Reverse Logistics: A Review of Case Studies

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Abstract. Reverse logistics deals with the processes associated with the flows of products, components and materials from users/owners to re-users. This paper provides a review and content analysis of more than sixty case studies on reverse logistics. The case studies deal with issues such as the structure of the networks, the relationships between the different parties involved on the networks, inventory management, planning and control, and information technology. The analysis concerns the following questions: what is returned, why do these return flows exists, i.e. what are the drivers/reasons for these flows, how are these return flows being recovered, and finally, who is involved? We end with a summary and suggestions for further research.

Key words: Reverse logistics; Case studies; Content analysis.

1 Introduction

Reverse logistics, dealing with the physical flows of products, components and materials flowing from users/owners to re-users, is a growing field both in practice and in the academic world. In order to get insight in how reverse logistics are dealt with in practice, field studies and surveys are useful. Examples of the latter are presented in (Rogers and Tibben-Lembke, 1999; Guide, 2000).

This paper gives some idea about the diversity of logistics practices via a content analysis for more than 60 case studies. This analysis is useful for both practitioners and academics, by giving insight in how companies are dealing with reverse logistics, which are the trade-offs that play a role during decision making, how these decisions are supported and so on. Quite some case studies on reverse logistics have been described in the literature, dealing with different industries, recovery options and drivers, see e.g. (Kopicki et al., 1993; Kostecki, 1998; Lund, 2001; Flapper et al., 2004). However, there are many more case studies available in literature that are scattered over journals for very different research communities. Besides, in a number of countries in the forefront of reverse logistics, a substantial number of case studies has been published in languages other than the lingua franca and is therefore not accessible for the majority of the research community. The main purpose of this paper is to give an overview of the above case studies.

The remainder of the paper is organized as follows. In Section 2 we firstly define what we mean by case study and describe the methodology used for finding and classifying the case studies presented in this paper. Next, in Section 3, we provide overall statistics for the set of cases discussed. After that, in Sections 4 to 8, we discuss the case studies that we found in detail, and present observations, propositions and research opportunities. Finally, in Section 9, we end with a summary of our main findings and our main conclusions.

2 Methodology

By case study we mean an in-depth analysis of a practice, leading to an understanding of a situation within its context (Stake, 1995). This definition rules out mere examples short on details, as well as the sole description of business practice often found in professional journals. The latter does not mean that we think that professional journals are not useful for learning about reverse logistics. However, publications in these journals are more likely to be biased than publications in scientific literature, for instance because often they are also used as a marketing tool. We used the following on-line sources: Science Citation Index Expanded (http://www.sciencedirect.com/) of the Institute of Scientific Information, and ABI/INFORM Global (http://www.proquest.umi.com) of the Bell & Howell Information and Learning Company, using the key words listed in Table 1 and (a combination of) the words: logistics, planning, control, transport, inventory, capacity, production, information.

Asset recovery		
By-products/byproducts	Post-consumer	Repair
Containers	Producer responsibility	Repairable
Co-products/co-products	Product ownership	Resale / re-sale
Core	Product recovery	Resell / re-sell
Defects	Product stewardship	Return(includes commericial returns)
Defective	Reassembly	Reuse/ re-use
Disassembly	Rebuild	Reutilisation
Dismantling	Recalls	Reusable
Disposal	Reclaim	Reverse logistics
Downgrading	Reclamation	Rework
Energy recovery	Reconditioning	Salvage
Environment	Re-consumption	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 1. Key-words used for the literature search

Moreover, we went through some other sources dedicated to reverse logistics: the (Dutch) Handbook of reverse logistics, and the proceedings related to the Reman conferences organized by APICS (The American Production and Inventory Control Society), see (http://www.apics.org/), and the proceedings related to the conferences on Electronics and the Environment, organized by IEEE (Institute of Electrical and Electronics Engineers), see (http://www.ieee.org/). The main search took place in early 2001 but continued till the end of 2002. The case studies are structured according to a framework for reverse logistics presented in (De Brito and Dekker, 2004). Accordingly, for each case study we collected data on

- What: the products entering the reverse logistics network (product-in's) and the products leaving the reverse logistics network (product-out's)
- How: the main recovery process used
- Who: the actors and their function in the reverse logistics network (supplier (i.e. the owners/users of the product-in's), collector, processor, customer and initiator);
- Why: the driving forces for the suppliers of the product-in's and the initiator of the reverse logistics activities.

The above information is summarised in a number of tables, where each table gives the following general case information: the reference and the geographical area of the case study, the product-in, the main recovery process used, the product-out, the supplier, the collector, the processor, the customer (re-user), the initiator, the reason(s) for the sender to take part, the driver(s) for the initiator, where an empty cell in a table indicates that the corresponding information is not given in the reference.

