Closed-Loop Supply Chains:

A Guide to Theory and Practice

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Abstract

During the last decades, attention to the environment has grown substantially. The main reasons are related to the lack of resources, the increasing disposal costs, the introduction of stricter legislation and the higher consciousness of the customers to environmental problems. Companies put an increasing effort into the development and the implementation of 'green' production and operations strategies, in order to increase the sustainability of the whole supply chain. A remarkable and significant trend in sustainable supply chain has been the recognition of the strategic importance of reverse logistics and closed-loop supply chain, in particular in the last ten years, as a consequence of the Directive on Waste of Electrical and Electronic Equipment (WEEE Directive). In this paper, after a short introduction to green supply chain management, we analyze the transformation of the supply chain from an 'open-loop supply chain' to a 'closed-loop supply chain'. Our aim is to guide the reader through the main aspects of both *theory* and *practice* in closed-loop supply chains: starting from the existing literature, we adopt a broader approach and define the guidelines for managers to follow in the supply chain decision process. Assuming a producer responsibility perspective, we pay a special attention to some of the most important sustainable strategic decisions (and associated potential problems) that a company has to face in order to implement and effectively manage the closed-loop supply chain: i) location-allocation decisions, ii) returns collection, iii) inventory control of returned products, iv) returns grading decisions, and v) performance management of closed-loop supply chain design. We describe each typology of problems and their mathematical formulations, the quantitative methods used for the solution and the implications through both an environment and business perspective. We highlight the managerial implication and then underline the limits of the current literature, and define future directions for research to explore.

Keywords: reverse logistics; closed-loop supply chains design; customer returns; inventory control; returns grading; sustainability.

1 Introduction

Sustainable supply chain management is gaining increasing interest among researchers and managers. The lack of resources, the increasing disposal costs, the introduction of stricter legislation and the higher consciousness of the customers to environmental problems are the main reasons of the increasing attention paid to the environmental problems. While, historically, business was seen exclusively as a source of economic value creation, more recently a holistic approach to business was delineated: besides creating economic value, business should also preserve the environment and integrate business, environmental and social facets. The goal is not to balance competing perspectives, but to optimize and maximize value in all areas of the so-called triple bottom line. Hence, sustainable supply chain is not restricted to environmental issues, but it recognizes that, in order to be truly sustainable, supply chain has to produce economic advantage, as well as contribute value to society. Thus, a real definition of sustainable supply chain management must take account of all relevant economic, social and environmental issues. In his book 'Earth, Inc.' (Unruh 2010), the author defines five principles that identify what companies should do and in which order to reach sustainability. These five 'rules' are:

1. Materials parsimony, i.e., minimize the types of materials used in products, of course giving priority to recyclable materials;
2. Power autonomy, i.e., switch to renewable energies;
3. Value cycles, i.e., focus on recovery activities of end-of-use products;
4. Sustainable product platforms, i.e., leverage the value cycle as a product platform for profitable scale, scope and knowledge economies;
5. Function over form, i.e., be able to fulfill customer's needs.

In this paper, we decided to focus our attention on the value cycles principle. This decision derives not only from our belief that companies should take economic advantage from end-of-use and end-of-life products, but also from an environmental consciousness and the resulting new requirements deriving from legislations. A remarkable and significant trend in sustainable supply chain has been, indeed, the recognition of the strategic importance of reverse logistics and closed-loop supply chain (CLSC), in particular in the last ten years, as a consequence of the Directive on Waste of Electrical and Electronic Equipment (WEEE Directive). As explained in Toyasaki et al. (2011), the legislation's goal was to create and develop producer responsibility for e-waste. The directive required member states to undertake, directly or indirectly, the collection and recycling activities in order to let consumers return the discarded equipment for free. The legislation involved ten categories of goods, such as large and small household devices (e.g., washers, refrigerators and televisions) and technical devices (e.g., printers and phones). Of course producers were not required to manage e-waste themselves, but they could resort to collection and recycling organizations (CROs). On these bases, on December 16, 2002, Braun, Electrolux, Hewlett-Packard and Sony founded the not-profit corporation European Recycling Platform (ERP): companies would join ERP to buy take back and recycling services (on a European level) that would enable them to meet their producer obligations deriving from the directive. The venture was therefore an alternative to the monopolistic e-waste take back organizations then existing in several European countries. This solution presented several benefits on the above mentioned triple bottom line basis; in particular, the legislation introduced competition principles so as to promote and obtain high efficiencies in the recycling activities and provide strong incentive for eco-design. In the following years, the European producer responsibility legislation was used as a model outside Europe, especially among the U.S. states. The goals achieved in the last decade are extremely relevant; however there are still several questions to work on, for example whether to expand to other countries and to new product categories. Therefore, the stricter legislations concerning e-waste (and, more in general, industrial waste), together with society consciousness, economic issues and lack of resources, have grown substantial interest towards producers responsibility. The main aim is of course to define and optimize the take back and recovery activities, i.e., to manage those activities that close the loop. It is now clear the extreme strategic importance of focusing on this new facet of green supply chain management. In the last years, several literature reviews about closed-loop supply chains have been edited (see for example Kleindorfer et al. 2005, Souza 2013). However, current literature usually tends to follow a too theoretical and academic slant, lacking in particular a concrete support for practitioners. Moreover, most of these studies do not adopt an integrated approach; they restrict themselves to solve isolated classes of problems rather than offering an overall view.

Our paper provides a guide to theory and practice about closed-loop supply chains, assuming the producer responsibility point of view. Our analysis explores some of the most important issues related to this broad topic, starting from the physical setting of the CLSC and gradually refining the decisions level, converging to the CLSC performance management. More in particular, we classify the existing literature in five main streams and, for each of them, delineate the closed-loop supply chain problem. Besides the more theoretical aspects, this paper aims to reveal some applications to the most relevant problems arising from industry, giving a more complete and concrete overview of the issues and decisions that managers should face when implementing CLSCs. Our work tries to go beyond the focus on isolated classes of problems: we rather follow an integrated approach and discuss the main interrelations among different classes of problems, and how a decision on one of them can impact the other decisions on different levels as well as the other players of the CLSC.

The paper is organized as follows: in Section 2, we present the typologies of returns that companies have to manage, and their interaction with the traditional open-loop supply chain, leading to the definition of the closed-loop supply chain; in Section 3, we present and analyze the five typologies of sustainable strategic decisions as introduced above; in Section 4, we discuss the managerial insights and offer directions for future research.

2 Closed-loop supply chain fundamentals

Closed-loop supply chain manages the reverse flow of materials and integrates it with the traditional supply chain. Today we define closed-loop supply chains as ‘the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volume of returns over time’ (Guide and Van Wassenhove 2009a). While companies, and more in general society, give considerable attention to many facets of sustainable supply chain management, they don’t well understand the connection between forward and backward supply chains. In particular, ‘progress is slow since closed-loop supply chains are rarely considered as creating value systems’ (Guide et al. 2003). That is the reason why researchers should also focus on this more recent issue and investigate on how to obtain concrete economic advantage from the management of the reverse logistics activities. In this section, we present the evolution from the open-loop supply chain to the closed-loop supply chain. Without lingering over the technological and operational issues, we first introduce and classify the typologies of returns that allow the transformation of the supply chain, and then illustrate how the supply chain design has evolved according to the new features presented.

2.1 Typologies of returns

Of course there could be several reasons for product returns. Retailers and (re)manufacturers experience different typologies of returns in different times (Guide and Van Wassenhove 2009a): i) commercial returns, ii) end of use returns and iii) end of life returns. Commercial returns occur for many different reasons: according to Guide et al. (2006), commercial returns can be classified as ‘defective’ and ‘non-defective’. The non-defective returns may occur, for example, when the customer cannot use the product correctly, the item does not satisfy the customer’s expectations, or the customer simply changes his mind. Some of these non-defective products are viewed as ‘new returns’, i.e., returned products are essentially new and can usually be resold after inspection, possible low touch refurbishment and repackaging. Commercial returns’ curve is similar to product life cycle’s curve, of course shifted to the right in the time axis (see Figure 1).

