# Reverse Logistics: a review of case studies

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**Abstract**: This paper gives an overview of scientific literature that describes and discusses cases of reverse logistics activities in practice. Over sixty case studies are considered. Based on these studies we are able to indicate critical factors for the practice of reverse logistics. In addition we compare practice with theoretical models and point out research opportunities in the field.

**Key words**: Reverse Logistics, Case studies, Supply Chain, Overview.

## 1. Introduction

Traditionally a product was developed to be manufactured and go through the supply chain (e.g. manufacturer-wholesaler-retailer) to be sold to a customer. However, supply chains are steadily integrating more activities than those concerned with supply alone, like including service and product recovery. Here we will focus on the latter, and especially reverse logistics, i.e. the handling of products, components and materials during the recovery process (see Revlog, 1998-). Several forces drive reverse logistics, like, competition and marketing motives, direct economic motives and concerns with the environment.

Especially during the last decade, reverse logistics has obtained recognition both as a research field and as a practice. During the early nineties, the Council of Logistics Management published two studies on reverse logistics. The first by Stock (1992) recognized the field of reverse logistics as being relevant for business and society in general. One year later Kopicki et al. (1993) paid attention to the discipline and practice of reverse logistics, pointing out opportunities on reuse and recycling. In the late nineties, several other studies on reverse logistics appeared. Kostecki (1998) discusses the marketing aspects of reuse and extended product life. Stock (1998) reports in detail how to set up and how to carry out reverse logistics programs. Rogers and Tibben-Lembke (1999) presented a broad collection of reverse logistics business practices, giving special attention to the US experience, where the authors carried out a comprehensive questionnaire. During the last years, many articles dedicated to the optimization and management of reverse logistics appeared, like Guide et al. (2000) on the characteristics of reverse logistics for remanufacturing systems.

In this paper we give an overview of articles that describe how firms and other organizations deal with reverse logistics. Contrary to previous work, we do not focus on a specific reverse logistics aspect (e.g. remanufacturing), discipline (like marketing), or geographic area (the cases come from several continents). In this way we get a better insight into the critical success factors for reverse logistics. Hereafter we confront these findings with the models that have been developed to support decision making in the area of reverse logistics. In this way we are able to point out gaps and are able to indicate research directions.

The remainder of the paper is organized as follows. First we introduce the topic reverse logistics. Then, we describe the methodology used for finding and classifying the case studies presented in this paper. After that, we present the case studies we found and the models in the literature. We end with final remarks and research directions.

## 2. Reverse Logistics: scope and reasons

Products, components, materials, equipment and even complete technical systems may go backwards in the supply chain (for brevity we will use the term products to refer to all of them). For some time we have been familiar with products being reworked during manufacturing due to unsatisfactory quality, or with good materials or components being returned from the production floor because they were leftover after production (manufacturing returns). Defective products may be detected after they have entered the supply chain resulting in a pull back of products through the chain (product recalls). From this stage there are more actors in the chain involved with the reverse flows on the basis of commercial agreements such as returning vs. taking back obsolete stocks of short-life products (B2B commercial returns). In addition, in the business-to-consumer scenery, products may be sent back due to mismatches in demand and supply in terms of timing or product quality (B2C commercial returns). A particular situation is e-commerce where high percentages of returned products are not a surprise. The average return rate has been estimated at some 36% (see Morphy, 2002). During use and in presence of warranty or service possibilities, products may also be returned to be substituted by others, or to be repaired (warranty and service returns). Ultimately, even after use or product life, products are collected to be e.g. remanufactured, recycled or incinerated (end-of-use and end-of-life returns). At this point both material's hazard and environmental impact have to be taken into account (the latter especially in EU countries). Concluding, products may reverse direction in the supply chain for a variety of reasons as listed below (see also Dekker and van der Laan, 2002; Dekker and de Brito, 2002):

1. manufacturing returns
2. commercial returns (B2B and B2C)
3. product recalls
4. warranty returns
5. service returns
6. end-of-use returns
7. end-of-life returns

Summarizing, a product is developed and goes into production following the supply chain with the purpose of reaching a customer. However, at any moment, the product may go back in the chain. From this moment on, the chain does not deal any longer with supply alone, but also with recovery-related activities. Ergo, we refer to it as the supply chain loop. This denomination underlines the possible integration of forward and reverse flows. Furthermore, it embraces both the closed loop supply chains, where supposedly the reverse flow goes back to the original user or original function, as well as open loop supply chains. Figure 1 illustrates the two phases of the life-path of a product, supply chain loop and customer (potentially recurrent) accompanied by the return reasons, which may occur in each phase.

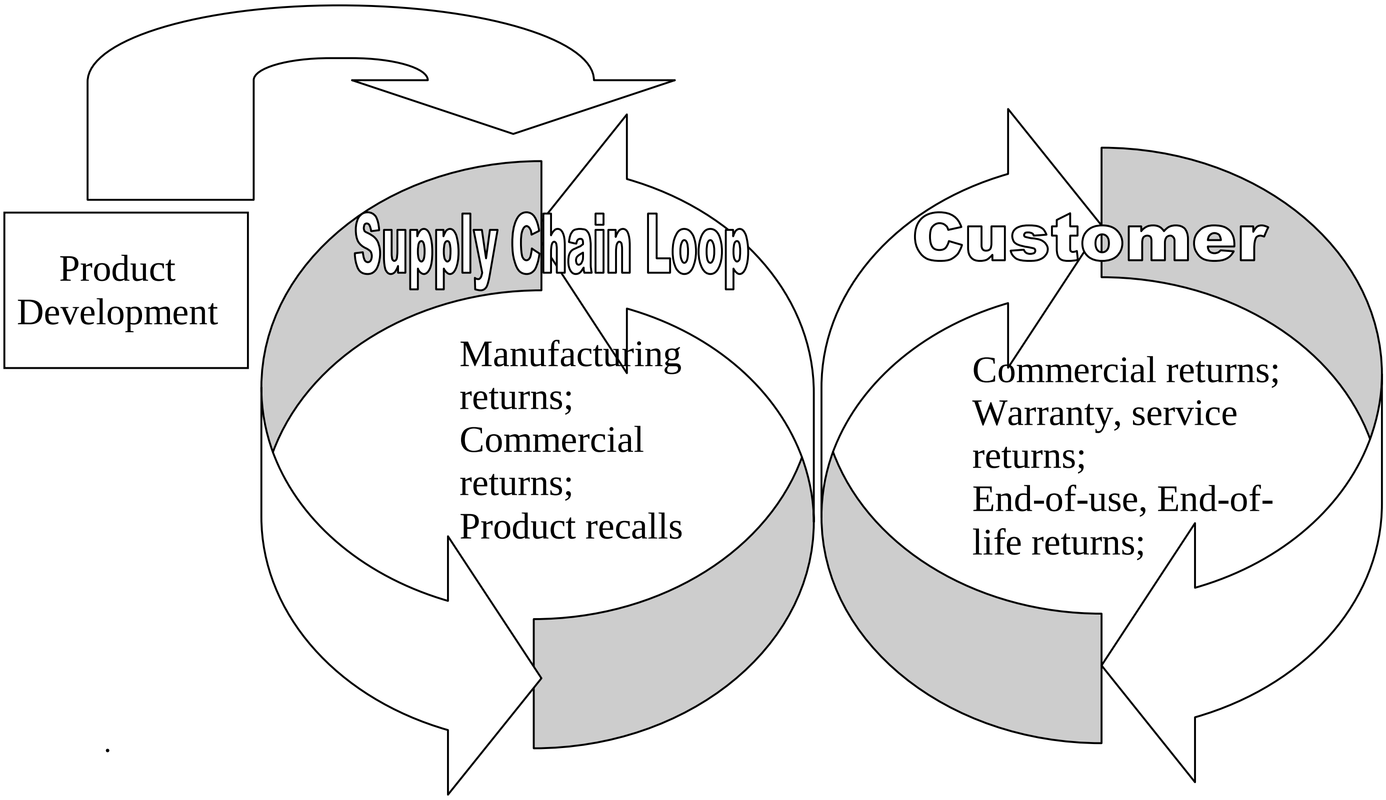


Figure 1. The product life-path and return reasons.

### 3. Methodology

We make use of published case studies on real reverse logistics practices as our data source. As mentioned by Lewis (1998), "Existing case studies offer a potentially effective and efficient means for comparing complex and disparate operations settings.'" The search procedure for this literature was as follows. We inspected the Science Citation, and the ABI/Inform online libraries, using the combination of key words listed in Appendix A. We also surveyed literature that is especially dedicated to the topic, like the Handbook of reverse logistics and Proceedings of renowned conferences, namely the APICS Reman [115] and IEEE on Electronics and the Environment [117]. The main search took place in early 2001.

To give the reader the supply chain loop context, we gathered the following information for each case study (summarized in Appendix C):

- Product-in (entering the chain), foremost re-process activity and product-out (leaving the chain);
- Actors with their function in the chain (sender, collector, processor, customer and initiator);
- Driving forces for sender, customer and initiator of the recovery process;

To present the cases we expand Ganeshan et al.'s (1999) perspective to classify relevant matters on traditional supply chain management. In order to be engaged or to anticipate recovery activities, firms have to consider several strategic, tactical and operational matters. At the strategic level, the design of the recovery network has to be decided upon first. At the tactical level, relationships with partners have to be developed. Where measures to influence the behavior of partners are the relevant issue here. At the operational level, inventories have to be managed and controlled, as well as the recovery activities themselves. As usual, information and communication technology plays an important supporting role.

Thus, we present the case studies according to the following decision-making focus: Network Structures, Relationships, Inventory Management, and Planning and Control. Furthermore, we give an overview of Information and Communication Technology (ICT) applications showing its potential for reverse logistics. By ICT we denote technological means to process and transmit information. We base this dnotation on a comparison of the ICT definition by OECD [119] and NAICS [118]. If a case focuses on multiple issues, we may discuss it in more than one section. During the characterization of the cases and related matters, we uncover auspicious factors for a successful implementation and management of reverse logistics. Finally we classify the cases according to industry and product types.