Hereafter a summary is given of the different sub classifications used for describing the different cases, based on (De Brito and Dekker, 2004).

Products:

- civil objects (like buildings, dikes, bridges, roads)
- consumer goods (like furniture, TV sets, cars)
- industrial goods (like trucks, machines)
- ores, oils and chemicals
- other materials (like glass, paper pulp)
- distribution items (like bottles, crates, pellets)
- spare parts

Recovery processes:

- direct recovery, i.e. recovery without any major processing
  - re-sale
  - re-use
  - re-distribution
- recovery requiring processing
  - repair (i.e. making products working again, bringing them to working condition)
  - refurbishing (i.e., product upgrading)
  - remanufacturing (i.e., the recovery of products to an as new level)
  - (parts) retrieval (i.e., the recovery of a selected number of parts from products)
  - recycling (i.e., the recovery of materials from products)
  - incineration
  - (proper) disposal.

Actors:

- forward supply network actors (such as manufacturers, wholesalers, retailers, service providers)
- specialized reverse logistics actors (such as recyclers, independent remanufacturers)
- governmental entities (such as European Union and national governments)
- opportunistic players (such as charity organisations)

Return reasons:

- Manufacturing returns, i.e., returns related to the execution of production processes, including
  - raw material surplus
  - quality-control returns
  - production leftovers
  - by-products
- Distribution returns, i.e., returns related to the distribution of production to (potential) customers, including
  - product recalls,
  - B2B commercial returns,
  - stock adjustments,
  - distribution items

- Market returns, i.e., returns from the users of products, including
  - B2C commercial/reimbursement returns
  - warranties
  - service returns (repairs and spare parts)
  - end-of-use returns
  - end-of-life returns

Drivers:

- Economics (direct and indirect profits related to reduced production costs, green image, market protection, improved customer/supplier relations, etc)
- Legislation
- Corporate Citizenship

The main idea behind de Brito and Dekker's framework is that a specification of the why, what, how and who using the above classification defines and explains the various ways in which reverse logistic activities are done. Moreover, the hypothesis is that a specification of the why and the what determine the processes (the how) and the actors (the who's).

In the context of reverse logistics, companies have to make several strategic, tactical and operational decisions. At strategic level, the collection network has to be designed. At tactical level, the relationships with partners have to be developed. At operational level, inventories have to be managed and activities have to be planned and controlled, see also (Ganeshan et al., 1999; Fleischmann et al., 1997). Based on the above, we discuss the case studies according to the following decision-making focus: Network Structure, Relationships, Inventory Management, and Planning and Control. As usual, information and communication technology plays an important role. For this reason, we also give an overview of Information and Technology (IT) for reverse logistics. If a case study focuses on more than one decision area, we discuss it in more than one section.

3 Statistics

Using the United Nations' classifications for industry (see http://esa.un.org), it turns out that roughly 60% of the cases concern manufacturing, 20% concern wholesale and retail trade, and about 10% concern construction. We have also found cases related to the classes transport and communication, public administration and defense, and other community, social and personal service activities.

Using the United Nations' classification for products (see http://esa.un.org), we observe that almost half of the cases deal with metal products, machinery and equipment. About 30% of the products being processed are other transportable goods like wood, paper and plastic products, whereas about 20% concern food, beverages, tobaccos, textiles and apparel. Less than 10% of the cases are related to the class Ores and minerals.

The majority of the cases are from Europe. In fact, we report on 1 case from Central-America, 1 case from South-America, 2 cases from Asia, 17 cases from North-America and more than 40 cases from Europe, where some cases are related to more than one geographical area. The unequal distribution of cases over geographic areas corresponds to the unequal past development of reverse logistics research in the different continents.

4 Case studies on Reverse Logistics Network Structures

Main activities in reverse logistics are the collection of the products to be recovered, their processing and the redistribution of the processed goods. Although at first sight, these activities seem to resemble the activities in standard forward production-distribution networks, there are also some differences.

Reverse logistics networks often have many suppliers (owners/users of products) from whom products are collected, far more than in many forward production-distribution networks. Moreover, the condition and configuration of the returned products is often uncertain, the packaging of the returned products is generally more problematic, the cooperation of the suppliers is much more needed and often the collected products have a relatively low value. In case a new network for reverse logistics has to be setup, decisions have to be made with respect to the number of echelons in the network, the number and locations of intermediate depots, the use of drop points for collection, the integration with the forward network of new products, and the financing of the network. See also (Fleischmann et al., 2004).