Insert Figure 1

When a new product is introduced into the market (ramp-up phase), commercial returns increase, then they remain approximately constant (steady state phase) and finally they decrease (ramp-down phase) because the product is discontinued and the warranties expire. End of use returns occur when the product's original use has been completed, although it is still functional (for example, a product replaced by technological upgrade). This happens especially for technological products, e.g., mobile telephones. Finally, end of life returns occur when the product is no longer functional. In addition to commercial returns, end of use returns and end of life returns, Guide et al. (2005) also present the 'channel returns' that can derive from overstock or stock adjustment, and the demonstration returns. A further classification is characterized by the 'operational goal' of the return: a product can be returned in order to be reused without any additional production process (this can be for example the case of non-defective commercial returns), can be remanufactured and reintroduced in the market with the same form and quality of the original product (this can be for example the case of end of use returns), or can be recycled, i.e., transformed into new raw material (this can be for example the case of end of life returns).

2.2 From open-loop to closed-loop supply chain

In the past decades, it was only considered the flow of products from manufacturer to consumers. The process was entirely linear; cyclic processes, sustainability and industrial ecology principles have not been introduced yet. Figure 2 shows a traditional representation of the open-loop supply chain: materials flow from the primary producer to the final consumers through manufacturer, distributors and retailers in a completely linear process.

Insert Figure 2

The introduction of the collection and recovery activities due to the increasing attention to the environmental facets changed the physical structure of the network, leading to the more complex system represented in Figure 3. A closed-loop supply chain is a supply chain that is designed to consider the acquisition and return flows of products, reuse, remanufacturing and recycling activities, and the distribution of the recovered items. Products may be reused by the user (in the primary or secondary market), returned to the manufacturer for remanufacturing, returned to the primary producer for recycling or disposed. Smart companies have understood that returned products often contain value to be recovered. So, in addition to the sustainable aim, companies should also implement recovery activities in order to obtain economic advantages. In this paradigm, environment and profit are not competing perspectives to be balanced, but can be maximized and optimized at the same time.

Insert Figure 3

3 Decisions related to the closed-loop supply chain

In this section, we present and discuss some of the most important decisions related to the closed-loop supply chain: i) location-allocation problem, ii) returns collection design, iii) inventory control with product returns, iv) returns grading decisions, and v) performance management of closed-loop supply chain design.

3.1 Methodology

This study was triggered by a conversation we had with a multinational beverage can manufacturer, who is actively involved in the development of sustainable practices. We were asked, in particular, what are the main steps to follow in order to build and manage a sustainable closed-loop supply chain, and what are the main guidelines that managers, in practice, should follow when implementing and monitoring it. Partially driven by the main literature reviews on CLSC theories (e.g., Souza, 2013), we started searching in the literature the most relevant topics under both a theoretical and practical point of view. We selected five main classes of problems and, among the top journals in these fields, we individuated the most relevant papers published in the last ten-fifteen years. In order to address concrete issues, we finally selected only the articles that presented a possible real application in the industry. On this basis, we clustered our selection in five main classes and, for each of them, presented the main characteristics and research questions, the methodologies used for the modeling and solution and the main applications to real world problems. We then provided guidelines for managers in order to concretely apply these theories and alert them on the main issues that can arise when implementing CLSC's strategies. The logical flow we adopted follows the CLSC decision process: we started with the definition of the general problem (i.e., physical setting of the network) and gradually refined the decision level, converging to the CLSC performance management.

3.2 Location-allocation problem

The location-allocation problem is one of the first issues considered in the network design; in fact it was formerly studied in the forward supply chain implementation. Problems like distribution centers or warehouses location concerning the forward flow were widely discussed in the previous decades. But only in the last decade, with the definition and increasing attention to the closed-loop supply chain, the reverse flow and the related facilities have aroused a growing interest. Similarly to the forward design, we have to face analogous problems in the backward supply chain: for example, we have to locate the center(s) for the collection of the returned products, to locate the (re)manufacturing centers and to optimize the collection routing.

3.2.1 The general model

As already presented in Section 2, the general closed-loop network consists of (one or more) production plants, (one or more) warehouses, customers and (one or more) collection/disassembly centers. The forward network manages the flow from the manufacturer to the final customers, through the warehouses and possible distribution centers; the backward flow takes into account the flow from the final customers to the (re)manufacturer, through the collection/disassembly centers. Usually, in order to more easily model the network, customers are grouped in zones, each of them with a known demand to be satisfied. Figure 4 represents a general supply chain with reverse flow, including manufacturer, warehouses, customers and disassembly centers.

Insert Figure 4

One of the first issues formulated was the definition of the channel for the reverse flow: Fleischmann et al. (2001) investigated whether or not, and under which conditions, to integrate collection and recovery activities within the existing forward network. Most of the recent models (Jayaraman et al. 1999, Beamon and Fernandes 2004, Sahyouni et al. 2007, Salema et al. 2009, Salema et al. 2010) combine forward and reverse networks into one integrated bidirectional network, and simultaneously solve the location and assignment problems both for the forward and the reverse network. Of course, one of the main reasons of combining the two networks is the economic advantage that can be gained using the same facilities. A very interesting case is presented in Sahyouni et al. (2007). Here, besides the basic model with economic incentive to induce the integration of the forward and reverse network, the authors present two alternative models imposing physical constraints that require one network to fit within the other. In the first case (forward dominant model), the set of reverse collection centers is required to be a subset of the forward distribution centers. Of course this model could be efficiently applied when the amount of returns is low (i.e., products are in the early stage of their life cycle). In the second model proposed (reverse dominant model), the set of forward distribution centers is required to be a subset of the reverse collection centers. This time, the model could be appropriate for products near their end of life, when the number of sales is (largely) decreasing, while the number of returns is supposed to be increasing.

3.2.2 Variables and objective

The primary objective of the general location-allocation problems is to determine which of the potential facilities (warehouses and collection centers) will be opened, which customers are served from which plant/warehouse and to which warehouse/collection center each customer returns the products. The problem is usually formulated as a linear problem minimizing the total costs in terms of investment costs (opening and installation cost for the facility) and operational costs (maintenance, sorting, holding and transportation costs), both in the forward and in the backward chain. Of course the problem is subject to several constraints, i.e., conservation of the flow, capacity constraints in the facilities, demand fulfillment and constraints on the variables (e.g., integer or binary requirements on the variables). Sometimes, instead of minimizing the total costs, the objective could be to maximize the global supply chain profit (see for example Salema et al. 2009). Finally, in some models, the authors also consider penalty costs for the non-satisfied demand or returns: Fleischmann et al. (2001), Salema et al. (2009) and Salema et al. (2010) introduce two different kinds of penalty cost, one for not serving demand of the customers (forward network) and another one for not collecting returns from customers (backward network). Beamon and Fernandes (2004) consider a different typology of penalty cost: in their model, the transportation cost from the customers to the warehouses is affected by a penalty cost depending on the condition of the returned products. Then, a used product returned in a 'poor condition' (in terms of remanufacturing process), will be affected by the penalty cost. The main reason of this strategy is to avoid the useless transportation of products that will be rejected at the remanufacturer center because of their bad condition. In reverse logistics, some authors don't consider the economic value of time, or they just introduce an equivalent cost. Within the models proposed in this section, only Beamon and Fernandes (2004) give attention to this facet: in particular, they apply the present worth method, yielding a more accurate estimation of the network costs.

3.2.3 Quantitative methods for problems solution

Most of the logistics network design problems are solved using mixed-integer linear programming (MILP). One of the main limits of the MILP models is the exponential growth if applied to real problem instances. In some cases (see for example Sahyouni et al. 2007), the solution time and the complexity of the problem lead to the use of special methods, such as Lagrangian relaxation algorithms. In le Blanc et al. (2004), in order to face the high uncertainty in parameter estimation, the authors model the transportation activities as a separate vehicle routing problem. In this way, they are able to provide an estimation of the transportation costs for each candidate location (dismantlers) and use this estimation as input to the optimization model, in order to optimize the allocation and determine the optimal number of depots.