## 4. Case studies

### 4.1 Reverse Logistics Network Structures

A main activity in reverse logistics is the collection of the products to be recovered and the redistribution of the processed goods. Although this problem resembles the standard forward distribution problem, there are also some differences. There are usually many points from which goods need to be collected, the product packaging is generally problematic, cooperation of the sender is much more needed and the goods tend to have a low value. On the other hand, time is of less a problem. As reverse logistics is quite new, in many cases new networks need to be constructed. Major issues in this respect are the determination of the number of layers in the network, the number and location of depots or intermediary points, the use of drop points in the collection, the issue of integrating the reverse chain with the forward chain and finally the financing of the network.

Quite some case studies were found on this subject, they are listed in the Appendix, Table C.1. Apart from one, De Koster et al. (2001) which deals with the handling of returns in warehouses, they all deal with network structures. They can be classified according to two dimensions. The first is the type of recovery, i.e. re-use, remanufacturing and recycling, which was also used in Fleischmann (1999). The second dimension concerns the initiative, being either public or private. Although this yields in principle six classes, we only found four, as no public re-use or remanufacturing networks seem to exist. Below we discuss these classes, viz. networks for re-usable items, networks for remanufacturing, public networks for recycling and finally private networks for recycling.

**Networks for re-usable items**

Containers, packaging and refillable bottles are typically items, which can be re-used without much work. They are used to contain other goods. In the industrial market these items are exchanged between several companies. Three cases were found.

Kroon and Vrijens (1995) discuss the design of a logistics system for reusable transportation packaging. The issues addressed are the role of all the parties in the system, the economics of the system, the amount of containers needed to sustain the system, the cost allocation to all parties, the locations of the depots of the containers. Del Castillo and Cochran (1996) study the production planning, product distribution and collection of re-usable containers and apply it to re-usable bottles at a soft drink company in Mexico. Duhaime et al. (2001) discuss the collection and distribution of returnable containers for Canada Post. Again the inventory balance between the different locations is a major problem. The last two cases also have production planning and control issues and are also discussed in Section 4.4.

From the cases the following critical issues came forward. It is important to determine how many distribution items are needed to support the operations. An efficient redistribution of empty distribution items is hereby a critical success factor.

**Networks for remanufacturing**

Remanufacturing is typically applied for complex equipment or machinery with many modules and parts. It is usually a labor-intensive activity, which requires much testing. Fleischmann (2002) makes a further distinction into networks set up by the OEM and by independents, as in the latter case there can be no integration with the forward chain. Four cases were found on OEM networks.

Krikke et al. (1999a) discuss the remanufacturing of photocopiers. The authors consider two options for the remanufacturing facility, one coinciding with the manufacturing facility and one in a cheap labor country. They evaluate the costs of both options, including the transportation effects. Meijer (1998) discusses the remanufacturing of used scanners, printers, copiers, faxes with Canon. Dijkhuizen (1997) discusses the repair network of IBM. He deals with the problem where to repair the products: in each country, or centrally at one place in Europe.

The following critical issues came forward. First of all, where should the remanufacturing facility be located, secondly, how can one ensure a sustainable volume of products to be remanufactured (see also the next section) and finally, how can one reduce the uncertainty in the supply of the products to be remanufactured cores.

**Public Reverse Logistics Networks and Environmental Regulation**
These networks were created out of legislation in order to reduce waste. We did not include networks set up for pure waste disposal, since these cases do not consider what to do with the waste and they do not consider typical reverse logistic activities like sorting, disassembly and recycling.

There are several papers describing the set-up and organization of recycling networks in The Netherlands. Bartels (1998) discusses the recycling of batteries. De Koster et al. (2000) deal with recycling of white and brown goods. White goods are large consumer appliances, like washers, dryers, and refrigerators. Brown goods are small domestic appliances. Van Notten (2000) explains the glass recycling system in the Netherlands, while Van Burik (1998) describes the car-recycling scheme. It uses a deposit on all new cars, which is used to pay for the recycling. Discarded cars are first assembled at car dismantling centres. Resulting materials are collected and centrally recycled. Recyclers are paid for processing volumes.

Barros et al (1998) discuss the design of a network for the recycling of sand case that comes free during the sieving of building waste. The main problem tackled is the determination of the number and location of depots of the sand. Kleineidam et al. (2000) consider the choice between paper incineration and recycling. Finally, Chang et al. (2000) discuss the possibilities of recycling household waste in Taiwan.

From the cases we identified the following main issues:

- The way the recycling is financed and which party does what for which costs. The recycling is often paid through a deposit fee on newly sold products. The amount of money needed depends on the recycling targets set beforehand.
- The actual recycling often consists of four stages, viz. the dismantling of the product and removal of hazardous materials, the grinding of the product into fine parts, the sorting of these parts and the final processing them. The latter is often a technologically difficult and expensive process, which is likely to be centralized. In order to be economically viable, sufficient volumes should be realized. Accordingly, much transportation is needed.
- Reverse logistics in public recovery networks is very much a push process, that is, materials are collected and the environmental aspects are the main objective in recovery.

**Private Reverse Logistics Networks for Product Recovery**
The difference between private and public networks is that the first mainly concerns production waste or end-of-use products, for which recycling is economically attractive. Three cases were found, which will be discussed hereafter.

Louwers et al. (1999) discuss the set up of a carpet recycling system. It concerns a special type of carpets, which can be recycled and its output used as feedstock in the chemical industry. Both the organization and the collection network are discussed. Realff et al. (2000) discuss a similar network, using the same technology, but now in the USA.

Spengler et al. (1997) discuss two cases, one for recycling building debris and one for the recycling of by products in the German steel industry. He considers the effect of various recycling options, like cooperation between companies.

From the cases we conclude that private networks for reverse logistics are much more a pull process than public networks. The processor of the materials pays the recycling and transportation. The acquisition process is much more important in these cases, as often a certain volume needs to be processed for recycling to be economical. Yet private networks only recycle the economic attractive parts and not all discarded products.

**Quantitative models**
Many cases for the design of networks present deterministic integer programming models to determine the location of reverse logistic facilities. One could see this as the first step in the research, since in many studies it is said there is much more uncertainty in reverse logistics, and in fact stochastic programming approaches are needed (see e.g. Listes and Dekker 2001). The models presented for locating reverse logistic facilities differ in structure hardly from the traditional location models. Fleischmann (2000) is the only paper found which gives a theoretical investigation of the synergy between the forward and the reverse chain.

## 4.2 Reverse Logistics Relationships

In this subsection we will discuss the incentives that may be used to stimulate/enforce a desired behavior of partners in the context of product recovery. A summary of all the cases is provided in Table C.2.

A distinction should be made between two categories of incentives: 1) incentives that may be used to getting hold of goods a company would like to recovery; and 2) incentives that may be used to influence others to accept the goods a company wants to get rid of To be concrete: a producer of toner cartridges may be interested in incentives for getting back its cartridges; a company buying chemicals in kegs for producing its products, may want these kegs to be collected and environmentally consciously processed by its supplier in order to avoid the high costs for disposing the kegs once they are empty. Accordingly, this company is therefore looking for incentives to make this happen against the lowest costs.

Defining incentives to stimulate/enforce the desired behavior of partners both outside and inside a company requires insight into the alternatives for these partners with respect to the products to be recovered and the costs (time, money, space) and benefits related to each of these alternatives. Clearly the incentive should be relevant for the partner, where creating a win-win situation for all might not be enough.

The incentives used in the context of acquisition are used to influence the quantity that is acquired, the configuration and condition of the items that are acquired as well as the moment that these items are acquired (which usually determines to a large extent the possibilities for recovery and reuse). The incentives to accept disposal concern the same three main issues.

The incentives found in literature can be subdivided into (direct) economical and non-economical incentives. In the following we shall describe the incentives to influence acquisition. All these incentives can also be used to stimulate others to accept goods for recovery. The incentives found in literature concern commercial returns, product recalls, end-of-use returns and end-of-life returns.

**Economic incentives to stimulate/enforce the acquisition or withdraw of products for recovery**
Five different incentives can be identified. We will discuss them below.
*Deposit fee*. This fee may concern the product itself or the item used for its distribution like a bottle, box, and pallet. An example of the former is the deposit fee that has to be paid when renting a car,

whereas an example of the latter are the deposit fee on beer bottles from glass and PET bottles used for the distribution of soft drinks, see e.g. Vroom et al (2001).

*Buy back option*. At the moment that a product is sold, the buyer is offered the possibility to sell the product to the seller for a preset price when the product meets some preset requirements at the moment of return which either is based on the use of the product, like kilometers driven, or based on expected possibilities for selling the returned product via a preset last moment of return for which the option holds. Numerous examples of buy back options for unused products are presented in literature, see e.g. Tsay (2001) where no explicit attention is paid to what happens to these products hereafter.

*Reduced price "new"*. A buyer gets a reduction on a similar or different product when (s)he delivers a used product fulfilling certain requirements during certain periods of time. A well known example are car dealers, offering a higher refund depending on what is delivered and what is asked for by other potential customers of the dealer.

*Fee*. This fee is paid when a person delivers a product for recovery. Usually the fee depends on the condition and configuration of the product delivered, but sometimes also on the moment that a product is delivered because this may determine the possibilities to reuse (parts of) it. Well-known examples of companies using fees to stimulate the acquisition of products for recovery are car brokers and "second hand" shops. Other examples are Varta, the German battery manufacturer, that pays 50p in the UK for every returned rechargeable battery send to a collection point (Faria de Almeida and Robertson, 1995), and UNISYS, paying for each toner cartridge returned (Bartel, 1995).

*Take back with or without costs for supplier*. A person who wants to dispose a product can do this for free or for a lower price than he would have to pay else. An example of the latter concerns the take back of its rock wool after use by Rockwool Lapinus, subsidiary of the Danish Rockwool Company producing rock wool, in The Netherlands (Wijshof, 1997).

**Non-economic incentives to stimulate/enforce the acquisition or withdraw of products for recovery**

At least eight non-economic incentives could be identified. They are:

"*New for old*". One can only get a new copy of a product if another copy is returned.
This incentive is among others used by Daimler-Benz for the engines that they produce for Mercedes-Benz passenger cars and small vans (Driesch et al, 1998). Owners of a Mercedes-Benz (MB) passenger car or small van with an MB engine can go to an authorised MB dealer in order to have their present engine be replaced by a reconditioned engine. The MB dealer removes the present engine and sends it to the central parts DC of MB. From this DC, the reconditioned engine is sent to the dealer where the engine is available within 24 hours. The MB-dealer puts the reconditioned engine in the MB passenger car or van, after which its owner can use the car again.