4.1 The case studies

We found 26 case studies on this subject, presented in Table 2. Hereafter, we discuss the cases in more detail, using the classification based on the recovery process used, which was also done in (Fleischmann et al., 2000). The most often described recovery process is direct recovery, either re-distribution or re-sale (12 cases), followed by recycling (11) and remanufacturing (3 cases).

Networks for re-use/re-distribution/re-sale

The cases that we found concern on the one hand commercial returns to retailers and on the other hand distribution items such as bottles, crates, pallets and containers.

De Koster et al. (2001) compare the return handling operations of three food retailers, three department chains and three mail-order companies. In total these are nine cases.

Kroon and Vrijens (1995) discuss the design of a network for reusable containers. The issues addressed by them are the role of the different actors, the economics of the system, the costs allocation to the different actors, the amount of containers needed, and the locations of the depots for the containers. Del Castillo and Cochran (1996) study the integral planning of production, product distribution and collection of re-usable containers used for distributing the products. They apply their model to the re-usable bottles used by a soft drink company in Mexico. Duhaime et al. (2000) discuss the distribution and collection of returnable containers by Canada Post.

Networks for remanufacturing

Typically, remanufacturing concerns complex equipment with many parts. Usually, remanufacturing is labour-intensive, requiring much testing. Fleischmann et al. (2000) distinguish further between networks setup by OEMs (Original Equipment Manufacturers) and networks setup by independent third parties, because in the latter case integration with the original production-distribution network is hardly possible.

Krikke et al. (1999a) discuss the remanufacturing of copiers. The authors examine the economic consequences of two alternative locations for the remanufacturing facility: one coinciding with the location of the manufacturing facility and one in a cheap labour country. Meijer (1998) discusses Canon's remanufacturing network for printers, scanners, copiers and faxes in the Netherlands, Belgium and Luxemburg. Dijkhuizen (1997) discusses the remanufacturing network of IBM. He tackles the question: where to remanufacture the products of IBM in Europe: in each country or at one central location?

Networks for recycling

Two types of networks can be distinguished in this context: private and public networks. The same classification has been used by Fleischmann et al. (1997) and Goggin and Browne (2000). We identified eight cases on public networks and three on private.

Private networks

Louwers et al. (1999) discuss the setup of a carpet recycling network for part of Europe. Realff et al. (2000) discuss a similar network in the USA. Spengler et al. (1997) discuss two networks: one for the recycling of building waste, and one for recycling the by-products in the German steel industry. The authors pay among others attention to the cooperation between companies.

Public networks.

There are several papers describing the setup and organization of public recycling networks in the Netherlands. Bartels (1998) describes the Dutch nation wide network for battery recycling. In the Netherlands since 1995, all manufacturers and importers of portable batteries with a weight of less than one kg have to collect and recycle as much as possible the batteries that they sell in the Dutch market. For this purpose, the above mentioned companies founded the Stibat organisation to take care of this on behalf of them. De Koster et al. (2000) describe the Dutch nationwide network for the collection and processing of white goods, paying special attention to big white goods like refrigerators. Buyers of new white goods have to pay a disposal fee, which is used for financing the network. Van Notten (2000) describes the Dutch glass recycling network. In order to cope with the Dutch legislation, the glass industry in the Netherlands founded the Glass Recycling Foundation. The authors discuss the collect and pickup systems for the collection of glass from households.

Van Burik (1998) describes the Dutch nationwide network for dealing with car wrecks. Car manufacturers, importers, car recyclers and other parties together established a special organisation called Auto Recycling Netherlands (ARN) to fulfil legal requirements. Like in the case of white goods discussed earlier, in the Netherlands buyers of a new car have to pay a fee to finance the system. Barros et al. (1998) discuss the network for the recycling of sand from building waste in the Netherlands. Because the Dutch government aims to increase the percentage of sand that is recycled, from 70% at the moment to 90% in the near future, a group of construction waste processors wants to improve the sand recycling network, by the number and locations of depots where the sand is stored waiting to be recycled and the depots where the actual recycling will take place.

Kleineidam et al. (2000) consider the structure of the recycling network of the paper industry in the Netherlands. Companies selling paper and cardboard to the Dutch market, setup the Dutch Paper Recycling Cooperation. This cooperation takes care of the collection of paper, its processing into pulp that is the raw material for the paper industry. The authors focus on the network for the collection of paper from households run by non-profit organizations. The authors study the dynamic behaviour of the network, analysing the consequences of incineration costs and paper taxes. Chang and Wei (2000) discuss the location of the recycling drop-off stations in the recycling network for household waste in the city of Kaohsiung in Taiwan for which the Environmental Protection Bureau of the city is responsible.