3.2.4 Applications of the models

In some cases, the models are developed in order to solve a specific and already well defined problem, other times the main aim of the paper is to develop a more general model and then apply it to some case studies. Fleischmann et al. (2001) develop a very generic model for product recovery network design. The main aim is to examine the impact of product recovery on the physical network structure, and investigate whether or not to integrate the forward network in the existing one. For this reason, they present two different models: in the first one, they develop a model for the forward flow only and, after that, the product recovery is introduced and is integrated into the existing network (sequential network). A different approach is to develop a model that simultaneously optimizes the forward and backward flow (integrated network). They illustrate the models by means of two examples inspired by real life industrial cases: the first example is a copy machine supply chain, involving the activities of collection of the used copy machines, remanufacturing and reselling; the second example concerns a paper supply chain, involving recovery activities. In both examples, the sequential and integrated networks lead to different solutions; however, while in the copy machine example there are no substantial differences of costs between the two models, in the paper example the integrated model lead to significant cost benefits. This means that, while in some models we can easily extend the existing forward network to the product recovery activities, sometimes we can't ignore the important advantage of the integration of the forward and backward flows. Jayaraman et al. (1999) develop a generic reverse logistics model for closed-loop supply chains and test their model on a set of problems in the electronics industry in North America. Once again, the model consists of some potential locations for remanufacturing and distribution, some collection zones and some customer zones that demand different lines of products. Sahyouni et al. (2007) test their models on two data sets, one based on the 150 largest cities in Europe, and the other on the 263 largest cities in U.S. states, representing the prospective facility site locations. As already stated in Section 3.2.1, the conclusion of this study determines when one typology of network is to be preferred to the others: the forward dominant model could be efficiently applied when the products are in the early stage of their life cycle, the reverse dominant model could be appropriate for products near the end of their life cycle and the location model could be appropriate for products in the middle of their life cycle. Beamon and Fernandes (2004) create four different scenarios in the generic location problem, with the aim of analyzing the impact of different operational costs (maintenance, sorting, holding and transportation costs) on network design. In the first scenario, the maintenance cost represents the highest component of the operational costs; in the second one, the inspection/testing/sorting cost is the highest; in the third one, the transportation cost is the highest and in the fourth one, the holding cost is the highest. The results of the models show that, in order to minimize the total costs, the first two scenarios lead to the use of collection centers, while the last two scenarios lead to the use of warehouses. In Salema et al. (2009), the authors apply their model to a modified case study. They consider a company in the Iberian Peninsula with different possible locations for the manufacturing plants, for the warehouses and for the disassembly centers. In addition, the company manages three families of product in the forward chain, and two families of products in the reverse chain. The paper considers strategic decisions (i.e., design of the network) and tactical decisions (i.e., production, storage and distribution planning). Salema et al. (2010)' s model is applied to a Portuguese glass company that wants to integrate her only factory with others on a national basis; furthermore, that company also needs to open new warehouse and sorting facilities, simultaneously considering both the forward and reverse supply chain. Similar to their previous work, the authors focus both on strategic and tactical decisions. le Blanc et al. (2004)' s study focuses on the problem of the collection and recycling of end of life (gas) vehicles (ELV) in The Netherlands. This case study, besides the 'standard' characteristics similar to the other models, also introduces a high safety risk. The existing model involved the collection and dismantling of the liquefied petrol gas (LPG) tanks by the ELV dismantler. From here, the tanks were sent to the degassing facility, and finally reintroduced in the secondary market. The problem arose when the ELV dismantler, in order to take advantage of the more profitable trade of the LPG tanks, didn't send the tanks to the degassing facility for degassing, but directly traded them in the secondary market. If a LPG tank is not degassed, the remaining gas inside it can cause an explosion. For this reason, the Auto Recycling Nederland (ARN) changed the recycling system in order to let the tanks return to the ELV dismantlers and let them trade the tanks themselves. At this point, a redesign of the network was required. The paper presents two alternative models: the first one consists of a central strategy, where the tanks are periodically collected at the ELV dismantlers and delivered to the current central degassing station (one location). After that, the tanks are redistributed to the ELV dismantlers for reselling. The second model consists of a regional strategy: the tanks are brought to some regional depots, where a mobile degassing facility periodically goes. Once again, after the degassing process, the tanks are redistributed to the ELV dismantlers for reselling. The aims of the models are to implement the best strategy in terms of costs and (in case of regional strategy) determine the number and location of regional depots.

3.2.5 Managerial implications for the location-allocation problem

One of the first questions managers should investigate when implementing CLSCs is the effect of the reverse flow on the forward chain and whether to integrate or not the forward and the backward network. In some cases, the presence of the reverse flow doesn't affect that much the forward facilities; this means that the product recovery can be implemented without big changes in the forward network. In other cases, instead, a—sometimes high—economic advantage emerges from the simultaneous integration of the forward and reverse logistics. In general, the forward flows dominate the network design and the impact of reverse flow increases with the increase of the return volumes, and therefore with the economic incentive for product recovery. An important facet when choosing the most appropriate network design is the product life cycle stage: according to the phase in which the product is (beginning, middle or end of life), a typology of network would be preferred to another; a similar consideration occurs for the return rate. Optimizing the network design is not sufficient by itself: managers should also make sure to have enough reverse flow and the necessary facilities/technologies in order to process items and generate adequate benefit from the returns management activities. In such context, companies should always consider the high level of uncertainties deriving from the timing and quality of returns, and from the interaction with the other supply chain players (e.g., suppliers and customers). Moreover, they should also compare the results deriving from the analysis of the reverse chain with those deriving from the analysis of the forward chain in order to reach a higher level of integration.

3.3 Returns collection design

The organization of products take-back can vary largely, depending on the structure of the supply chain, the product characteristics, and the technical processes available to reuse, remanufacture and recycle the products. In this section, we focus on the product collection from the retailer; in particular, we investigate when a manufacturer would choose to collect used products directly from the consumers instead of allocating the reverse channel responsibility to the retailer(s) and managing collection indirectly via the retailer.

3.3.1 The general model

We are going to present two different typologies of models for the returns collection, one centralized and one decentralized model. Both models consists of a manufacturer, a retailer (in some models, we extend this assumption to the case of two retailers), customers and a possible third party. In Figure 5, we provide an example for the centralized model and the decentralized model (direct and indirect collection) for the returns collection.

Insert Figure 5

3.3.2 Definition, solution and applications of the models

Savaskan et al. (2004) present three decentralized models and one centralized model, involving some or all of the following actors: manufacturer, retailer and third party. In each model, the actors choose to maximize their single profit (in case of decentralized model), or the overall profit (in case of centralized model). The first model proposed (model C) is a centrally coordinated system with a single decision maker who therefore maximizes the profit of the whole supply chain. The other three models are decentralized models: in one case (model M), the manufacturer undertakes the collection of the used products and determines the wholesale price and the return rate; in the second case (model R), the retailer undertakes the collection of used products, and in the last case (model 3P), a third party undertakes the solely returns collection. The results of this paper show that, in terms of return rate, the third party has less incentive to invest in increasing the return rate than the manufacturer and the retailer since her marginal gains is less compared to the other models. However, although the manufacturer and the retailer face the same marginal gains from investing on increasing return rate, it results that the model M has a lower product return rate than the R model. Another important consideration is about the profits: the centralized model's profit always dominates the profits of the other models; in particular, we can grade the total (centralized or manufacturer plus retailer) profits in the four different models as follow: $\Pi^*_C > \Pi^*_R > \Pi^*_M > \Pi^*_{3P}$. The paper also presents a way to further improve the profit of the manufacturer in the R model using a single two-part tariff. In a second paper, Savaskan and Van Wassenhove (2006) extend this previous work introducing competition between two retailers. The paper presents two centralized models (direct collection from the customers) and two decentralized models (indirect collection from the customers–via retailers), each of them consisting of a manufacturer/central planner and two competitive retailers. In the centralized models, there is a single planner for the forward and reverse supply chain that maximizes the overall profit. In this way, the double marginalization is eliminated, leading to a higher incentive in the returns collection and remanufacturing. In fact, in case of double marginalization, the retailer price is higher, resulting in a lower demand and a lower level of returns. That means, a lower incentive for investment in returns collection and lower profitability in remanufacturing operations. In the centralized direct collection model (model CD), the central planner undertakes the collection of the used products from the customers and maximizes the whole (forward and backward) supply chain profit. In the centralized indirect collection model (model CI), the central planner indirectly undertakes the collection of the used products from the customers via the retailers. Once again, the central planner maximizes the overall profit. The first model is to be preferred to the other when there is a collection cost advantage. The decentralized models consist of a manufacturer and two competitive retailers. Each player acts independently and maximizes his own profit. In this way, we are not able to avoid the double marginalization with its negative effects discussed above. In the decentralized direct collection model (model DD), the manufacturer undertakes the returned products collection from both the retailers. In this model, each retailer chooses the retail price taking into account the wholesale price charged by the manufacturer and the competition with the other retailer. In the decentralized indirect collection model (model DI), the manufacturer indirectly undertakes the collection of the used products from the customers via the retailers. In this model, the manufacturer pays each retailer a fixed fee for every unit returned. A different situation is presented in Shulman et al. (2010). In their paper, the authors consider a different typology of returns, due to a product mismatch with customer's preferences. The basic model involves a manufacturer who produces two products located on a Hotelling unit line. The manufacturer sells the products to the retailer and the retailer sells the products to the consumers. Consumers are uninformed about the net utility (i.e., the utility given by the difference between their ideal taste parameter and the real location on the Hotelling line of the product purchased) before acquisition. For this reason, after the purchase, it may happen that they decide to return the product and exchange it with the other one. When the customers return the products, they have to pay a penalty (that includes for example shipping costs for the return). Once the product is returned, the retailer can decide whether or not to return it to the manufacturer (receiving a refund) who resells it to a secondary market. Alternatively, she can directly resell it to the secondary market himself. Of course, a crucial point is the salvage value of the product returned: if this value is greater than the refund paid by the manufacturer, the retailer doesn't have any incentive to return the product back. Similarly to the other models described in this section, the paper presents three alternative reverse channel structures, one centralized and two decentralized. In the vertically integrated system (VIS), there is a single agent (the manufacturer) who takes both the forward and reverse decisions, maximizing the overall profit. In the decentralized models, the retailer and the manufacturer maximize their single profits: in the first case, the retailer assumes the returns responsibility; in the other case, she returns the products to the manufacturer who will sell them in a secondary market. Atasu et al. (2013) extend the model of Savaskan et al. (2004), introducing in the collection cost function, in addition to the return rate, also a new component, i.e., the collected quantities. In this way, they model the economies or diseconomies of scale deriving from the collection quantity. Furthermore, they also enlarge the analysis to the scenario where new and remanufactured products are not perfectly substitutes. Comparing the optimal solutions under different scenarios, it results that, under economies of scale, the retailer would undertake the returns collection and she would collect all possible units; while under diseconomies of scale, the manufacturer would undertake it. Concerning the collection cost, the results show that there exists an interval of values between which the retailer-managed collection leads to higher profits; in all the other cases it will be adopted a manufacturer-managed collection. The third party solution is always dominated by the other two.