*Lease or rent contracts*. Products are not sold, but leased or rented. In the contract among others the (initial) end date and time of the contract is stated. Usually the configuration and condition of products that are leased are quite well known. Via the duration of the contract, the moment and thereby the condition of the product that is returned can be influenced, see also (Sterman, 2000).

*Easy and simple method of supply*. Two main supply systems can be found in practice: pickup systems where (parts of) products to be recovered are collected at the location where they are disposed, and bring systems where the disposer has to bring the goods to dispose at a certain location (Kopicki et al, 1993). In practice, usually combined systems are found, like in the case of glass containers where the households have to bring the glass to a container that is emptied by a collector who brings the glass to a processor (Lund, 2001). Some suppliers for toner cartridges, including UNISYS, deliver their cartridge in a box that can be returned for free to them either by post (mixed bring-pickup system) (Bartel, 1995) or via another third party logistics service provider (pickup system) like Hewlett Packard (McGavis, 1994). Also manufacturers of batteries do use this type of incentive (Yender, 1998).There are numerous examples where companies want only certain parts of products to be returned. For instance, usually producers of beverages are only interested in having their refillable bottles returned but do not want the caps to close these bottles be returned because these caps can not be reused by them. This requires that it should be easy to remove the caps from the bottles by the consumers.

*Timely and clear information*. How important this incentive is, is illustrated by a pilot system for the collection of different types of batteries in Denmark and Germany, where it turned out that it was for a number of batteries too difficult to make suppliers clear which type of battery they have (Faria de Almeida and Robertson, 1995).

*Legislation*. Disposal bans and high disposal costs may help to realize a cheap supply of desired products for recovery to companies interested in the recovery of these products, as discussed earlier in this section for the collection of glass from households in The Netherlands. As mentioned before, this is also an important reason for the success of Rockwool Lapinus with respect to the return of rock wool (Wijshof, 1997).

*Power*. As always, power can be used to force desired behavior. An example is New England Foam of Windsor. One of the customers of this company, Walden Paddlers uses her power as a customer to force New England Foam of Windsor to take back the cardboard boxes that this supplier uses to distribute foam foot braces and seat pads to Walden (Farrow et al., 2000).

*Appeal to the environmental consciousness of people*. This incentive usually requires a lot of advertising, and is in general not very reliable as is illustrated by the collection of toner cartridges by Hewlett Packard (McGavis, 1994).

*Appeal to the charity's consciousness of people*. For each product received for recovery, a non-profit organization receives an amount of money. This incentive was used by Hewlett Packard in order to get her toner cartridges back after an attempt to refer to the charity's consciousness of customers did not result in a satisfying number of returns (McGavis, 1994).

**Quantitative models**

Using each of the above tools incentives requires a lot of parameters to be specified, including the period of time during which a certain incentive will be applied, how the configuration and condition of what is supplied can be (quickly) estimated, the height of a fee and so on. Although all the above mentioned incentives can be found in practice, no models supporting the decision which incentive to use under which conditions have been found in literature. With respect to the values of the different parameters related to an incentive, only some (related) research is available. Klausner and Hendrickson (2000) present a mathematical model that might be used for estimating the buy back price. Guide et al (2001) present a mathematical model to determine the optimal acquisition price for products from the field as well as the selling price of these products. In the above two models the time aspect is neglected, i.e. a steady state situation is considered. As mentioned before, there is quite a lot of literature on sales contracts with return options for unused products, see Tsay (2001), Anupindi and Bassok (1999), Corbett and Tang (1999), Lariviere (1999), Tsay et al. (1999). Once more it should be stressed that the prime focus of all this literature on contracts with a return option is on what may be gained by both sellers and customers by allowing customers to order more under certain return options, where a fixed sales price is assumed for the products that are taken back by the seller. Moreover, all these publications concern unused products.

With respect to the consequences of the collection frequency as a method to influence the supply of goods for recovery, Tucker et al. (2000) examined the relation between the frequency of picking up paper etc. at households and the quantities collected.

**Summary and remarks**

There are quite a lot of different incentives described in literature via case studies. Many of these incentives are also used to attract customers/suppliers in general. Deposit fees and buy back options seem to be specific. Almost all the case studies that we have found describe incentives for the supply of goods for recovery. Most of them describe the incentives that are used, without explaining why that incentive has been chosen and how the values of parameters related to that incentive have been determined. Some incentives make up part of the sales contract, like deposit fees, other incentives like reduction price "new" can only be made effective when selling something "new", and still others are not coupled to a selling activity like a gift to a non-profit organization for returning an item.

Note that the economic incentives deposit fees, buy back options and sometimes also reduced price new, as well as the non-economic incentives "new for old" and lease/rent result in changed relations between producers, distributors and their customers. This especially holds when companies no longer sell products but lease them. Note that the number of different products that are leased is rapidly increasing which among others pressed many car importers in The Netherlands to setup their own lease company.

One of the main problems with each of the above incentives is how to estimate quickly the configuration and condition of the item supplied. The use of chips in products in which data on the use of products are stored as done by Robert Bosch in its power tools (Klausner and Hendrickson, 2000) seems to be a step forward from this point of view. See further Section 4.4 on ICT for reverse logistics.

## 4.3 Inventory Management

The cases on inventory management within reverse logistics are given in the Appendix, Table C.3. They can be classified according to the return reasons from section 2. We did not find cases for all reasons, in fact only for commercial returns, service returns, end-of-use returns and end-of-life returns. The reasons behind these omissions may be the following. Manufacturing returns, such as rework are often treated in production planning contexts. Product recalls are often special events, which are left of consideration in inventory management. Warranty returns have similar characteristics as repairs. They differ mainly in the contractual side and accordingly one cannot expect many publications on its inventory management. Below we treat the cases found in detail together with the mathematical models applied.

**Commercial returns cases**

Commercial returns occur in a wholesaler - retailer or in a retailer - customer setting, where the buyer has a right to return the product, usually within a certain period. The reason behind the return option differs between the cases. In the first setting, the retailer faces the problem of how much he might sell and giving him a buy-back option lowers this risk for him. The returns are likely to be in bulk at the end of the season. In the second case the reason for the return option is that the buyer might not be sure whether the product (or the amount of products) really meets his/her requirements.

Sanders et al. (2000) describe how the inventories of products are controlled within Wehkamp, A Dutch mail order company, selling all kinds of consumer goods to the Dutch and Belgium market. Two types of products are distinguished: products which are asked for during a very short period of time only, which are controlled by using an amended version of the newsboy model taking into account returns, and products that can be sold during a long period of time, which are controlled via a (R, S) policy with variable R and S.

De Brito and Dekker (2001) investigate the distribution of the return lag, i.e. the time between the purchase and the return of an item for three cases, viz. a mail order company, a spare parts warehouse at a petrochemical plant and the warehouse at the center for nuclear research, CERN.

From the cases it appears that the inventory issues are twofold, first what should happen with the returned item and secondly how is the reordering influenced by the returns. In case of commercial returns, the items are usually of new or almost as new quality, hence they can often be included into inventory after a simple inspection. With respect to the ordering it is important to know the return rate and the return lag (how long does it take for a return to come back). These aspects are especially important in case of seasonal or non-stationary demands where the determination of the amount needed in a certain period is the crucial issue.

**Service return cases**
Within service systems returns may originate in three ways. First of all the products themselves may be brought or sent to a center for repair. If the repair is successful, they are brought back, else a new product or system needs to be bought and the failed one is discarded. Secondly, if one needs a continuous functioning of the product or system, one may directly replace the system or part by a spare one. The failed system or part is then be repaired later, after which it will enter the inventory of spare systems or parts. Finally, in order for such a replacement scheme to be successful, service engineers need to have replacement parts with them to do the repair. This requires a sophisticated logistic system for ordering and delivering the parts (frequently using in night services). Beforehand however, it is not always clear which new parts are needed and as a result often the engineers order more parts than needed. The leftover parts then need to be returned to the parts warehouse. This is the third stream of returns. The cases found only cover the first two return ways; they are described below in detail.

Díaz and Fu (1997) study a 2-echelon repairable item inventory model with limited repair capacity. For several classes of arrival processes they develop analytic expression for the number of items in queue at the different stages of the system. They analyze the impact of the capacity limitation and compare the performance of their approach with an uncapacitated METRIC type of model. Both models are applied to the case of spare parts management at the Caracas subway system.

Donker and Van der Ploeg (2001) describe how the optimal stock of reparable service parts of telephone exchanges is determined within Lucent Technologies Netherlands. They use an amended METRIC model, where the service measure is fill rate (i.e. the percentage of demand that can immediately fulfilled from stock) and there is no budget restriction for service parts.

Moffat (1992) provides a brief summary of a Markov chain model for analyzing the performance of repair and maintenance policies of aircraft engines at the Royal Air force.

Van der Laan (1999) describes the remanufacturing chain of engines and automotive parts for Volkswagen. It is very similar to the engine remanufacturing case with Mercedes Benz in the previous section.

The cases have the following characteristics: the repair chain consists of multiple echelons. It is important to determine how many parts are needed at each stocking location. Another critical issue is how much repair capacity there should be in order to guarantee throughput times.

**End- of-use returns cases**
This return reason concerns items that are only temporary needed by a user. The product may either be leased, rented or temporary given into the authority of the recipient. The latter is the case with distribution items, that is, products like containers, bottles, railcars and crates, which are used for distribution purposes. The two cases found, viz. Swinkels (1998) and Del Castillo (1996) primarily concern distribution items for. Here the location of the items is a major issue in the inventory decision.

Del Castillo and Cochran (1996) study production and distribution planning for products delivered in reusable containers. Their model includes transportation of empty containers back to the plants. Availability of empty containers is modeled as a resource constraint for the production of the original product. The model is applied to a case study of a soft drink company using returnable bottles.

Swinkels and Van Esch (1998) describe how the optimal stock of refillable beer kegs is determined within Bavaria, a Dutch beer brewery.

Toktay et al. (1999) consider inventory management for Kodak’s single use cameras. As the camera acts as a container for the film, one may see this also as a distribution case. Printed circuit boards for the production of these cameras are either bought from overseas suppliers or remanufactured from the cameras returned by the customers via photo laboratories. The issue is to determine a cost--efficient order policy for the external supplies. Major difficulties arise from the fact that return probabilities and market sojourn--time distribution are largely unknown and difficult to observe. The authors propose a closed queuing network model to address these issues. They assess the importance of information on the returns for the control of the network. Rudi et al. (00) discuss the product recovery actions of the Norwegian national insurance administration. This public entity retrieves no longer needed wheel chairs, hearing aids and similar products provided to people with handicaps. They assess how many are needed to meet all demands.