4.2 Remarks

The reader should have noticed that this section focuses on the how and who. Typologies of the how and who also have been (more or less consciously) employed in previous literature to distinguish reverse logistic networks (see Fleischmann et al. 1999; Goggin and Brown 2000; Fleischmann et al. 2000; Fleischmann et al. 2004). Based on the case studies described above, one can make several conjectures about relations between elements of the framework. For example, all public recycling networks are oriented at avoiding waste. They consider end-of-life returns and are based on cooperation between companies. Cooperation or not between companies is a big issue for the other networks. In some cases it is done, but in other cases not.

So far, the models used for deciding on the locations of reverse logistics processing facilities are based on deterministic integer programming models (Fleischmann et al., 2003). However, often the uncertainty in reverse logistics networks is much higher than in the production-distribution networks for many products. Stochastic programming models may be useful in this context (Listes and Dekker, 2001).

5 Case Studies on Reverse Logistics Relationships

To stimulate/enforce a certain behavior of their partners, parties in the reverse chain may use various incentives. In this section we will discuss our findings with respect to the incentives that are used in practice to stimulate/enforce a desired behavior of partners in the context of product recovery. Thereby a distinction should be made between 1) incentives that may be used to influence the supply of goods to a company in the context of product 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, whereas 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.

Defining incentives to stimulate/enforce the desired behaviour 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, where creating a win-win situation might not be enough.

Incentives are used to influence 1) the quantity, 2) the quality (configuration and condition), and 3) the moment of supply. These three factors determine to a large extent the possibilities for recovery and reuse.

5.1 The case studies

Table 3 gives the general data for the case studies that we found where special attention is paid to the above mentioned incentives. We found eight different types of incentives in literature.

Deposit fee

This fee may concern the product itself or the item used for its distribution like a bottle, box or 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).

Take back

There are different types of take back options offered in practice. A company may offer to collect its products from its customers when these customers want to dispose them, either for free, or for a lower price than the customers would have to pay else. An example of the latter is the take back program of Rockwool Lapinus B.V., subsidiary of the Danish Rockwool company, in the Netherlands (Wijshof, 1997). Sometimes, 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 during some time after the product has been bought if the returned product fulfils some preset requirements at the moment of return based on the use of the product, like kilometers driven, and expected possibilities for selling the returned product. This holds for instance, for the Ford Options program (http://www.ford.nl). 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.

Fee

A fee is paid when a product is delivered 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 supply of products for recovery are car brokers and "second hand" shops. Other examples are Varta, the German battery manufacturer, in the UK paying 50 pence for every returned rechargeable battery sent to a collection point (Faria de Almeida and Robertson, 1995), UNISYS, paying for each toner cartridge returned (Bartel, 1995), and ReCellular, buying used cellular phones (Guide and Van Wassenhove, 2001). Sometimes, not the supplier of a product receives a fee for each product returned, but a non-profit organisation that may or may not be chosen by the supplier. This incentive was used by Hewlett Packard in order to get her toner cartridges back after an attempt to refer to the environmental consciousness of customers did not result in a satisfying number of returns (McGavis, 1994), and by Tesco to get cellular phones (http://www.tesco.com).

Trade-in

One can only get a new copy of a product if another copy is returned. This incentive is among others used by Daimler-Chrysler 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 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 the car can be used again by its owner.

Easy and simple method of supply

Two main supply systems can be found in practice: 1) pickup systems where (parts of) products to be recovered are collected at the locations where they are disposed, and 2) bring systems where the disposer has to bring the products to 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). Tucker et al. (2000) study the optimal picking frequencies to achieve a certain collected quantity. Some suppliers for toner cartridges, including UNISYS, deliver their cartridge in a box that can be returned for free either by mail (mixed bring-pickup system) (Bartel, 1995) or via a third party logistics service provider (pickup system) as done by Hewlett Packard (McGavis, 1994). The same incentive is used by some manufacturers of batteries (Yender, 1998).

Timely and clear information about the reverse logistics activities

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).

Environmental responsibility

The idea is to 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).

Power

As always, power can be used to force desired behaviour. An example is Walden Paddlers, using 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 Paddlers (Farrow et al., 2000).

5.2 Remarks

From the above, it is clear that a variety of incentives are used in practice to influence the behavior of partners in reverse logistics networks. Some incentives make up part of sales contracts, like the buy back option offered by Ford (http://www.ford.nl) and deposit fees. Other incentives, like trade-ins, require the customer to buy another product, as applies to the engine trade-in offered by Daimler-Chrysler (Driesch et al., 1998). There are also incentives not directly coupled to a selling activity, like a gift to a non-profit organisation as used by Hewlett Packard (McGavis, 1994) and Tesco (http://www.tesco.com). It seems that only deposit fees are specific for product recovery. The other incentives are also used to attract customers in general.