3.3.3 Managerial implications for the returns collection design

In Table 1, we summarize the characteristics of the models presented. In general, we can argue that the main reason of undertaking or not the products collection derives from the economic advantage that the players have in the collection/recovery/reselling activities. From the analysis of these models, the immediate disadvantage for undertaking the returns collection results to be the investment cost related to the collection activities supported by the manufacturer or the retailers. In a competitive environment, the manufacturer would prefer the indirect collecting system because the competition between the retailers would incentive them to decrease the selling prize. In that way, the demand for the product will increase with obvious benefit for the manufacturer. Furthermore, when a manufacturer or retailer undertakes the returns collection, additional coordination with the other departments within the same company and with the other supply chain players is required. Similarly to the forward supply chain design, a different CLSC structure can be preferred to another depending on the surrounding environment (e.g., number of competitors, cost structures, available technology, etc.). Managers should also consider that the results showed so far could change considerably in case that the retailer (or the manufacturer) charges or increases a penalty fee for returns.

Insert Table 1

A further extension of these models is presented in Toyasaki et al. (2011). The paper considers a two manufacturers-two recyclers environment. The first difference from the previous problems is the introduction of competitive manufacturers. Secondly, instead of remanufacturing processes, the authors focus on recycling of collected end of life products. This involves the presence of recyclers that sell recycled materials to a different market (recycling material market): in particular, the basic model analyzes two scenarios, one with two recyclers and another one with two recyclers and a nonprofit organization. The results show that consumer and manufacturer generally prefer the competitive scheme (because of lower prices for customers and higher profits for manufacturers), while recyclers' preferences depend on product substitutability and economies of scale in recycling costs; therefore, it is not always possible to get to a 'win-win' result.

3.4 Inventory control problem with product returns

Inventory management has been widely discussed in the traditional inventory control literature. The introduction of the activities related to the reuse/remanufacture/recycle of product returns arose the need to analyze the impact of an exogenous inbound material flow on inventory control and manage the returned products inventory in their different stages. The first approach to closed-loop supply chain inventory management only involved the reuse activities, i.e., returned items are added to a serviceable stock immediately (possibly after a short inspection/sorting/repackaging activity) and can be directly reused. Alternatively, the returned products can't be immediately reused, but require to be repaired or remanufactured: the basic model was so extended to different recovering activities.

3.4.1 The general model

The general inventory system with returns, represented in Figure 6, involves a recoverable inventory, where the returned products are temporarily stored, a possible 'tested inventory', where the products that successfully passed the test are stored, and finally a serviceable inventory, where the recovered products are stored before being reintroduced into the market/production process.

Insert Figure 6

The costs involved in the general inventory control problem are: order/shipment cost, remanufacturing cost, disposal cost, holding cost (at the recovery facility and at the warehouses) and penalty cost due to unsatisfied demand (a typical assumption is that excess demand in each period is fully backlogged). Product demand consists of two different (usually complementary) sources: part of demand is served from the returned (and possibly remanufactured) items, another part from the new manufactured items. In reality, demand could be modeled as a function of the returns in the previous periods, i.e., returns occur because of a previous demand: this can be for example the case of commercial returns (if a customer returns a product for some reason, he usually expects to get a new one). However, modeling this scenario would significantly increase the complexity of the model; for this reason we usually don't consider this eventuality, and assume demand to be independent identically distributed as an integer random variable. Typically demand assumes positive values; however, in some models (Fleischmann and Kuik 2003, Khawam et al. 2007) it may assume both positive and negative values. Furthermore, inventory control models with returns usually consider the presence of backorders that must be fulfilled in the following period. Concerning the time for manufacturing, remanufacturing and deliveries, the models consider constant values for the lead times. Assuming the same lead time, Zhou et al. (2011) transform the model into an identical one with zero lead times: this means that quantities ordered or remanufactured in a certain period can be used to fulfill demand in the same period. In this way, they can focus on inventory positions instead of inventory levels and find an analytical solution. Successively, they relax the assumption of zero lead times and consider a system with non-identical lead times. However, in this case, the model can't provide an analytical solution, and so they develop a simple heuristic. Khawam et al. (2007) assume first a constant value for the remanufacturing lead times, and then they extend their model to the case of variable lead times. In order to implement the optimal policy, DeCroix (2006) assume that delivery lead times are fixed but can vary among stages, although they assume that the delivery time of remanufactured products from the recovery facility to stage k coincides with the one to stage $k + 1$.

3.4.2 Variables and objective

Similarly to the traditional inventory control problem, the aim of the inventory control problem with returns is to minimize inventory levels in order to minimize the total costs. In this case, the objective is to find the optimal manufacturing (i.e., orders for new items), remanufacturing (in case returns are also subject to remanufacturing activities) and disposal policies, in order to minimize the expected total costs. Some models add a further characteristic to the recovery process: in Zhou et al. (2011) and Tao et al. (2012) the returned products, after inspection, are classified into different typologies (with different remanufacturing costs) according to their physical condition. Of course, this increases the complexity of the decisions because each time a new serviceable product can be remanufactured from different types of returns. Khawam et al. (2007) add to the model's goal a specified service level to be satisfied. In particular, the model requires customers' orders to be fulfilled within a certain time.

3.4.3 Quantitative models

Due to the prohibitive complexity of the network, some models can't be solved in a closed-form expression, but they can only provide an approximation of the optimal behavior (for example through heuristics). Fleischmann and Kuik (2003) transform their model into an equivalent one with non-negative demand only, for which it can be demonstrated the optimality of a (s, S) control policy. In DeCroix (2006) the problem is formulated as a minimization problem, optimizing the total discounted cost: the optimal policy is given by the combination between a traditional series system without remanufacturing and a single-stage system with remanufacturing. Khawam et al. (2007), due to the complexity of the model, provide a near optimal solution through heuristics. Zhou et al. (2011) formulate their model as a dynamic programming problem. In order to demonstrate the value of the optimal policy, the authors compare the resulting cost of the optimal policy with two heuristics policies. However, extending the model to non-identical manufacturing/remanufacturing lead times, the model is not able to provide an analytical solution anymore, but it develops a simple heuristic. In order to find the optimal ordering/remanufacturing policy, Tao et al. (2012) solve a multi-period stochastic dynamic problem so to minimize the total discounted cost.