From the cases it appears that the main issue is the match between returns and demands in time and place. How much are needed at which location and how much should be relocated within a certain time interval. Most items issued come back, but it is not always known when.

**End-of-life returns cases**

The difference between end-of-life and end-of-use may be smaller than it seems beforehand. It seems that in this case recovery intends valuable parts only, whereas in the end-of-use case similar products were made with the returned products. Products and systems not only age intrinsically, but also because their environment puts higher requirements on them. This is especially the case for computers and electronic equipment. We speak of end-of-life returns if they are that aged that their functionality (if available) is far below actual standards. Yet they may still function satisfactorily and hence they can be used as source for spare parts for similar systems. Fleischmann (2000) describes the dismantling of returned, end-of-life computers into useable spare parts with IBM. This source nicely combines with return obligations and it s a cheap source for spare parts for systems on which one does not want to spend too much. The problems identified were a lack of knowledge of what actually was in the computers as well as an insufficient information system to handle the operations.

Klausner and Hendrickson (2000) develop a model to determine the optimal buy-back amount to guarantee a continuous flow to remanufacturing power-tools. The authors apply the model to the actual voluntary take-back program in Germany, where costs go beyond profits.

## 4.4. Planning & control of recovery activities

This subsection deals with the planning and control of the recovery activities, i.e. the actual decision *where* should *when how much of what* be collected, disassembled or processed. In this subsection we assume that the potential recovery options are given.

Part of the planning and control of product recovery concerns the planning and control of supply of goods to be recovered in which context incentives play an important role. This important aspect of planning and control has already been dealt with in subsection 4.2. In this subsection the above incentives and their effect on supply and acceptance are assumed to be given.

Planning and control of recovery activities is strongly related to inventory management, the topic of the previous section. The latter includes the levels triggering recovery activities. Hereafter it is assumed that the inventory strategy has already been decided on. What are left are decisions concerning disassembly planning, the lot sizes used for executing the actual recovery activities for certain groups of products, the priorities for dealing with each of these groups of products, and the actual allocation of used products to recovery activities.

The case studies on planning and control of product recovery activities that we found in literature can be subdivided into case studies dealing with disassembly planning, the separate collection of (parts of) products for recovery, the separate processing of (parts of) products for reuse (or disposal), as well as with the combined planning and control of collection and distribution, and processing and production. The cases are succinctly presented in Table C.4.

**Disassembly planning**
Two cases have been found, which deal with the sequence in which products should be disassembled as well as the method and degree of disassembly, i.e. the choice between destructive and nondestructive disassembly and the extent of the disassembly. Krikke et al. (1999b) discuss the disassembly of PC monitors, where it appears difficult to come to advanced disassembly because of the heterogeneity of the products to be recovered. Kobeissi (2001) studies the disassembly of washing machines and comes with an optimal disassembly plan.

**Planning and control of collection activities**
In a number of case studies the lot size used for collection is given, usually without explaining how these lot sizes have been determined. All the case studies that we found concern end-of-use or end-of-life returns.

*End-of-use returns*
Andriesse (1999) mention that the lot size agreed upon by Philip Morris Holland BV and most of its suppliers for returning reusable pallets to the latter is a completely filled truck.

Del Castillo and Cochran (1996) describe the model used by EMSA, a soft drink producer in Mexico City, for determining the quantities of refillable bottles to be returned to the bottling plants from the final customers for the soft drink, via the stores selling the soft drinks and the depots delivering the soft drinks to the stores.

Duhaime et al (2001) present a model that is used by Canada Post to determine the number of empty containers that should be distributed and returned each month, as well as the number of containers stored each month per region.

Klausner and Hendrickson (2000) mention the lot size used for the collection of power tools by Robert Bosch GmbH.

*End-of-life returns*
Bartels (1998) describes the Dutch nation wide collection and processing of disposed batteries. Among others attention is paid to the collection of batteries at municipality collection points. These depots can call one of the contracted collectors to collect, which has to be taken care of within one month.

Van Donk (1999) describes the system setup by Nelis Utiliteitsbouw B.V., a Dutch building company, to keeping the rest flows of different types of materials separated at building locations in order to higher level reuse of these flows and lower costs related to them. Among others, attention is paid to the number and sizes of containers used for collection. Whenever at a building location it is expected that a container will be filled soon, a recycler is called who replaces the filled container by an empty one.

Van Notten (2000) describes the recovery of glass in The Netherlands. The bring and pickup systems for the collection of glass scrap from households are discussed, including the sizes of the containers used and the collection scheme, usually being once a week.

Schinkel (2000) describes the Dutch nation wide system for the recycling of gypsum. Attention is paid to the actual collection of gypsum rest flows via special containers and bags.

‘t Slot and Ploos van Amstel (1999) describe the pilot project proceeding the introduction of a nation wide system for the collection and processing of discarded white and brown goods. Among others attention is paid to the collection scheme at households (fixed, once per month or quarter), and the collection frequency at sales points of white and brown goods.

Ubbens (2000) describes the recovery of metal from metal packaging materials in The Netherlands. Among others attention is paid to the number and sizes of special containers for collecting from households.

Wijshof (1997) describes the system setup by Rockwool Benelux in the Netherlands for the collection and processing of rockwool production scrap and waste, as well as for the rockwool disposed after use. Among others attention is paid to the sizes of the bags that are used for collection, and the number of bags that has to be filled before a third party is collecting them for Rockwool. The disposer has to contact the third party to do this.

**Planning and control of processing**
The case studies related to this issue consider service or end-of-life returns.

*Service returns*
Bentley et al (1986) mention that Morrison-Knudsen uses MRP II to plan the remanufacturing of subway/transit overhaul, without explaining how. The latter also holds for Robison (1992) who mentions the use of MRP by Detroit Diesel Remanufacturing West, remanufacturing Detroit Diesel engines.

Driesch et al (1998) describe the car engine recovery network setup by Mercedes-Benz For Europe, including the actual planning and control of the recovery activities in the plant in Berlin. Among others it is mentioned that the disassembly, cleaning, test, remanufacturing and reassembly activities are dealt with in lots, and that the number of engines that are disassembled is related to the number of reconditioned engines that are reassembled. Also here no further details are given, nor is explained how these lot sizes have been determined.

Guide and Spencer (1997), Guide and Srivastava (1997) and Guide et al. (1997b) discuss a method for rough cut capacity planning to the above Depot. Guide and Srivastava (1998) discussed for the same depot also a method to determine the inventory buffers between the disassembly and the remanufacturing shop, and the inventory buffer between the remanufacturing and the reassembly shop.

Thomas Jr. (1997) mentions that the Pratt Whitney Aircraft remanufacturing facility in West Virginia uses MRP to schedule inspection and rebuild of military and commercial aircraft engines. The batch size is one because different engines have to go through different routings. Bottleneck is the engine reassembly. Buffer time is used to protect this activity form variations in foregoing activities. This time is determined via LP, but no formulas are given.

*End-of-life returns*
Spengler et al (1997) discuss an MILP model used for the planning of processing components arising from the dismantling of buildings in the Upper Rhine Valley.

**Integral planning and control of collection-distribution**
The two case studies that we found both concern end-of-life returns (reason 7).

Simons (1998) describes the system setup by Trespa International B.V., a producer of sheets made from resins and wood fibers, for the recycling and reuse as an energy carrier of (parts of) these sheets, which are used in the building industry both for the outside and inside buildings. Attention is paid to the collection of (parts of) the sheets leftover from building activities. These leftovers are put into containers supplied by Trespa. The customer lets Trespa know when a container is filled. Empty containers replace filled containers when new Trespa sheets are delivered to the customer. The reusable pallets used for the distribution of the Trespa sheets to the customers are collected by third party logistics service providers (3P LSP's).

Bakkers and Ploos van Amstel Jr (2000) describe the system setup by Ortes Lecluyse, a Dutch producer of PVC lamellas, for the recycling of these lamellas. Attention is paid to the sizes of the containers used for collection and the frequency for emptying these containers located at their direct customers, being once a week when new lamellas are delivered.

**Integral planning and control of processing-production**
Here only case studies where a direct relation between the two is described, i.e. cases in practice where the resources used for production are also partly used for processing. We found two case studies, both concerning manufacturing returns.

Gupta and Chakraborty (1984) describe the processing of glass scrap generated during the production of glass. A mathematical model is presented to determine the optimal production lot size, taking into account the recycling activities.

Teunter et al (2000) describe the mathematical model presently used by Schering AG, a German producer of medicines, including the processing of by-products resulting from the production of medicines.

**Quantitative Models**
A lot of mathematical models have been developed that give insight into the results that might be obtained with certain planning and control concepts for product recovery. Many of these models actually deal with inventory management. These models are included in the overview given in Section 4.3 of this paper. It goes beyond the scope of this paper to go into detail into the other models. Only references will be given, using an extension of the classification for the case studies found.
With respect to collection, Du and Hall (1997) give a mathematical model for determining the fleet size and the redistribution of empty equipment for center-terminal transportation networks. Crainic et al. (1993) present a mathematical model for the allocation of empty containers.

Regarding processing, Guide et al (1997a,b), and Guide and Srivastava (1998) present mathematical models for the planning and control of remanufacturing, distinguishing between disassembly, repair and reassembly activities. Spengler et al (1997) and Uzsoy and Ventakatachalam (1998) present deterministic models for the planning and control of remanufacturing in case different products can be disassembled to obtain desired products, whereas Inderfurth et al (2001) present a stochastic model in case a used product can be reused in a number of different ways. Stuart and Lu (2000ab) present an MIP model for determining the optimal processing level of a number of input materials all sharing the same processing facility.

A number of papers have appeared on collection-distribution issues, as for combined delivery-pickup (back-haul), including (Dethloff, 2001) and (Anily, 1996).

In the processing-production context, Flapper and Jensen (2002) and Flapper et al. (2002) discuss mathematical models developed to support rework involving the same resources as for production.

A mathematical model to support the integral planning and control of collection, processing and distribution for reusable containers is given in (Del Castillo and Cochran, 1996). Finally, Richter (1996, 1997ab) present deterministic models combining collection, processing and distribution as well as production.