Although all the above mentioned incentives can be found in practice, as far as we know, no models exist to support the decision which incentive to use in which situation. With respect to the values of the different parameters related to an incentive, some research is available. Klausner et al. (1998) and 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. However, in the above two models the time aspect is neglected, i.e. a steady state situation is considered. There is quite a lot of literature on sales contracts with return options for unused products, including (Tsay, 2001; Anupindi and

Bassok, 1999; Corbett and Tang, 1999; Lariviere, 1999; Tsay et al., 1999). The prime focus of the latter literature on contracts with a return option is on what may be gained by both sellers and buyers by allowing buyers to order more under certain return options, where a fixed sales price is assumed for the products that are taken back by the seller.

6 Case studies on Inventory Management

The cases studies focusing on inventory management within reverse logistics are given in Table 4. They can be classified according to the return reasons (see Section 2). We did not find cases for all reasons. We found cases for B2C commercial returns, service returns, end-of-use returns and end-of-life returns. Omissions can be explained as follows. Manufacturing returns are often treated in production planning contexts. Product recalls are often special events, which are left out of consideration in inventory management. Warranty returns have similar characteristics as repairs. Stock adjustments are somewhat similar with some of B2B commercial returns (bulk returns) and might not even be distinguished from them in the case descriptions. Below we discuss the cases found in detail together with the mathematical models applied.

6.1 The case studies

Commercial returns cases

Commercial returns occur in a B2B or in a B2C 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 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 (fashion products), 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 (2003) investigate the distribution of the return lag, i.e. the time between the purchase and the return of an item, and its consequences for inventory management. Three cases are considered, viz. a mail order company, a spare parts warehouse at a petrochemical plant and the warehouse at the center for nuclear research, CERN.

Service return cases

Within service systems (like repair systems) returns occur basically in two 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 restore functionality by replacing a part. The failed part is then repaired, after which it will enter the inventory of spare parts. The cases found are described below in detail.

Diaz 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 (1997) describes the remanufacturing network of engines and automotive parts for Volkswagen. It is very similar to the engine remanufacturing case related to Mercedes Benz in the previous section. Guide and Srivastava (1998) discuss for an air force depot a method to determine the inventory buffers between the disassembly and the remanufacturing shop, and the inventory buffer between the remanufacturing shop and the reassembly shop.

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 and van Esch (1998) and Del Castillo and Cochran (1996) primarily concern distribution items. 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 modelled 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. (2000) 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. (2000) 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.

End-of-life returns cases

Fleischmann (2000) describes the dismantling of returned, end-of-life computers into useable spare parts with IBM. This case study shows how return obligations can be used as 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 returned 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 of remanufactured power-tools. The authors apply the model to the actual voluntary take-back program in Germany, where costs go beyond profits.

6.2 Remarks

We have grouped the presentation of the cases according to the return reason as follows: commercial returns, service returns, end-of-use and finally end-of-life returns. This seems a natural way of grouping and discriminating the reverse logistics issues rising from each inventory system. Other authors have done the same (see Dekker and Van der Laan, 2003). It remains to investigate in which degree inventory systems' characteristics are really dependent of the return reason, as well as on the type of product *(what)*.

Many have defended that product data are essential for efficient handling of returns. For instance, Kokkinaki et al. (2003) provide an example of the value of information for disassembly. Other authors have investigated the impact of data on the movement of return and quantity influence inventory management performance, including (Kelle and Silver, 1989; Toktay et al., 2000; De Brito and Van der Laan, 2003). Yet, there is room to model the impact of having a priori information on what can be recovered, i.e. on which parts are likely to be recoverable. In practice, the existent forecasting techniques would have to be enriched with broader explanatory variables. We refer to Toktay (2003) for a discussion of other factors influencing returns, which are potential explanatory variables in advanced forecasting models.

Many authors have investigated the impact of data on inventory management performance in the context of reverse logistics, including (Kelle and Silver, 1989; Toktay et al., 2000; De Brito and Van der Laan, 2002). Yet, there is room to model the impact of having a priori information on what can be recovered, i.e. on which parts are likely to be recoverable. In practice, the existent forecasting techniques would have to be enriched with broader explanatory variables. We refer to (Toktay, 2003) for a discussion of other factors influencing returns, which are potential explanatory variables in advanced forecasting models.