3.4.4 Managerial implications for the inventory control problem with product returns

We can conclude that the inventory control problem with returns extends the traditional inventory control problem. Its main goal is to analyze the impact of an exogenous inbound material flow on inventory control and manage the returned products inventory in their different stages. The main feature that should guide managers in the remanufacturing choices is the trade-off between the disposal costs and the remanufacturing costs for used items, of course in relation to the manufacturing costs for new items. As the cost savings deriving from the recovery processes increase, companies will try to fulfill demand with returned items, and only after that, have recourse to new items. Within their analysis, companies should also be aware of the correlation that usually exists between return rate and product demand and try to adjust their demand forecast and processes accordingly.

3.5 Remanufacturing problem with returns grading

3.5.1 The general model

Most of the literature presented so far considers the returned items as homogeneous, i.e., does not differentiate returned items according to their residual quality. In this section, we investigate the case of a firm (may it be a manufacturer, a remanufacturer or a third party) who receives and grade returns on the basis of to their residual quality. Following this classification, each class of return is remanufactured according to a certain remanufacturing cost: processing returns with high residual quality will result cheaper than for the ones with low residual quality. In Figure 7, we present a general model for the remanufacturing problem with multiple quality classes: returns are collected into the grading facility, classified, and remanufactured according to their residual quality.

Insert Figure 7

Some papers (Souza et al. 2002, Guide et al. 2008) also add the possibility of selling the item ‘as is’, without any additional recovery activity, while in some other cases (see Tao et al. 2012) remanufactured—as well as and new items—are entirely used to satisfy demand, i.e., there is no product disposal. We do not include in our analysis the market segmentation deriving from different willingness to pay of customers for new and remanufactured products. Souza et al. (2002) present a model in which returned items are classified into different classes according to their residual quality and then, depending on this classification, are either remanufactured or sold ‘as is’ at a lower price. In this way, companies sell to different market segments, providing different product quality at different prices. Modeling the different quality classes as a GI/G/1 queue network, the authors determine the optimal returns mix to be remanufactured such to maximize the profit. The model also introduces a service level constraint defined as the maximum throughput time that items can spend in the reverse chain. Galbreth and Blackburn (2006) present the problem of defining how many unsorted returned products a remanufacturer should buy from a third party and the sorting policy for those items. The sorting activity will reveal which returns should be remanufactured and which should be scrapped. Guide et al. (2008) define when it results more convenient to remanufacture returns (and then sell them in the secondary market) instead of selling them ‘as is’ (at a salvage value), according to the required remanufacturing time. This model differs from the others since here the driver for the recovery activity is the required remanufacturing time rather then the residual quality level. In their model, remanufacturing costs are indeed increasing with remanufacturing time, and the secondary market price is time sensitive, i.e., the secondary market price decreases with remanufacturing time. Therefore, an increase of the delay in the remanufacturing activities will increase the benefit of selling the product ‘as is’ (i.e., without being remanufactured). Ferguson et al. (2009) develop a production planning problem in order to find the optimal returns mix and the amount of inventory to carry for future periods when different quality levels of returned items are available. Tao et al. (2012) present a model that determines the optimal order/remanufacturing policy (for new and remanufactured items) that minimizes the total expected discounted costs over a finite horizon, when different quality levels of returned items are available. In this model, the complexity of the problem further increases because, besides the uncertainty deriving from returns quality, the manufacturer also faces uncertainty in terms of coordination of new and remanufactured products.

3.5.2 Variables and objective

The objective of this class of problem is either to maximize the profit or minimize the total cost. Souza et al. (2002) define a maximization problem as function of the quantity to be remanufactured at each station, where each station is associated with a different quality class. Galbreth and Blackburn (2006) minimize the total cost at the remanufacturer, as function of the returns quantity purchased. Guide et al. (2008) maximize the total discounted profit as function of the threshold value for admitting returns into the refurbishment queue. Ferguson et al. (2009) maximize the total profit as function of the quantity to be remanufactured and the quantity to be salvaged in each period.

3.5.3 Quantitative methods

Due to the complexity of the models, this class of problems can be solved using different methodologies. Souza et al. (2002) define a maximization constrained problem that is always able to provide an optimal solution to their problem. Furthermore, they also resort to simulation in order to test different dispatching rules for the returns classification, and analyze the effect of inaccuracies in returns grading. Galbreth and Blackburn (2006) develop a cost minimization problem and they prove the existence of a unique solution. Guide et al. (2008)'s problem can be solved using any search algorithm provided that the flow time of each job is approximated with its expected value. Ferguson et al. (2009) formulate a stochastic dynamic program to maximize the total profit. Furthermore, they provide a simple greedy heuristic in the case of deterministic demand and returns.

3.5.4 Managerial implications for the returns quality problem

The main benefit of grading returns derives from the cost savings in remanufacturing first items with high residual quality rather then—or before—the ones with low residual quality, which is more expensive. The choice of the dispatching rule represents a key point for decreasing the flow time and increase the service level and therefore the profit. When remanufacturing returns with low residual quality results not convenient due to high remanufacturing cost, they can be sold 'as is' at a lower price. The main issues to keep in mind when setting the returns grading are the sorting and testing costs, the uncertainty in timing and quality of returns, and the definition of a good dispatching rules to increase service level. The main conditions under which returns grading represents a relevant strategic decision for companies are that the cost of remanufacturing considerably vary among classes, returns quality follows a uniform distribution across classes, the rate of product returns is high enough, and the higher such rate is, the more beneficial is the advantage of products grading. Within these considerations, managers should not underestimate the presence of grading errors which affects the results. Therefore, they should try to mitigate and prevent such effect by using well defined standards for grading.

3.6 Performance management of closed-loop supply chain design

In this section, we present the performance management of the closed-loop supply chain design. Former research in the past decades only focused on the forward supply chain modeling, while the concept of reverse logistics and backward supply chain started to be advanced only in the last decade.

3.6.1 The general model

A closed-loop supply chain usually involves the following typology of actors (or some of them): manufacturer, distributor, retailer, customer, collection/evaluation center, and remanufacturing center that may or may not coincide with the manufacturer. Besides the operational ones, the flow of material involves other typologies of activities. For example, returns require to be stored in different stages of the supply chain before testing or remanufacturing, or the repaired parts needs to be stored before being resold. While most of the models involve all the players of the closed-loop supply chain, some models (Fleischmann et al. 2003) only focus on the design of the reverse flow, i.e., they don't consider the role of the supplier, of the manufacturer, and of the customers either in the forward flow. The standard organization of the returns always involves the customers who return the used products to the retailer (Guide et al. 2005, Guide et al. 2006, Khawam et al. 2007), to the collection center (Fleischmann et al. 2003, Biehl et al. 2007, Guide et al. 2006) or directly to the (re)manufacturer/recycler (Ferretti et al. 2007). Figure 8 shows a general model for the closed-loop supply chain, under the assumption that part of the returned products are reintroduced in the primary market and the other part are sold in the secondary market after remanufacturing activities.

Insert Figure 8

The network design problem can be solved using many different methods: sometimes it is possible to provide a solution in a closed-form expression, other times, we have to resort to heuristics (which provide insight and near optimal solutions) and simulation. Especially when the complexity becomes prohibitive, we can formulate the problem as a queueing network, develop a simulation model and test its robustness. When modeling a network as a queueing system, or, more in general, when the complexity of the model involves stochastic variables, we have to set some important elements that will influence the analysis of the supply chain performance: the inter-arrival time distribution, the service time distribution and the products demand. The inter-arrival time distribution is the distribution according to which the used products are returned to a particular player in the network (retailer, collection center, (re)manufacturer); the service time distribution is the distribution of the processing time at each node, and the stochastic demand can be referred to the finish goods or to the raw materials when the closed-loop supply chain includes recycling activities (Biehl et al. 2007). In Table 2, we summarize how some of the most relevant papers in the network design literature model the uncertainties described above.

Insert Table 2

As we can see, the inter-arrival times can follow different distributions, while the service time distribution is usually considered constant. It was chosen to model the service times as a constant in order to avoid extremely complex structures, or simply for lack of data. The importance of available data in order to better model the network is attested, for example, in Guide et al. (2005), where there is no information about the waiting time at the retailers before the products collection, or in Biehl et al. (2007), where the lack of data and the high variability in the returns lead to a problematic setup of the reverse logistics system and a difficult management of the bottlenecks.