**Summary and remarks**
The number of case studies describing the actual planning and control of product recovery activities is very limited. This holds especially for the actual processing. In many of the case studies we found, one or more planning and control issues are very globally described, most of the time being the lot sizes that are used (without further explanation). The authors hardly found descriptions of the planning and control concept, nor the (quantitative) motivation behind it. The case studies found hardly give insight

into the problems companies have with the planning and control of the product recovery activities, nor in the results obtained with their planning and control concept.

On the other hand, quite a number of planning and control concepts for product recovery have been presented in academic literature, many of them including mathematical models to estimate the usefulness of the concepts. Thereby, often autonomous supply of products that might be recovered is assumed, with apart from some literature on repair, no direct relation between foregoing distribution of these products, which is one of the essential differences with many other production situations. Moreover, as holds for literature on planning and control in general, most publications deal either with the materials aspects or with the non-material resource aspects (men, machines). Uncertainty has been incorporated as far as the arrival of products for recovery and the duration of repair related activities are concerned. Not, or only indirectly, uncertainty with respect to the result of the processing activities is taken into account.

Concluding, it seems useful to do case studies in order to estimate which planning and control concepts are used in practice, how the values of the different parameters related to them are calculated, and how well they are performing. It also seems worthwhile to estimate the usefulness of the theoretical concepts developed or under development.

## 4.5. ICT for Reverse Logistics

We have found various cases concentrating on applications of ICT for reverse logistics activities (see Table C.5 in Appendix C). We observed that ICT is used to support reverse logistics during different stages of a life-path of a product. Below, we go over the case studies according to the product life-path stages. We allow for considerations on the ICT affairs for supply chain loop and related literature. Furthermore, we provide additional examples to illustrate particular aspects together with theory available on the subject.

**The Cases: description and related matters**

*Product Development*

Regarding this phase there are two variables to consider: material content and product structure. The materials that are used and how they are combined determine the degree and the type of a potential recovery once the product is at the end of its life. Marking parts with manufacture identification are also helpful when a product has to be pulled out of the market due to defect, i.e. product recalls (see Smith, 1996). Many companies have already in place product development programs encompassing design for the environment, for recovery, for disassembly, and so on – generally called as Design for X, or just DfX. This is the case of Xerox Europe, reported by Maslennikova and Foley (2000). Xerox has in place an extensive Design-for-the-Environment program. The design of each new component has to be accompanied with instructions for the end-of-use.

Recovery can also be the starting point for product development, as it is the case of Walden Paddlers, which launched a 100% recycled kayak project (Farrow et al., 2000). The project had to very much rely on computed experiments as no design then available suited recycled resins. The company was able to attract a manufacturer to invest in advanced rotational molding technology and to convince the supplier to proceed to further resins' separation

There is a vast group of literature on the technical aspects of DfX (for a review, see Kuo et al., 2001). Besides this, there are also studies trying to indicate how to organize a successful implementation of DfX programs. For instance, Lenox et al. (2000) compare four leading US electronic companies with respect to the set-up of design for the environment (DfE) teams. Though all the four firms have corresponding technology and analogous consumer pressures, only two (one being Xerox) have managed to root design DfE. According to the authors, the way knowledge and expertise is being diffused explains the success of the teams. Firms seem to have difficulty to switch from traditional design to recovery-related DfX since it demands pre-information on not only new techniques but also information on the related costs and potential profit.

*Supply Chain Loop*

A supply chain loop embraces both products going forward and backwards through the chain. One can use ICT for individually tracking and tracing of product returns and link them with previous sales. ICT has also vast applications for the handling of product returns and for the planning and control of recovery activities. The cases below illustrate this.

Logistics operations largely depend on ICT. For instance one can use ICT to know the location of items in the chain (tracking) and also to know their historic path through the chain (tracing), see van Dorp (2002). To fully exploit ICT in the presence of returns, ICT has to allow the communication between forward and the reverse paths. In many situations the returned products are as good as new, so they can be put back in inventory. To relate a product return with a past sale can support forecasting of product returns and is therefore helpful for inventory management (see de Brito and Dekker, 2001).

Landers et al. (2000) highlight the importance of tracking component's orders in the case of a closed-loop business telephones supply chain. The authors use a concept called "virtual warehousing" where real-time information feeds expeditious algorithms to support decisions. The use of ICT leads to an improvement in stock levels, routing and picking processes when compared with the pre-ICT scenario. Xerox (Maslennikova and Foley, 2000) uses bar code labels to track packaging material with the aim of achieving resources' preservation.

The focus of tracking and tracing has mainly been on the outbound flows (see Gurin, 1999). Regarding the application of tracking and tracing in the (reverse) supply chain there is research taking into account the use of ICT to elaborate on inventory and purchasing policies (see Kelle and Silver, 1989; Toktay et al., 2000). There is also literature on how to use information and new technologies to improve processes in the reverse chain, for the situation products and equipment need to be disassembled. To illustrate, Mok et al. (1997) develop criteria for the disassembling process. Among others they take into consideration different degrees of technological effort, which can be employed in a specific situation. They illustrate their methodology with the disassembly of an automobile. Commercial software specifically designed for supporting the reverse chain is however not available (Caldwell, 1999). While for some time specialists have suggested logic extensions of packages such MRPII (Grommesh, 1991; McNeill, 1991) many firms are pushed to develop their own tailor-made software.

Fraunhofer IML has developed software to embed data on recovery processes as reported in Nagel and Meyer (1999). The authors consider two chains in Germany: the national refrigerator and the computer recycling networks. Costs could be minimized with the optimization of the location of facilities, vehicle routing and operations' scheduling supported by the software. For the case of the German computer-recycling network, transport volume (in tons per km) could be reduced by almost 20%.

Estée Lauder is another firm that has developed specialized software to handle product returns (see Meyer, 1999). The system checks the cosmetic items for expiration date and damages and recovery-related decisions are accelerated. The software is linked to an automatic sorting system, which smoothes away labor costs. Estée Lauder could reclaim the investment on ICT within one year's time.

In the case of Nortel Networks, a Decision Support System (DSS) was developed to assist remanufacturing (see Linton and Jonhson, 2000). The tool permits to apprehend the interrelations between the production and the remanufacturing of products. By this mean both processes can be better planned and controlled resulting in a more efficient allocation of resources.

*Customer*

Once the product reaches a consumer, either 1) the customer does not keep the product, or 2) the customer keeps it for use. For both scenarios, ICT has latent applications.

In the first scenario, the main application is in fact to prevent elective returns. One of the many reasons to lead a customer to return a product is to have ordered the wrong item. Internet offers opportunities to ensure that the customer asks for the right product. For instance, Office Depot (online) asks for the printer specifications when a customer places an order for toner cartridges (see Meyer, 1999). Customers also return products when they perceive that the product is defected or when the product does not seem to fit customer's needs. On-line help desks may constitute a means to avoid these returns. This type of returns is common with high-tech, very specialized or innovative products, which demand a thorough study of pre-installation manuals. Online helpdesks can be used to tutor customers to fully exploit product's potential. Such helpdesks may form a service tool that prevents unnecessary product returns. Not only in online businesses, efforts can be made to reduce returns. When Sharp Consumer Electronics realized that half of the returned products where in good condition, several actions where taken. For example, the VCR manual was simplified and a telephone line was attributed for customers having questions regarding the installation of equipment (see Meyer, 1999).

If the customer decides to return the product, pre-information on product returns can simplify operations. The customer can be encouraged to register, on-line or via e-mail, the intention to return a product. In this way, the firm acquires information in advance on which products are to be returned. Among others, this knowledge can be used to schedule operations. In addition, to keep databases on customer information including purchases and product returns can be used to uncover return patterns. Data mining is therefore an opportune utensil for identifying abusive returns.

After the customer has accepted the product and starts using it, the product may need maintenance. Xerox has in place a remote faulty detection system called the Sixth Sense (see Maslennikova and Foley, 2000). In some situations, the problem is remotely identified and solved. Customers are assisted by a multi-functional database that permits them to get thorough acquaintance with product characteristics.

While being in the market a product may be upgraded, e.g. PC's, or degraded (e.g. some components may become completely worn-out, beyond any possible recovery). It could be very useful if this information would be registered or accessed some how. For the particular example of PC's in the end-of-use phase, Kokkinaki et al. (2002) discuss the set up of a virtual reverse logistics network. Software for on-line hardware detection is included, so that the exact contents of the computer are known. Nagel and Meyer (1999) report real software development by the German recycler Covertronic to read the configuration of a computer and to compute costs and revenues of subsequent recovery. Based on this, an appropriate bonus is offered to the final user when the computer is returned. Covertronic operates this software in tandem with Vobis, a large computer retailer in Germany. Another technology available is the so-called data loggers (see EUREKA [116]). These devices are able to store data on physical parameters, which can be retrieved later. The idea is to put them into products or equipment (as is done for some coffee machines) and to register information about heat or other parameters as they are used. Thus, at the point of recovery, one could make use of this information to decide which destiny to give to certain product without first investing resources in disassembling and testing components. Klausner et al. (1998) have investigated the benefits of collecting information via this chip technology in electric motors. Likewise Simon et al. (2001) apply both a steady state and transient models to evaluate the benefits of using a data logger in washing machines.

After using the products or equipment, one can opt to re-sell them if there is a market for it. E-market places can facilitate matching supply of second-hand items with demand. The study by Kokkinaki et al. (2000) relates to this. In this paper the existent electronic business models are delineated. Three features are contemplated: the supported activities, the degree of control and the added value. The authors are able to identify three e-business models for reverse logistics: return aggregators, specialty locators and integrated solution providers. This facilitates the identification of tools to improve services.