7 Case studies on Planning and Control of Reverse Logistics Activities

This section deals with the planning and control of reverse logistics activities. The planning and control of reverse logistics activities are strongly related to inventory management, the topic dealt with in the previous section. The latter includes the inventory levels that trigger the execution of activities. We are left with the decisions on lot sizes and scheduling. The case studies that we found can be divided in case studies primarily dealing with collection, disassembly, repair and reassembly, and case studies where attention is paid to the combined planning and control of distribution and collection, and production and processing. The general data on the following case studies is presented in Table 5.

7.1 The case studies

Collection

In a number of case studies, the lot size used for collection is just given, without explaining how this lot size has been determined. All the case studies that we found concern end-of-use or end-of-life returns.

Andriesse (1999) describes the Packaging Return System of Philip Morris Holland BV for among others reusable pallets. Philip Morris Holland BV and most of its suppliers agreed that the lot size for returning empty pallets should be a full truck load. Del Castillo and Cochran (1996) describe the mathematical model used by EMSA, a producer of soft drinks 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 drink and the depots delivering the soft drinks to the stores. Duhaime et al. (2001) present the mathematical model 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 per region each month. Klausner and Hendrickson (2000) mention the lot size used for the collection of power tools by Robert Bosch GmbH. Bartels (1998), describing the Dutch nationwide network for collecting and processing portable batteries, pays among others attention to the collection of batteries at municipality collection points. These points can call one of the contracted collectors once a month to collect. Van Donk (1999) describes the system setup by Nelis Utitlieitsbouw BV, a Dutch building company, to keep the rest flows of different types of materials separated at building locations in order to allow a higher level of reuse of these flows, resulting in lower costs. Among others, attention is paid to the number and sizes of the containers used for collection. Whenever a container at a building location is expected to be completely filled soon, a recycling company is called to replace the filled container by an empty one. Van Notten (2000), discussing the bring and pickup systems for the collection of glass from households in the Netherlands, also pays attention to the sizes of the containers used and the collection scheme, often once a week. Schinkel (2000) describes the Dutch nation wide system for the collection 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 in and around Eindhoven, the Netherlands, preceeding the introduction of a nationwide network for the collection and processing of disposed white and brown goods. Examples of white goods are refrigerators, washing machines, whereas examples of brown goods are PC's, TV and radio sets. Among others attention is paid to the collection scheme at households being fixed (once a month or quarter), and the collection frequency at selling points of white and brown goods. Ubbens (2000), describing the recovery of metal from metal packaging in the Netherlands, pays among others attention to the number and sizes of special containers for the collection from households. Wijshof (1997) describing the collection and processing of the rockwool produced by Rockwool Benelux in the Netherlands, pays among others attention to the sizes that are used for collection and the number of bags that has to be filled before a third party is collecting them for Rockwool after having been contacted by the disposer. Finally, Tucker et al. (2000) pay attention to the consequences of changing the kerbsite collection frequency for newspapers at households for recycling from once per two weeks to once per four weeks in the Borough of Fylde in Lancashire in Great Britain, resulting in a very small decrease in the total quantity collected.

Processing

Bentley et al. (1986) mention that Morrison-Knudsen uses MRP II to plan the remanufacturing of subway overhaul, but the authors do not explain how. This also holds for Robinson (1992), who mentions the use of MRP by Detroit Diesel Remanufacturing West, where Detroit Diesel engines are remanufactured. Driesch et al. (1997), describing the recovery network for engines of Mercedes-Benz cars and vans in Europe, also describe the planning and control of the actual processing of collected engines in the central recovery plant in Berlin, Germany. 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. Aso here no further details are given, nor is explained how these lot sizes have been determined. Guide and Srivastava (1997a) discuss the application of the drum-buffer-rope principle in a US Navy Overhaul/repair Depot consisting of a disassembly, remanufacturing and a reassembly shop. Guide and Spencer (1997) and Guide et al. (1997) discuss a method for rough cut capacity planning for the above depot.

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. 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 in Germany.

Combined collection and distribution

Simons (1998) describes the system setup by Trespa International B.V. This company produces sheets made from resins and wood fibers which are used in the building industry. The recycling system was setup to recycle or incinerate (parts of) these sheets. Among others 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 customers let Trespa know when a container is filled. Filled containers are replaced by empty containers when new Trespa sheets are delivered to the customers. The reusable pallets used for the distribution of the Trespa sheets to the customers are collected either by third party logistics service providers who get money for the pallets that they deliver to Trespa, or by third party logistics service providers appointed by Trespa for the above collection. In the latter case, at least 15 pallets should be available at the moment of collection. Trespa promises its customers to collect these pallets within 3 weeks. The third party logistics service providers working for Trespa pickup the reusable pallets when they deliver new Trespa sheets.

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. Thereby also 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.

Combined processing and production

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 used by Schering AG, a German producer of medicines, for the planning of their production activities, including the processing of the by-products resulting from the production of medicines.