3.6.2 Variables and objective

In the optimization of the network design, we can focus on many different facets: the whole closed-loop supply chain costs (Ferretti et al. 2007), the whole closed-loop supply chain profit (Guide et al. 2005, Guide et al. 2006) and the inventory control model (Fleischmann et al. 2003, Khawam et al. 2007, Biehl et al. 2007). Ferretti et al. (2007) present three different models for the metal supply of the raw material (virgin and recycled material) in the aluminum supply chain. These models don't differ substantially in the network design, but they differ in the typology of metal supplied (entirely solid, entirely molten or both). The paper minimizes the total supply chain costs and compares the difference among the costs supported. Another paper that considers the interaction of different raw materials sources is Biehl et al. (2007). The authors present the carpet industry reverse logistics, focusing on the recovery of the nylon from the returned carpets and on the inventory management of the raw materials (virgin and recycled nylon). Fleischmann et al. (2003) develop an inventory control model for the management of the spare parts of personal computers: in particular, the authors analyze the interaction between new and used parts, and how the presence of the returned machines can affect the demand for the spare parts. A first basic model is presented and solved using inventory control theory; after that the paper increases the complexity of the network (including aspects such as stocking between dismantling and testing activities and two additional supply sources) and has recourse to simulation. Particularly innovative are the models proposed by Guide et al. (2005) and Guide et al. (2006) because they concentrate on the potential value of time sensitive returns. So far, very few papers have considered the economic value of time in the closed-loop supply chain. In fact, especially in the electronic market where products rapidly lose their value (for example it is estimated that personal computers can lose 1% of their value per week, Guide et al. 2006), delays can represent a significant loss. In particular, in Guide et al. (2005), the authors focus on the returns of notebook and desktop personal computers. The authors estimate the value erosion of the returns waiting for warehousing, test and remanufacturing and develop an optimization model in order to maximize the overall profit and reduce the lead times for the refurbishment activities (and then the value erosion of the returns). Guide et al. (2006) consider the problem of how to design the reverse supply chain in order to maximize net asset value recovered from the flow of returned products.

In their paper, the authors assume for both new and remanufactured products exponential price and variable cost decay function. This means that when delays occur (for example the delay of returned products until sale, or the delay of returned products to reach the evaluating facility), the overall profit decreases. Minimizing the processing rate (and so the waiting times) at each facility enables to maximize the profit. Khawam et al. (2007) present four alternative warranty models for electronic returns and provide near optimal solution to the inventory problems. Besides the stochastic characteristics already presented in the other models, here we face additional sources of uncertainty, i.e., the request for credit instead of the replacement of the returned product and the introduction of the lead time variability for the remanufacturing process. Some models also try to measure the environmental performance of the reverse processes: in Biehl et al. (2007) the authors measure, through simulation processes, the average content of recycled nylon in the new carpets produced; in Ferretti et al. (2007) the authors propose a trade-off analysis between the environmental impact (measured considering the emission of the main pollutant related to the recycling activities) and the supply chain costs.

3.6.3 Quantitative methods

As already said, some models can be solved in a closed-form expression, others can only provide an approximation of the optimal behavior (through heuristics and simulation). Ferretti et al. (2007) and Guide et al. (2005) provide an analytical solution for the models proposed; Khawam et al. (2007) provide a near-optimal solution through heuristics, Biehl et al. (2007) model their closed-loop supply chain using a simulation package, while Fleischmann et al. (2003) and Guide et al. (2006) provide both an analytical solution for the basic network and a simulation model for the more complex one.

3.6.4 Managerial implications and strategies to increase the network performance

The basis for a profitable CLSC implementation and management is that companies perceive product returns as a ‘value’ rather than a ‘waste’. Therefore, instead of passively accept returns, companies should actively try to forecast and manage them. When doing so, they always have to adopt the triple bottom line view: the CLSC has to produce economic advantage as well as creating value fo the society and the environment.

As discussed in the previous sections, the strategic value of time in CLSCs has been recognized only recently. There are several possible strategies affecting the timing of returns processing that can increase the closed-loop supply chain efficiency and effectiveness. Fleischmann et al. (2003) and Guide et al. (2006) present alternative models where the anticipation or the delay of some activities can increase the network responsiveness: Fleischmann et al. (2003) propose two alternative channels where the firm can choose whether to test the dismantled parts immediately or to postpone this activity until it really needs those parts. With the first option, the company can avoid holding defective parts in stock and reduce throughput time; with the second option the company can delay the investment in testing and can reduce its opportunity costs and risk of testing parts it won't need in future. Guide et al. (2006) consider an alternative design of the network where returns are sorted and immediately restocked at the retailer instead of being processed at the evaluation center, and then reach the retailer again through the distributor. This alternative model reduces the transportation costs, the workload for the evaluation center and the distributor and decreases the overall delay in the network. On the other hand, it increases the workload at the retailer, and so requires a capacity adjustment (e.g., hire and train workers). Of course, time by time, companies should consider the trade-off among the different choices available and select the best solution. Guide et al. (2006) also propose to decrease the average transportation time among the different agents (e.g., different location of facilities or choose faster transportation modes). When the company faces a peak in the supply of used products, it may be necessary to intervene in order to increase the processing rate at the collection center or at the (re)manufacturer. In order to face the peak at the remanufacturer, Guide et al. (2005) propose to introduce a broker who is able to remanufacture the exceeding quantities; in this way it is possible to decrease the unmet/delayed demand. Alternatively, the company can choose to transfer some activities in house, in order to decrease the workload at the remanufacturer. In Table 3, we summarize the model proposed in the selected literature about closed-loop supply chains design: for each model presented, we report the actors involved in the network, the organization of the return activity, the decision variables, the objective and the quantitative models used for the solution of the problems.

Insert Table 3

4 Managerial insights and further research

In the previous sections, we presented the main strategic decisions discussed in the closed-loop supply chains literature in order to implement sustainable policies. We classified the literature in five main streams: i) the location-allocation problem, dealing with the management of the reverse flow and the related facilities; ii) the product collection problem, dealing with the design of the collection process of used products from the customers; iii) the inventory control problem with remanufacturing, dealing with the impact of the exogenous inbound material flow on inventory control and the management of the returned products inventory in their different stages, iv) returns grading decisions, dealing with the classification of returned items according to their residual quality before processing them, and v) the performance management of the closed-loop supply chain design, dealing with the modeling of the closed-loop network and analysis of its performance. We briefly described the mathematical formulation of these problems, the quantitative methods for their solution and presented their applications to real life models.

4.1 Managerial insights

The conducted analysis reveals that the implementation of sustainable strategies can be complex and costly because it requires a high level of coordination and integration, and investment for building up (or integrating) the reverse network. However, if correctly implemented and managed, closed-loop supply chains can generate benefit, not only under the environmental perspective, but also under the social and economical one: environment and profit are not competing perspectives to be balanced, but they can be maximized and optimized at the same time. We highlighted several practical applications and provided concrete guidelines for managers (see also Sections 3.2.5; 3.3.3; 3.4.4; 3.5.4; 3.6.4), which can be briefly summarized as follows. Companies should consider returns as a value to be maximized rather than a waste to be minimized: in this view, they should always take into account the sensitivity of the network (and related performance) to the return volume. In order to implement their solutions, managers should analyze whether the reverse flow, the available technologies and the facilities are adequate to effectively manage the supply chain. Moreover, they should be able to correctly estimate all the relevant returns management costs and effort required, and be aware of their competitors both in the forward and in the reverse chain. Concerning the returns grading possibility, it is important to first understand if and under which condition a dispatching rule could benefit the remanufacturing process and how to implement it. In addition, companies need to be prepared to manage all the uncertainties deriving from product returns. Most important for managers is to understand the necessity to adopt a boarder view, focusing on several facets of the same issue at the same time and considering the impact of a decision taken on a particular level on the whole CLSC performance. Our paper tries to face the CLSC decision problems as an integrated set of decisions. Although there are still several direction of research to explore, we believe that our approach offers a beginning for a more in depth and complete analysis of CLSCs.