**Discussion and remarks**

Table 4.5. summarizes the ICT tools to support reverse logistics activities described in the case studies presented above.

| ICT Tool | Requirements | Assists | Life path phase |
|---|---|---|---|
| DSS for end-of-use; (Nagel and Meyer, 1999) | Info. on operations' costs & recycling revenues | Cost optimization, facilities location, vehicle routing, etc. | Supply Chain Loop |
| Computer's configuration reader (Nagel and Meyer, 1999) | Info. on operations' costs & recycling revenues | Setting buy-back price; | Customer |
| Software specialized on return handling (Meyer, 1999) | Product's expiration data, damage check | Recovery-related decisions | Supply Chain Loop |
| DSS for remanufacturing (Linton and Jonhson, 2000) | In-depth information on processes | Remanufacturing-related decisions | Supply Chain Loop |
| DSS for warehousing (Landers et al., 2000) | Real-time data on orders, info. on capacity restrictions | Inventory control, transportation's choices, etc. | Supply Chain Loop |
| DfX, remote maintenance, etc. (Maslennikova & Foley, 2000) | Extensive data-base on products | Recovery options, environment's sustainability, and so forth. | All phases |
| DfX (X=Recyclability) (Farrow et al., 2000) | Further separation of resins; Technological innovation; | Developing a 100% recycled Kayak. | Supply Chain Loop |

Table 4.5 ICT tools, requirements and benefits for reverse logistics – a summary of the case studies.

The case studies here discussed illustrate ICT applications in all the phases of the life path of a product. In particular, Xerox (Maslennikova and Foley, 2000) has an integrated solution for reverse logistics from product creation to eventual disposal. ICT is indeed a supportive tool that can be used through the whole life path of a product with benefits for reverse logistics, as the cases show. Figure 2 illustrates the kind of ICT applications and respective implications in handling return flows. During the product development phase, DfX is a useful tool to future end-of-use recovery or in case a recall takes place. In the supply chain loop, integrated tracking and tracing supports inventory management and the planning and control of product returns and their recovery. In the customer phase the use of databases and respective data mining, as well as the data logger technology adds to avoid abusive returns and to pursue end-of-life recovery.

Although there is much literature available on ICT and reverse logistics, one can notice that there are pertinent questions that still need an answer. Products have commonly been designed for one straight path, i.e. from production to distribution, to use to disposal. Easy manufacturing was another aspect kept in mind. In the context of recovery, one also finds needs in the opposite end: products have to be teared apart calling for design to easy de-manufacturing. Besides this, disassembled parts may have to be re-assembled in re-manufactured products. As the case of Xerox shows, an integrated DfX is a critical factor for a sustainable development. Some studies take into account the impact of product design on the supply chain logistics (see e.g. Krikke et al., 2001). There is however a further opportunity to develop quantitative models to unravel trade-offs of integrated DfX, being X either manufacturing, or de-manufacturing, or re-manufacturing and so on.

Regarding the application of ICT in the chain, all the case studies presented here provide in one way or the other an evaluation on the benefits of this investment. However, except for the Estée Lauder (Meyer, 1999) case and partially Walden Paddlers (Farrow et al., 2000) the investments on such technologies or on gathering the information are not being taken into account. It is much welcome that in the future these shortsighted evaluations are broadened.

Finally, as the cases' descriptions show, information is very much a critical factor. The ICT tools are very demanding with respect to information for all the considered case studies, as Table 4.5 shows. Moreover, Nagel and Meyer (1999) declare that the lack of information is a bottleneck, which brings difficulties for the management of recycling systems. On the Nortel Networks case, the DSS could not be designed as desired due to a short of data on customer's returns (see Nagel and Meyer, 1999) Data is of alike importance in the Xerox's case (Maslennikova and Foley, 2000) as the key-role played by the databases on products corroborates. Faced with the case studies evidence we advance that presently data rather than technology is the critical factor with respect to ICT applications for reverse logistics.

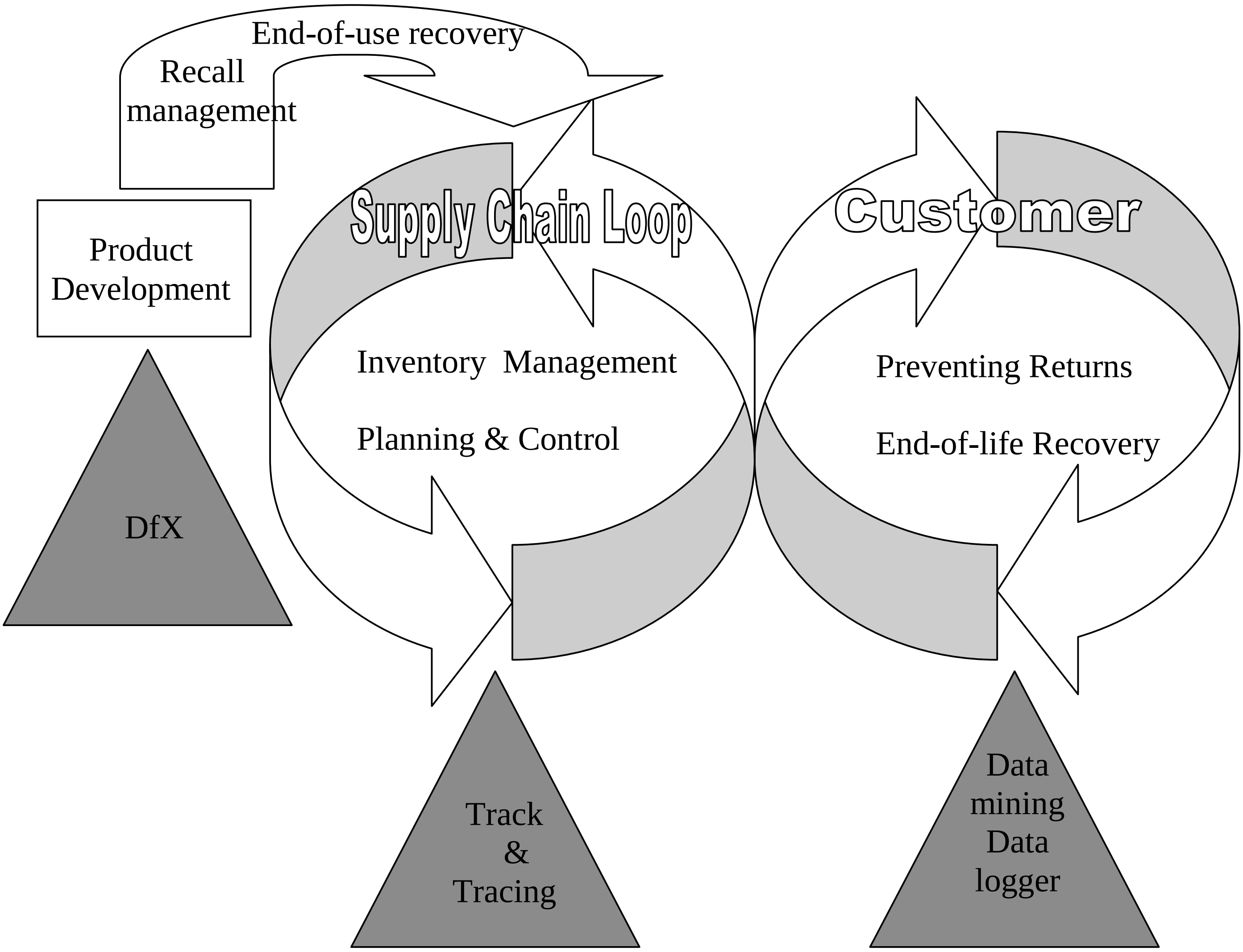


Figure 2. Applications and implications of ICT during product's life-path.

## 5. Implications and research opportunities

Up to here we have presented and highlighted particular matters of over than sixty real cases involving reverse logistics. By classifying the cases according to the United Nations classifications for Industry (see http://esa.un.org and Appendix B) one notices that around 60% of the cases are in the manufacturing category, about 20% are within wholesale and retail trade and about 10% in construction. We have also found cases in the following categories: transport and communication, public administration and defense, and other community services (like refuse disposal). The majority of the cases concern manufacturing activities. However, we do expect that in the future more case studies are carried out on wholesale and retail sale, as the problematic in this area has been catching attention from practitioners and researchers (e.g. e-commerce). With a similar grouping with respect to products, we observe that almost half of the cases deal with metal products, machinery and equipment. Around 30% of the products being processed were transportable goods like wood, paper and plastic products. Around 20% were food products, beverages, tobaccos, textiles and apparel. Less than 10% fell in the category ores and minerals. Not surprisingly, these numbers show that the majority of the cases are on products with high value.

Regarding (private) Network Structures for re-usable distribution items, we observed that the critical questions are: how many items and where. With respect to (private) remanufacturing networks, the main issues of concern are: where to allocate the remanufacturing facility while ensuring a sustainable volume of input products and how to reduce the uncertainty on the latter. Public recycling networks work very much as a push system and the amount of money needed to support it depends of the recycling targets set a priori. This is very relevant as EU advances in setting tighter recycling targets. Since economies of scale are usually required for economic feasibility, a lot of transport is generated (both an economic and an environmental drawback). This should also be taken into account in further EU policymaking and research because the primary force behind recycling quotas is sustainable development and concern with the environment. As for private recycling networks, they resemble more to a pull system and acquisition is therefore more important. The recycling and the transportation are paid by the processor and also a sufficient volume of input has to be guaranteed.

In the Relationships context, a critical factor is to be informed on the alternatives of the partners and costs associated with respect to recovery and/or disposal of products. This would help on the choice of incentives to enforce/stimulate certain desired behavior by the partner. The fact that for most of the case studies no reason is given for the specific incentive in place may indicate that actually in practice firms do not have satisfactory insights in the implementation of such incentives. Therefore, there is an opportunity to investigate the benefits/costs of recovery activities for the parties involved. In particular used products have been disregarded in this type of literature since all the models for buy-back or selling -prices concern unused products

In reference to Inventory Management the critical factors seem to be well grouped according to return reason. For commercial returns (B2B and B2C) the key-questions are how many and when will the products come back. The condition of those is many times as good as new, so they can after a brief inspection be put in inventory. However, in B2B, the products come back in bulk while in the B2C they do not. Service and warranty returns have large commonalities with respect to inventory management. The critical question is how many parts in which stock location should be kept. The bottleneck is that the return of parts is outside one's control. On end-of-use returns a critical question is the match between demand for used products and the supply, both in time, quantity and quality.

On the subject of planning and control of recovery activities, the case studies describe in a global manner the issues, many times without grounding the way activities go on. The research gap here seems to be the lack of in-depth case studies. There is a need to get more thorough understanding on the concept of planning and control used in practice and to get to know more about its performance. In this way we could examine whether academic concepts are used or how can they be used in practice. Besides this, scientific research incorporates the uncertainty on the arrival of products but it systematically neglects that the outcome of re-processing is uncertain as well.