7.2 Remarks

In many of the case studies we found, only some planning and control issues are globally described, most of the time being the lot sizes that are used, without any further explanation. The authors hardly found descriptions of the planning and control concept for reverse logistics, let alone the quantitative motivation behind it. The case studies found hardly give insight into the problems companies have with the planning and control of their reverse logistics 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. For an overview, see (Dekker et al., 2004).

Many of these concepts assume autonomous supply of products that might be recovered, i.e., no direct, explicit relation between the number of products sold or leased, and the number of products returned is assumed, which is one of the essential differences between reverse logistics and many other production situations. Exceptions are literature on repair, see (Guide and Srivastava, 1997b) for an overview, and (Guide and Van Wassenhove, 2001; Guide et al., 2001). Uncertainty has been incorporated as far as the arrival of products for recovery and the duration of repair related activities are concerned. Uncertainty with respect to the result of the processing activities is hardly ever taken into account. An exception is (Souza et al., 2002).

Concluding, it seems useful to do more case studies 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.

8. Case studies on IT for Reverse Logistics

We have found various cases concerning applications of IT for reverse logistics activities (see Table 6). IT is used to support reverse logistics during different phases in the life cycle of a product, namely manufacturing, distribution and market (i.e., use), see also (Kokkinaki et al., 2003; Hendrickson et al., 2003). Table 7 shows more details about the case studies found on IT. Apart from listing the type of IT tool, it also shows which information it requires, the type of support it gives and for which lifecycle phase this is appropriate.

Reference / Geographical area	IT Tool	Information requirements	Type of support	Life cycle phase
Klausner et al. (1998) , Klausner and Hendrickson (2000) / Europe	EDL for electric motor reuse	potential cost savings	Reuse decisions through information on usage patterns	Product development, Market
Nagel and Meyer (1999) /Europe	DSS for end-of-use	operations costs and recycling revenues	Cost optimization, facilities location, vehicle routing, etc.	(Re-) distribution
Nagel and Meyer (1999) / Europe	Computer configuration reader	operations costs and recycling revenues	Setting buy-back price	Market
Meyer (1999) / North-America	software for return handling	product's expiration date, damage check	Recovery-related decisions	(Re-) distribution
Linton and Jonhson (2000) / North-America	DSS for remanufacturing	processing data	Remanufacturing-related decisions	(Re-) distribution
Maslennikova and Foley (2000) / Europe	DfX, remote maintenance, etc.	product data	Recovery options, environmental sustainability, etc.	All phases
Farrow et al. (2000) / North-America	DfX (X=Recyclability)	separation of resins, technological innovation	Design, production, recycling	(Re-) distribution

Table 7. Case studies focusing on IT tools, requirements and type of support for reverse logistics

8.1 The case studies

Manufacturing

Regarding the phase of product development and actual manufacturing, there are two variables to consider within the *what* dimension: 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 a defect, i.e. product recalls (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 holds for instance for Xerox Europe (Maslennikova and Foley, 2000). Xerox has an extensive Design-for-the-Environment program in place, where the design of each new component has to be accompanied with instructions for what to do with them at the end-of-use.

Recovery can also be the starting point for product development, as it is the case of Walden Paddlers, who launched a 100% recycled kayak project (Farrow et al., 2000). The project had to rely much on computer 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.

Distribution

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 uses bar code labels to track packaging material with the aim of achieving resources' preservation (Maslennikova and Foley, 2000).

The Fraunhofer IML institute has developed software to embed data on recovery processes as reported in (Nagel and Meyer, 1999). The authors consider two national reverse logistics networks in Germany: one for the recycling of refrigerators and one for the recycling of computers. Costs could be minimized by 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%.

Market

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

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

Estee Lauder is another firm that has developed specialized software to handle product returns (Meyer, 1999). The system checks the returned cosmetics with respect to their expiration date and damages. In this way, recovery related decisions are accelerated. The software is linked to an automatic sorting system, which saves labor costs. Estee Lauder could reclaim the investment on ICT within one year's time. Nagel and Meyer (1999) report on software developed 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 supplier when the computer is returned. Covertronic operates this software together with Vobis, a large computer retailer in Germany. Another technology available is the so-called electronic data logger (EDL). This device is 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 power tools, whereas Simon et al. (2001) apply both steady state and transient models to evaluate the benefits of using a data logger.