4.2 Future directions of research

Concerning the model formulation, future research in closed-loop supply chains aims to better model the network and refine most of the assumptions made in the earlier problems. First, we can relax some assumptions on the problem formulations: we can, for example, develop models including capacity constraints in the collection/remanufacturing centers, or consider, instead of constant lead times, variable lead times in the collection/remanufacturing/delivery activities. Another extension can introduce (or better define) a penalty function in order to avoid, in the collection activities, additional transportation of products not suitable for remanufacturing. Concerning, in particular, inventory control problem with product returns, future research can include setup costs for (re)manufacturing activities and extend the basic model to multiple locations. Another direction for further research could consider a different customer's willingness to pay for the new or remanufactured product. This can generate a market segmentation: retailers (or resellers) can sell different products in the primary market at different prices according to customers different utilities. In this way, they can address to different categories of consumers.

Besides the above-mentioned extensions of research, there is a general need of evolution in CLSCs research. Research in CLSC needs to follow and adapt to the technological evolution, like the new technologies used for returns collection/testing/remanufacturing and to the new technologies and the new directives followed for product design (e.g., design to disassemble). In a similar way, research also has to follow the market trend and the market's needs. First of all, product life cycles and selling seasons are shortening even further, revealing the significant role of time, especially for products that loose rapidly their value (like the electronic or the fashion ones). As already discussed in Section 3.6, for such items it becomes relevant to analyze the potential value of time sensitive returns and to examine the differences between returns management for the more traditional supply chains and for the fast-turnaround supply chains. Moreover, in the recent years, the explosive growth of the Internet has allowed for the introduction of new sales channels, which leads to rethink or readapt the existing supply chain structure, and which leads to completely new issues to be managed: a much higher returns volume and related processing issues; inventory forecast and coordination; higher competition and higher market segmentation. In addition to this, research cannot ignore the legislation evolution, like the environmental legislation discussed at the beginning of our paper or the more recent online sales regulations (just consider the impact of a legislation—like happened in the European countries until June 2014—which obliges retailers to undertake the collection costs for items sold through the online channel). Researchers should follow a boarder approach, moving from solving isolated classes of problems and link the operational issues of CLSCs (e.g., product collection, remanufacturing, etc.) with other functions and disciplines related to economics and marketing (e.g., optimal pricing, customers behaviour, product remarketing and multichannel sales). It is relevant, indeed, to include multidisciplinary perspectives, and integrate the supply chain in a more general context, trying to follow the evolution and the new trends in business, society and environmental issues.

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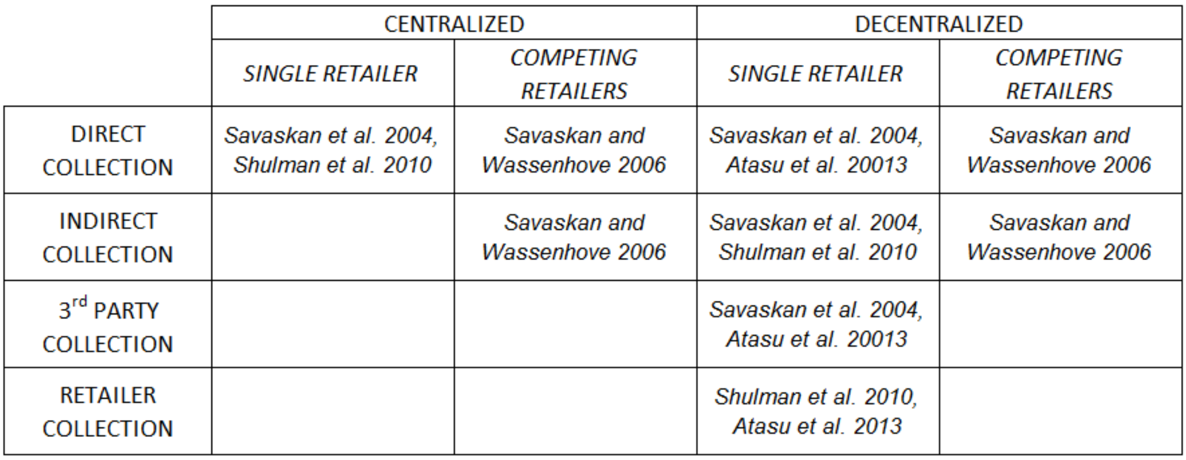
Table 1: Summary of product collection design



	CENTRALIZED		DECENTRALIZED	
	SINGLE RETAILER	*COMPETING RETAILERS*	*SINGLE RETAILER*	*COMPETING RETAILERS*
DIRECT COLLECTION	*Savaskan et al. 2004, Shulman et al. 2010*	*Savaskan and Wassenhove 2006*	*Savaskan et al. 2004, Atasu et al. 20013*	*Savaskan and Wassenhove 2006*
INDIRECT COLLECTION		*Savaskan and Wassenhove 2006*	*Savaskan et al. 2004, Shulman et al. 2010*	*Savaskan and Wassenhove 2006*
3rd PARTY COLLECTION			*Savaskan et al. 2004, Atasu et al. 20013*	
RETAILER COLLECTION			*Shulman et al. 2010, Atasu et al. 2013*	

Table 2: Summary of the network uncertainties' characteristics

References	Inter-arrival time distribution	Service time distribution	Demand
Fleischmann et al. (2003)	Poisson	Constant	Poisson
Guide et al. (2005)	Constant	Constant	Constant
Guide et al. (2006)	Exponential	Exponential	Exponential
Biehl et al. (2007)	Longnormal	Constant	Normal
Khawam et al. (2007)	Normal	Constant	Normal

Table 3: Summary of the closed-loop supply chain design models

REFERENCES	***Fleischmann et al. (2003)***	***Biehl et al. (2005)***	***Guide et al. (2005)***	***Guide et al. (2006)***	***Ferretti et al. (2007)***	***Khawam et al. (2007)***
ACTORS						
supplier			x		x	
manufacturer		x	x	x	x	x
distributor				x		
retailer			x	x		x
customers			x	x	x	x
collection/evaluation center	x	x	x	x		
test center	x					x
warehouse	x		x			x
refurbishment			x			
recycler		x				
remanufacturer			x	x	x	x
WHO RETURNS	customers	customers	customers	customers	customers	customers
TO WHOM	collection/evaluation center	collection center	retailer	evaluation center	remanufacturer	retailer
DECISION VARIABLES	order up-to level S	% of periods with backlogs; avg new carpet inventory; avg recycled content in new carpets	number of notebooks in different "status"	waiting time at each node	aluminium solid (q) and liquid (q´) quantities	quantities to order
OBJECTIVE	minimize long-run average costs	min periods with backlogs; min avg new carpet inventory; max avg recycled content in new carpets	max profit	max profit (function of the delay)	min [difference of costs (q, q´)]	min inventory level (mantaining a specific service level)
QUANTITATIVE METHODS FOR SOLUTION	inventory control (re-order point order up to (S-1,S) policy	simulation	linear programming	optimization, simulation	optimization	heuristics (near optimal solution)

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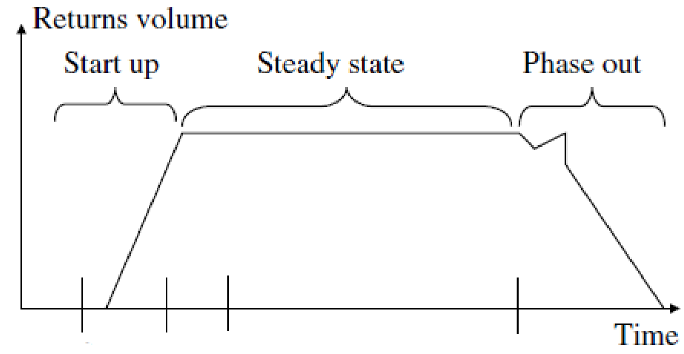

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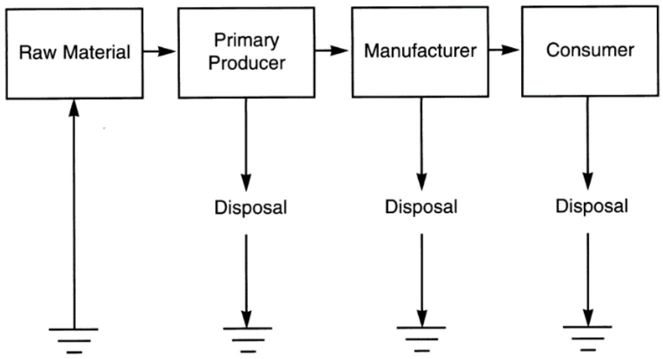
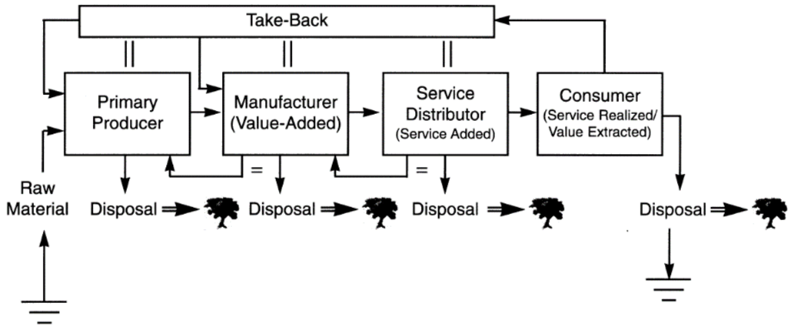