Finally, we found cases reporting evidence that ICT can be used in all the stages of the life-path of a product (product development, supply chain loop, and customer) with benefits for reverse logistics. For instance the data logger technology is very promising regarding the need of a quick access of the state of the product. In this way uncertainty on quality can be reduced and savings can be made on activities, as e.g. disassembling. Another point that came forward through the cases is that real benefits for reverse logistics are achieved through integrated DfX,. Not only DfX with X being for instance recycling in isolation, but even opposed processes should be taken into account as for example manufacturing vs. de-manufacturing. With this respect, there is a research opportunity to unravel the trade-off's between the various forms of DfX. Almost all the cases that focused on ICT disregard the required investment and reported profits only. It is important to broad such partial sighted reports. Finally, though the technology to process and to transmit information with promising benefits for reverse logistics seems to be available, the lack of appropriate data is in still a bottleneck in the implementation of decision support systems. The shortness of theory for reverse logistics (see Dowlatshahi, 2000) or even for supply chain management (Croom et al., 2000) adds to companies' inability of knowing which data matters. Therefore on top of the research agenda should be the development of theory for supporting reverse logistics decisions.

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### Appendix A – Search Words

| | | |
|---|---|---|
| Asset recovery | | |
| By-products/byproducts | Post-consumer | Repair |
| Containers | Producer responsibility | Repairables |
| Co-products/coproducts | Product ownership | Resale / re-sale |
| Core | Product recovery | Resell / re-sell |
| Defects | Product stewardship | Return (includes commerical returns) |
| Defective | Reassembly | Reuse/ re-use |
| Disassembly | Rebuild | Reutilisation |
| Dismantling | Recalls | Reusable |
| Disposal | Reclaim | Reverse logistics |
| Downgrading | Reclamation | Rework |
| Energy recovery | Reconditioning | Salvage |
| Environment | Reconsumption | Secondary (market, materials) |
| Garbage | Recovery (product, resource, asset) | Separation |
| Gate keeping | Recycling | Source reduction |
| Green logistics | Refill | Take back |
| Material recovery | Refillable | Upgrading |
| Obsolete (stock) | Refurbishing | Value recovery |
| Outlet | Remanufacturing | Warranty |
| Overstock | Repack | Waste |

Table A.1 Search words.

The search was executed with each of the words from Table A.1 and with the following combination of words: logistics, or planning, or control, or transport, or inventory, or capacity, or production, or information

### Appendix B- United Nations classifications for Industry and Product (see http://esa.un.org)

| Industry category | Product category |
|---|---|
| A-Agriculture, hunting and forestry | 1-Ores and minerals; |
| B-Fishing | 2-Food products, beverages, tobaccos; textiles, apparel and leather products |
| C-Mining and quarrying | |
| D-Manufacturing | 3-Other transportable goods, except metal products, machinery and equipment (e.g. wood, paper and plastic products) |
| E-Electricity, gas and water supply | |
| F-Construction | |
| G-Wholesale and retail trade | 4- Metal products, machinery and equipment |
| H-Hotels and restaurants | |
| I-Transport, storage and communications | |
| J-Financial intermediation | |
| K-Real estate, renting and business activities | |
| L-Public administration and defense | |
| O-Other community, social and personal service activities | |
| P-private households | |
| Q-Extra-territorial organizations | |

Table B.1 List of Industry and Product classifications.

# Appendix C – Summaries of the case studies

## Network structure

| | Product | | | Supply chain | | | | | Drivers | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reference** | **Product (in)** | **Process** | **Product (out)** | **Sender** | **Collector** | **Processor** | **Customer** | **Initiator** | **Sender** | **Initiator** | **Customer** |
| Barros et al. (1998) | construction waste | recycling | sand | waste processors | consortium | consortium | construction industry | consortium | waste disposal | environm. regulation | |
| Bartels (1998) | batteries | recycling | materials | households, Companies | municipalities, Retailer chains, Schools | specialized companies | | Ducth master organisation of importers of batteries (including the importers of products containing a battery) | environmental concern, small presents | legislation | |
| Chang et al. (2000) | household waste | recycling | | households | public authority: environmental protection bureau | public authorityr: environmental protection bureau | | Kaohsiung's city government | waste disposal | cost savings and environmental motives | |
| DelCastillo & Cochran (1996) | See Table on Inventory Management (C.3) | | | | | | | | | | |
| De Koster et al. (2000) | large white goods | recycling | materials | households | municipalities, Retailers, Third party logistics service providers (Vonk, Hoogers) | CoolRec (coolers and freezers), HKS Metals (other big white goods) | materials processing companies (including Corus) | VLEHAN and FIAR (Dutch organisations of suppliersand producers, importers and distributors of electronics resp.) | no disposal costs | legislation | |
| De Koster et al. (2001) | products, packaging materials, distribution items | Sorting, re-stocking | Input products, packaging and distribution items, and waste | Individual supermarkets | Supermarket chain DCs | Supermarket A | Individual supermarkets, materials collectors, processors, suppliers | Supermarket A | less disposal costs | less disposal costs | |
| De Koster et al. (2001) | unused shoes, sports attributes, paper waste and advertisement materials | Sorting, re-stocking | input products, packaging and distribution items, and waste | Customers / chain stores | Chain stores / DC | chain store A | Usual customers , customers special outlets returned products | chain store A | refund | | |
| De Koster et al. (2001) | unused products, coat hangers and racks | Sorting, re-stocking | resalable goods / waste / reusable containers, coat hangers | Customers / chain stores | Chain stores / DC | chain store B | Usual customers , customers returned products (special outlets) | chain store B | refund | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| De Koster et al. (2001) | unused products / advertisement materials / containers | Sorting, re-stocking | resalable goods / waste / reusable containers, coat hangers | Customers / chain stores | chain stores / DCs | chain store C | Usual customers , special outlets returned products | chain store C | refund | | |
| De Koster et al. (2001) | diverse products | sorting | Input products | customers | Mail order company A | Franklin mint | Usual customers | Mail order company A | refund | business requirement | |
| De Koster et al. (2001) | consumer goods | Sorting | Consumer goods | customers | DCs | Wehkamp | Usual customers | Mail order company B | refund | business requirement | |
| De Koster et al. (2001) | cloths, small appliances | Sorting | Cloths, small appliances | customers | DCs | Mail order company | Usual customers | Mail order company C | refund | business requirement | |
| Dijkhuizen (1997) | defective parts | repair | repaired parts | Customer | regional or national center | regional or national center | customer | IBM | deposit fee | cost savings, market protection for own service parts, insight into quality, environmental legislation | |
| Duhaime et al. (2001) | monotainers | collection, distribution | monotainers | Canada Post | Canada Post | Canada Post | Canada Post | Canada Post | cost savings | Costs savings | cost savings |
| Kleineidam et al. (2000) | wastepaper | collection; recycling vs. incineration | | households, businesses | mainly non-profit organisations | wastepaper processor vs. collector | pulp industry | | waste disposal, legal | | purchase of raw material |
| Kroon and Vrijens (1995) | packaging (Containers) | cleaning | packaging (Containers) | business customers | Nedlloyd | Nedlloyd | business customers | | deposit | rental income | |
| Krikke (1999) | used photocopiers | Remanufact. | New photocopiers | Local operating company | Oce, a copier firm in Venlo (NL) or Prague (Czech Rep.) | Oce | Usual customers and secondary market | Oce | Fee | economics | |
| Louwers et al. (1999) | carpets | recycling | fibers, filling materials for roads and dams etc | households, companies (e.g. involved in floor covering) | companies involved in floor covering, municipalities, special organization | special organization for sorting, fiber producers, cement industry | customers for fibers, cement, road and dam builders | Carpet industry, including their fiber suppliers | | Image, expected legislation, economic advantages | |
| Meijer (1998) | used scanners, printers, copiers, faxes, tonercartridges package materials | remanufact., recycling | remanufactured machines, materials; | households, companies | dealers, Third party logistics service providers | Canon France (recyc. Toner Cartdr.), Canon Scotland (reman. Copiers) | Canon | Canon | No disposal costs | Green image | |
| Realff et al. (2000) | Carpeting Mat. | recycling | nylon fibres | business customers | carpet dealers | DuPont | | DuPont | waste disposal | market value | |
| Spengler (1997) | steel by-products | recycling | reusable products | steel industry | steel industry | steel industry | steel and other industry | Industry/govern m. | Disposal cost saving | Public waste management | Low price |
| Idem | domestic buildings | recycling | reusable material | households | Demolition companies | recycler | industry | government | disposal Cost savings | public waste management | low price |
| Van Burik (1998) | car wrecks | recycling | materials, waste | car owner | certified disassembly companies | selected recycle companies | | Car importers in The Netherlands | No disposal costs | Legislation, costs | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Van Notten (2000) | glass from bottles, pots | recycling | Input material for glass industry | households, companies (notably glass producers, bottlers) | specialized companies | glass recycling companies | glass industry | Stichting Kringloop Glas (Glass collectors, glass recyclers, glass producers) | no disposal costs | legislation | |

Table C.1 Case studies with focus on Network Structures.

## Relationships

| | **Product** | | | **Supply chain** | | | | | **Drivers** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reference** | **Product (in)** | **Process** | **Product (out)** | **Sender/Giver** | **Collector** | **Processor** | **Customer** | **Initiator** | **Sender** | **Initiator** | |
| Bartel (1995) | tonercartridge | remanufact. | reusable tonercartridge or parts | customers of Unisys | US Postal Services | | Customers of Unisys | Unisys | fee | to offer customers recovered tonercartridges | cheaper |
| Driesch et al. (1998) | used car engines | remanufact., refurbishing | remanufactured or refurbished car engine | owners of a Mercedes benz (MB) car with an MB engine | MB dealers | DR MTR | owner of a MB car | Daimler-Chrysler (Mercedes-Benz) | costs | long term relation with present customers, attracting new customers | costs |
| Faria de Almeida and Robertson (1995) | batteries | recycling | materials | user batteries | shopping malls, hardware stores, mobile collection units recycl.points | different processors | customers raw materials | City of Leicester (UK) | | | |
| Farrow et al. (2000) | See Table on Information Technology (C.5) | | | | | | | | | | |
| McGavis (1994) | used tonercartridges | recycling | materials | user cartridge | UPS | several processors for different parts | HP | HP | donation by HP to WWF | energy savings, bad image by bad quality 3P remanufact. | energy savings, bad image by bad quality 3P remanufact. |
| Vroom et al. (2001) | PC bottles; crates, roll in containers, pallets; | cleaning | PC bottles ; crates, roll in containers, pallets; | households; supermark.; DCs supermarket chains; | supermarket; supermarket chains and DC's; Campina; | Campina | Campina | Campina | deposit fees | | |
| Wijshof (1997) | Rockwool from building or demolishing locations | cleaning, recycling | secondary input material production rockwool | building companies, demolishers, sellors rockwool | third party logistics service provider (BFI, Sovabo) | sorting by BFI or Sovabo; recycling by Rockwool | building industry | Rockwool | less disposal costs | green image | less disposal costs |
| Yender (98) | batteries | recycling | raw materials, batteries | households, companies | UPS, retailers, municipalities | different processors including INMETCO | raw materials users | rechargeable battery recycling corporation | | | |

Table C.2 Case studies with focus on Relationships.

