We review the available methods in tables 2 and 3.

Table 2. Methods available for return rate estimation.

Informational level: account management
<p>If reusable articles are not serialized and item-level tracked, it is not possible to determine when</p> <div style="border: 1px solid black; padding: 10px; margin: 10px auto; width: fit-content;"> $\text{Return rate} = \frac{R_a}{I_a} \quad (2)$ <p style="text-align: center;">Ra: number of articles that return in a given time period (such as the year) Ia: number of articles issued to the market in the same time period.</p> </div> <p>one particular article has been lost. When only account management data is available, firms can use ratios based on aggregate issues and returns in order to approximate their return rates.</p> <p>Goh and Varaprasad (1986) and Toktay et al. (2000) report the use in industry of the formula (2) ratio:</p> <p>This formulation for the recovery rate has the following shortcomings:</p> <ul style="list-style-type: none"> – it does not take into account that articles utilization can span several time periods, – the returns received in this year (period) can be originated from issues from previous years (periods), – there are returns that will take place in future periods as a result of issues taking place in this period. <p>Bojkow (1991) also reports the use of the formula (3) ratio:</p> <div style="border: 1px solid black; padding: 10px; margin: 10px auto; width: fit-content;"> $\text{Return rate} = \frac{R_\infty}{I_\infty} \quad (3)$ <p style="text-align: center;">R∞: cumulative number of articles returned since the first day of operation of the facility. I∞ : cumulative number of articles issued since the first day of operation of the facility.</p> </div>

In this formulation the main shortcoming resides in the fact that not always the information remounting to the first operative day of the depot or plant is available. The possible fluctuation in the value of the return rate probability along the time in such a long period (in which years or months the recovery rate was lower) is also neglected.

Informational level: item-level tracking

When articles are tracked on an individual basis, it is possible to determine which specific articles have not been returned to the depot. However, an extra issue arises in order to define a return rate in presence of item-level monitoring: which criteria will be defined for declaring an article definitively lost?

Table 3. Methods available for cycle time estimation.

Informational level: account management

Most closed-loop systems of reusable articles have been traditionally managed without item-level tracking. At best, only account management (aggregate issues and returns in a period of time) information has typically been available. Based only on aggregate issues and returns as input information, some statistical methods have been developed in literature in order to draw some relevant cycle time distribution parameters, such as Bojkow (1991) (Method 1), Goh and Varaprasad (1986) (Method 2a) and Toktay et al. (2000) (Method 2b).

– Method 1

Bojkow (1991) compiles different methods used for “trippage” calculation. Trippage is a concept closely related to cycle time; it measures the total number of trips made by a reusable article in its life-time (cycle time measures the duration of one trip). Bojkow defines the trippage number with (4) ratio:

$$Trippage = \frac{I_a}{I_a - R_a} \quad (4)$$

I_a : number of articles issued in a given time period (such as the year).

$I_a - R_a$: represents the number of “lost” articles in the same time period.

This ratio provides an order of magnitude of trippage figures, but suffers from gross inaccuracies which invalidate its use as input in the estimation of reusables fleet size. As it does not take into account that articles utilization can span several time periods, the same shortcomings identified for ratio (2) in Table 2 are also present here.

– Method 2

Goh and Varaprasad (1986) and Toktay et al. (2000) establish a dynamic regression to model the relationship between issues and returns. Returns in period t are a function of sales in past periods:

$$y_t = v_0 x_t + v_1 x_{t-1} + v_2 x_{t-2} + \dots + N_t \quad (5)$$

Where:

- The set of parameters $v_0, v_1, v_2, \dots, v_\infty$ represent the probability that an article issued on period t , returns to the system either on the same period t , on the next period $t+1$, on period $t+2$, and in general, i periods afterwards, $i=0,1,2,\dots$, provided that the item will ever be returned.
- v_∞ represents the probability that an article will never be returned ($v_\infty=1-r$, represents the loss rate).
- N_t can either be gaussian white noise ($N_t \sim N(0;\sigma)$) or not.

The model (5) can be estimated using historical data (time-series) of articles' issues and returns. This estimation consists in calculating the values of the set of parameters ($v_0, v_1, v_2, \dots, v_\infty$), which provides a good approximation to cycle time distribution while (theoretically) circumventing the need of tracking individual items for obtaining such information. Goh and Varaprasad (Method 2a) estimate the dynamic regression model in (5) using transfer function model approach., while in Toktay et al. (method 2b) model estimation is done using a distributed lag model approach (Bayesian inference). The advantage of this second approach is that less parameters are to be estimated and, thus, it requires smaller sample sizes for estimation. The disadvantage is that a given distribution is imposed on the data, based on theoretical consideration, which reduces generality.

The main shortcoming of both approaches to method 2 is that they assume that cycle time distribution is stationary ($(v_0, v_1, v_2, \dots, v_\infty)$ parameters are constant values to be determined), while empirical observations show that the turnaround process duration depends also on the product demand seasonality (Van Dalen et al., 2005, Van Dalen and Van Nunen, 2009; Carrasco-Gallego and Ponce-Cueto, 2009, Case #1 (Medgas) and Case #2 (LPG)). Then, a non-stationary description of cycle time distribution might be necessary. v_i are not constants but functions of time.

Informational level: item-level tracking

Unless some type of item-level tracking is put in place, accurate information about the average cycle time, a measure of its dispersion and the cycle time distribution shape would be at least complicated to obtain. In order to explore cycle time behaviour, item-level tracking can be implemented either in the whole fleet or just in a sample of articles. The resulting cycle times observed in the sample can be inferred (if experiments are well designed) to the reusable articles population (Van Dalen and Van Nunen, 2009). The technology used to track individual articles can range from human observations registered with pen and paper or in spreadsheets to bar code or RFID tagging. Regardless of the tracking technology used, articles need to be serialized in order to follow cycle times.

Within this informational level, the data obtained through the tracking application can be used by managers for observing the behaviour of the turnaround process and the way it varies over the time.

The data collection and analysis carried out throughout steps 1, 2, 3 and 4 should enable managers to characterize the behavior of demand and cycle time and, more specifically, their

average values, the dispersion and shape of their statistical distributions, and the way these distributions evolve with time. The completion of these four steps provides the required information to accurately use the yardstick we put forward in (1) for calculating the fleet size.

5. Conclusions

In this manuscript we describe, analyze and propose solutions to several management issues arising in the context of reuse. We expect these solutions can contribute to mitigate some of the problematic operational issues involved in reuse CLSC, so that we can advance towards a more environmentally and economically sustainable supply chain.

The six recovery strategies presented in this paper are by no means exclusive one respect the others. In fact, our case studies have shown that mixed strategies are also possible (usually an economical mixed with a non-economical policy, such as deposit with equal exchanges). Besides, depending on the product type and on supply chain relationships, some control strategies would be more suitable than others. For instance, repacking is only a sound strategy for RTI; rental requires item-level tracking. In the paper, we have also proposed a yardstick relating the magnitudes that define the fleet size in reuse CLSCs, and also an associated methodology for obtaining the data required for fleet size computation.

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