Figure 2: Open-loop supply chain; Blue et al. (1999)



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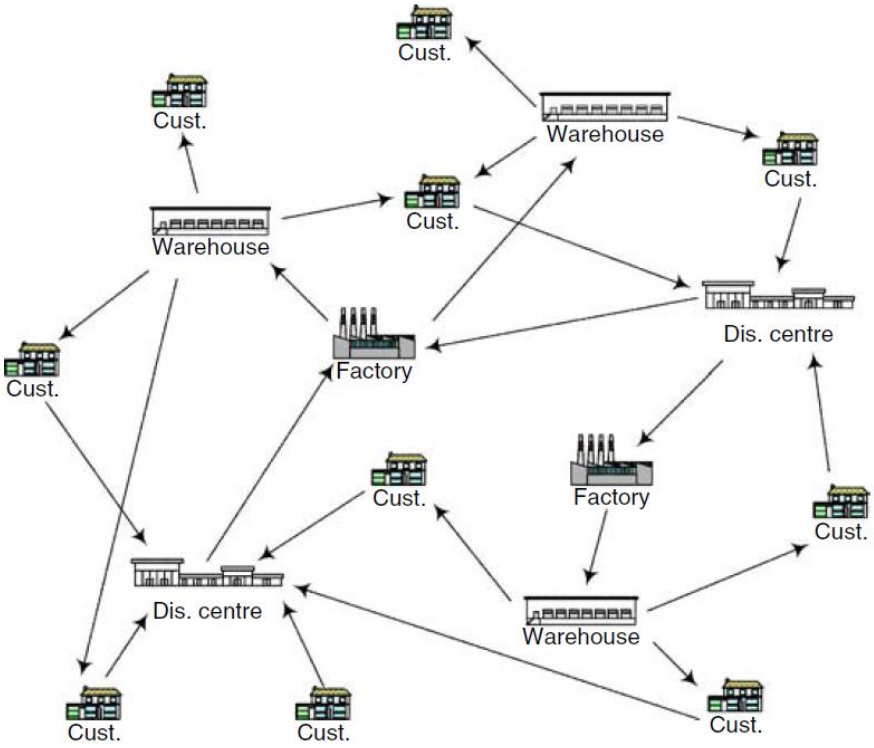

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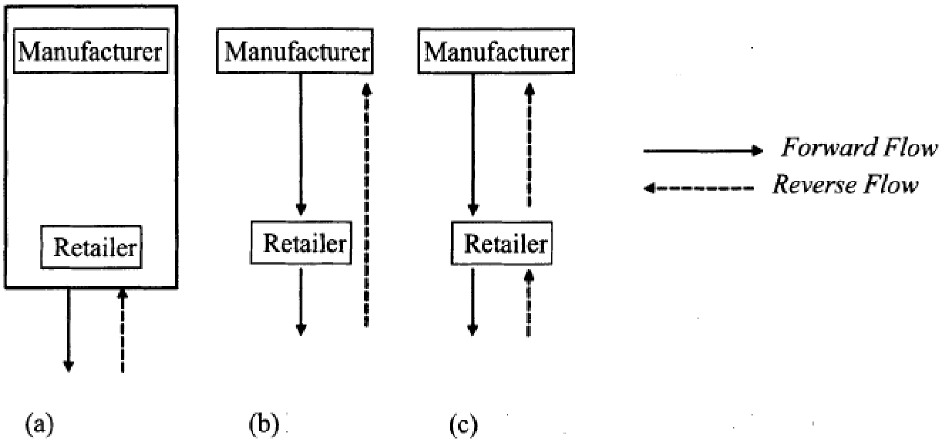

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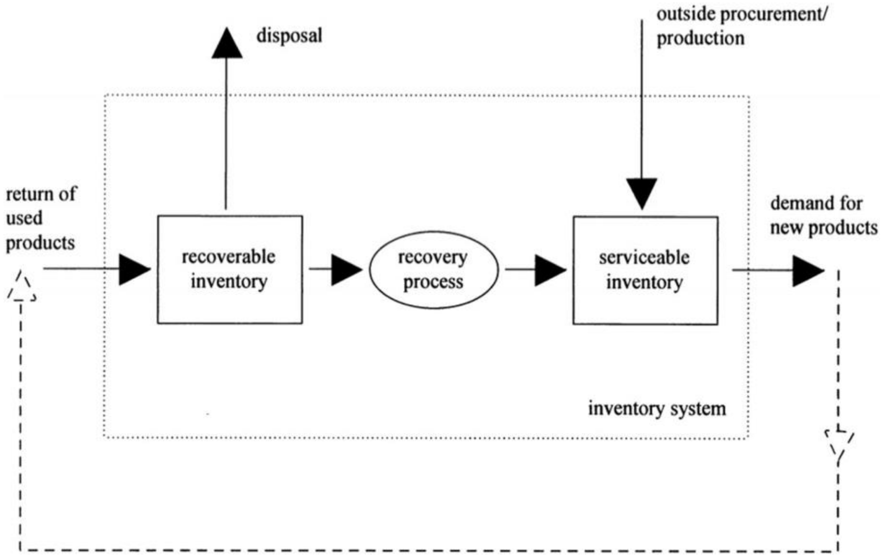

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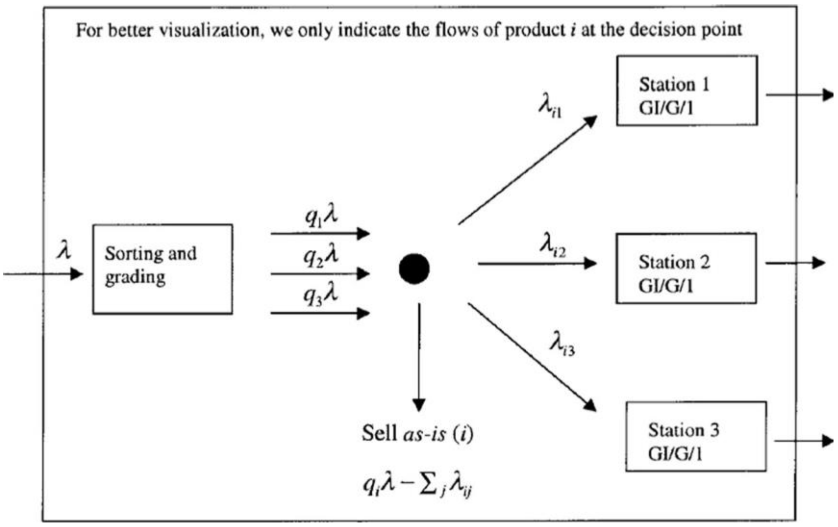

Figure 7: A remanufacturing model with multiple quality classes of returns (Souza et al. 2002)

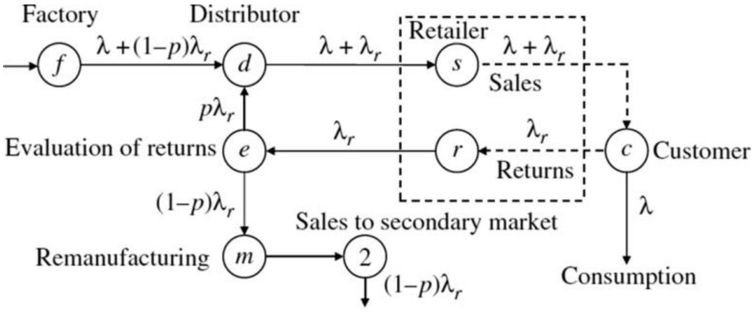

Figure 8: Closed-loop supply chain design: a general model; Guide et al. (2006)