## Inventory Management

| | Product | | | Supply chain | | | | | Drivers | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reference** | **Product (in)** | **Process** | **Product (out)** | **Sender** | **Collector** | **Processor** | **Customer** | **Initiator** | **Sender** | **Initiator** | **Customer** |
| De Brito and Dekker (2001) | Diverse out 15 000 sku | refunding and re-stocking | product (in) | internal customers | Customer brings it back | European Organization for Nuclear Research | internal customers | CERN | refund, no longer need it | | |
| De Brito and Dekker (2001) | fashion, electronics and furniture | Collection, inspection, re-stocking | product (in) | customers | mail-order-company | mail-order-company | customers (same chain) | mail-order-company | mismatch with needs | marketing, legislation | resold items are not recognized |
| De Brito and Dekker (2001) | thousands of spare parts | repair and/or re-stocking | product (in) | maintenance personnel | maintenance brings it back | refinery (as maintenance) | internal customers | | not needed | | need for a spare-part |
| DelCastillo and Cochran (1996) | softdrink bottles | cleaning | softdrink bottles | consumer | retailers | Coca Cola | original chain | Coca Cola | deposit | cost sacings | no distinction |
| Diaz and Fu (1997) | railway spare parts | repair | railway spare parts | Caracas Subway | Caracas Subway | Caracas Subway | Caracas Subway | Caracas Subway | (same company) | cost savings | (same company) |
| Donker and van der Ploeg (2001) | repairable circuit boards for telephone-exchanges | repair | repaired circuit boards | telephone companies | Lucent Technologies | Lucent Technologies | telephone companies | Lucent Technologies | | costs savings | |
| Fleischmann (2000) | used/ unused machines | dismantling, repair/ refurbishment | spare parts | business customers,/ retailers | | IBM facilities | | | Overstocks/ no longer needed | | |
| Klausner and Hendrickson (2000) | power tools | remanuf./ recycling | energy or power tools | customers | dealer, logistics provider | specialized facility | | manufacturers of power tools | no longer needed/ economic | pro-active policy | |
| Moffat (1992) | aircraft engine | repair, recondition | aircraft engine | UK Airforce | UK Airforce | UK Airforce | UK Airforce | UK Airforce | (same company) | cost savings | (same company) |
| Rudi et al. (2000) | wheel chairs, hearing aids, speech synthesizers, etc. | Reuse/ Refurbish/ Recycling/ cannibalization, landfill | wheel chairs, hearing aids, components, materials, etc. | users | Technical Aid Center (TAC) | TAC (in some cases recycling center) | people with handicaps | Norwegian National Insurance Administration | failure or no longer needed | economic, environmental | |
| Sanders et al. (2000) | complete products retail | sorting | complete products retail | customer Wehkamp | third party logistics service provider | Wehkamp | customer of Wehkamp | Wehkamp | not satisfied with product (right of return) | to attract and keep customers | |
| Swinkels and van Esch (1998) | Beer kegs | | Beer kegs | restaurants, bars, etc. | Bavaria, Agents | Bavaria | Bavaria | Bavaria | | lower costs | |
| Toktay et al. (2000) | disposable cameras | remanufactur. | disposable cameras | consumer | Photo Shops / Retailers | Kodak | original chain | Kodak | film developed | cost saving | |
| Van der Laan (1997) | used car parts | remanufactur. | remanufactur. parts | National Importer Organization | Volkswagen (Kasse'sl facility) | Kassel (remanufact.) | NIO which delivers to car sellers | Volkswagen (Kassel's facility) | no longer needed and legal | economic | |

Table C.3 Case studies with focus on the Inventory Management.

## Planning and Control

| | Product | | | Supply chain | | | | | Drivers | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reference** | **Product (in)** | **Process** | **Product (out)** | **Sender/Giver** | **Collector** | **Processor** | **Customer** | **Initiator** | **Sender** | **Initiator** | |
| Andriesse (1999) | pallets, pallet caps | sorting | pallets, pallet caps | suppliers | Philip Morris | Philip Morris | suppliers | Philip Morris | cost reduction | legislation | cost reduction |
| Bakkers and Ploos van Amstel Jr . (2000) | PVC lamellas | Recycling | PVC | Households, companies | Distributors lamellas | Ortes Lecluyse | Ortes Lecluyse | Ortes Lecluyse | no disposal costs | green image | green image |
| Bartels (1998) | See Network Structure table | | | | | | | | | | |
| Bentley et al. (1986) | subway/transit cars | overhaul | subway/transit cars | NY City , NJ, Chicago, Transit, etc | | Morrison-Knudsen Company | NYCity , NJ, Chicago Transit, etc | Morrison-Knudsen Company | | economic | |
| Del Castillo and Cochran (96 | See Inventory Management Table (C.3**)** | | | | | | | | | | |
| Duhaime et al. (2001) | See Network Structures Table (C.1) | | | | | | | | | | |
| Driesch et al. (1998) | See Relationships Table (C.2) | | | | | | | | | | |
| Guide and Spencer (1997); Guide et al (1997); Guide and Srivastava (1998) | aircraft, engines, avionics equipment | remanufactur. | aircraft, engines, avionics equipment | Airforce | Airforce | US Navy overhaul/ repair Depot | Airforce | Airforce | | | |
| Gupta and Chakraborty (1994) | Production glass scrap | Recycling | Raw materials | Producer glass | Producer glass | Producer glass | Producer glass | Producer glass | Cost savings | Costs savings | Costs savings |
| Klausner and Hendrickson (2000) | See Inventory Management Table (C.3) | | | | | | | | | | |
| Krikke et al. (1999b) | Roteb case | | | | | | | | | | |
| Robinson (1992) | Diesel engine components | remanufactur. | remanufactured Diesel engine components | | | Detroit Diesel remanufactur. -West | | Detroit Diesel remanufactur. - West | | | |
| Schinkel (2000) | gypsum (building industry) | sorting, recycling | gypsum | building companies | third party LSPo | producers of Gypsum products | customers producers Gypsum products | Producers of Gypsum products (organisation) | lower disposal costs | legislation | |
| Simons (1998) | Wooden sheets, prod. scrap (internal and external) | sorting, Recycling | wood | Trespa (prod. scrap)/Scrap from building sites | third party LSP , builders, demolishers | Trespa | Builders | Trespa | reduction disposal costs | green image, expected legislation | |
| Simons (1998) | pallets | sorting, cleaning | pallets | builders, demolishers | third party LSP, builders, demolishers | Trespa | Trespa | Trespa | | economics, legislation | |
| Spengler et al. (1997) | See Network Structures Table (C.1) | | | | | | | | | | |
| Teunter et al. (2000) | By-products | Re-process, reuse | valuable pharmaceut. materials | (manufactur. process) | | pharmaceut. company, Schering AG | (manufactur. process) | Schering AG | value of by-products | | |
| 't Slot and Ploos (1999) | white and brown goods | recycling | reusable materials | households | municipalities, retailers | Recycler | users materials | government | no disposal costs | environment | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Thomas Jr (1997) | aircraft | remanufactur. | airplane engines | | | | Pratt & hitney aircraft West Virginia | Pratt & hitney aircraft West Virginia | | | |
| Ubbens ('00) | Tin plate containers for beverages, food etc | recycling | Tin | households etc | municipalities (via household waste) | Household / metal waste processing companies | Metal industries | Stichting Blik | none | legislation | cheaper than virgin materials |
| Van Donk (1999) | leftovers from building activities | recycling | | buidling companies | special collectors | | | | legislation, lower disposal costs | environment | |
| Van Notten (2000) | | | | | | | | | | | |
| Wijshof (1997) | See Table on Network Structures (C.1) | | | | | | | | | | |

Table C.4 Case studies with focus on Planning and Control

## Information Technology

| | **Product** | | | **Supply chain** | | | | | **Drivers** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reference** | **Product (in)** | **Process** | **Product (out)** | **Sender/Giver** | **Collector** | **Processor** | **Customer** | **Initiator** | **Sender** | **Initiator** | **Customer** |
| Nagel and Meyer (1999) | end-of-use refrigerators | re(production) recycling | plastics; metals; | end-of-life user | dealer; service provider | recycling plant | | | no longer needed | legal, economic | |
| Idem | computers | possibly disassembly | Possibly components | End-of-life user | VOBIS (retailer) | Covertronic (Recycler) | | Covertronic (Recycler) | no longer needed | economic | |
| Meyer (1999) | cosmetics | consolidation | cosmetics | customer | Estee Lauder | Estee Lauder | (same chain or employees) | Estee Lauder | unfit needs | legal and economic | |
| Farrow et al. (2000) | post-consumer & other plastics | DfX, (Innovation), recycling | (100% recycled) Kayak | consumer | supplier of recycled resins | kayak's manufacturer | from the recreational Kayak Market | Walden Paddlers, Inc. | waste disposal | environmental responsibility | economic |
| Linton and Jonhson (2000) | circuit boards | remanufactur. | circuit boards | customer | customer Service (NN) | customer Service (NN) | (close-loop) | Nortel Networks | avoid waste (economic) | economic | |
| Landers et al. (2000) | telephones | rework | telephones | customer | service technician | repair center | (same chain) | | failure or malfunction | | |
| Maslennikova and Foley (2000) | recycled raw materials; used Xerox equipment | design for the Environment & Rework | Xerox's equipment | customer | Xerox Europe, Ltd. Service engineers | Xerox Europe, Ltd. | (same chain) | Xerox Europe, Ltd. | no longer needed | economic, legal | |

Table C.5 Case studies with focus on the Information Technology.

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