8.2 Remarks

Table 7 summarizes the IT tools to support reverse logistics activities described in the case studies presented above. The case studies illustrate IT applications in all the phases of the life cycle of a product and show how they may contribute to improvements in reverse logistics. For instance, Xerox (Maslennikova and Foley, 2000) has an integrated solution for reverse logistics from product development to recovery or proper disposal. All the case studies we found, provide insight in the benefits of IT. However, IT tools are very demanding regarding data on reverse logistic processes and associated costs and earnings. Often, this data is not available. Nagel and Meyer (1999) state that the lack of data is a bottleneck, which complicates the management of recycling systems. The DSS of Nortel Networks could not be designed as desired due to a shortage of data on returns from customers (Linton and Johnson, 2000). Besides this, to acquire and to manage the data is very expensive. However, the required investments in technologies or otherwise gathering data are not reported, except for the Estee Lauder case (Meyer, 1999) and partially for the Walden Paddlers case (Farrow et al., 2000). Therefore, the real benefit of IT investment is difficult to assess. In face of limited investment capacity, it would be helpful to know in which phase the investment would contribute most to the earnings of a company. In addition, if alternative technologies are available, one could investigate which one is the best. To do so, one has to take into account: costs and benefits of collecting and managing data and costs of investing and managing the technology. The following references are an excellent starting point, because they analysis the potential advantages or bottlenecks of some type of information in the context of reverse logistics: (Kelle and Silver, 1989; Inderfurth and Jensen, 1999; Klausner et al., 1998; Simon et al., 2001; De Brito and Van der Laan, 2003; Ferrer and Ketzenberg, 2003; Toktay, 2003).

9. Summary and conclusions

In this review we provided a content analysis of more than 60 cases of reverse logistics practices. With this content analysis, 1) we gave a substantial overview of the diversity of real life reverse logistics situations; and 2) we provided a reference guide to researchers searching for case support. The analysis was based on the framework for Reverse Logistics recently proposed by De Brito and Dekker (2004). Thus, for each case study we answered the following questions: *what* products/materials are being returned? *how* are they being recovered? *who* are the parties involved? and *why* is all this happening?

We presented the case studies according the following decision-making focus: Network Structures, Relationships, Inventory Management, and Planning and Control. Furthermore, there was an overview of Information and Technology (IT) for reverse logistics, based on the case studies.

The following observations come forward from this review.

- The how and who typologies can be used to characterize reverse logistic networks.
- The usual incentive tools in forward logistics are also employed in reverse logistics, which has only one extra tool, viz. deposit fees. There is a lack of literature supporting the *choice of incentive*.
- The *why-supplier* typology seems a natural way of grouping and discriminating the reverse logistics issues rising from the Inventory Management cases.
- Case studies on Planning and Control of product recovery were found on
  - separate collection of (parts of) products for recovery
  - separate processing of (parts of) products for reuse or disposal
  - combined planning and control of collection of products for recovery and distribution of new products:
  - combined planning and control of processing products for recovery and production of new products
- Cases on the use of IT exist for all the stages of the life-path of a product (product development, supply chain, and use with customer) with benefits for reverse logistics.
- Though the technology to process and transmit information useful for reverse logistics seems to be available, the lack of appropriate data is still a bottleneck in the implementation of reverse logistic decision support systems.

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ABI/Inform, ABI/Inform Global http://www.proquest.umi.com/

APICS, The American Production and Inventory Control Society http://www.apicsorg/

IEEE, Institute of Electrical and Electronics Engineers, Inc, http://www.ieee.org/

NAICS, North American Industry Classification System, http://www.naics.org/

OECD, Organization for Economic Co-operation and Development, http://www.oecd.org/

RevLog, the European Working group on Reverse Logistics http://www.fbk.eur.nl/OZ/REVLOG/

ScienceCitation, Science Citation Index Expanded, Elsevier Science B.V. http://www.sciencedirect.com/

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Table 2. Case studies focussing on Network Structures.

Reference / Geographical area	Product-in	Process	Product-out	Supplier (owner/user)	Collector	Processor	Customer			
Barros et al. (1998) / Europe	building waste	recycling	sand	waste processors	consortium building waste processors	consortium building waste processors	building industry			
Bartels (1998) / Europe	batteries	recycling	materials	households, companies	municipalities, retailer chains, schools	specialized companies				
Chang et al. (2000) / Asia	household waste	recycling		households	public authority environmental protection bureau	public authority environmental protection bureau				
Del Castillo and Cochran (1996) / Central-America	bottles	redistribution	bottles	consumer soft drinks	retailers		soft drinks producer			
De Koster et al. (2000) / Europe	large white goods	recycling	Materials	households	municipalities, retailers, 3rd party logistics service providers	recycling companies (CoolRec, HKS)	materials processing companies	[illegible]		
De Koster et al. (2002) / Europe (3 cases)	products, packaging, distribution items	redistribution	products, packaging, distribution items, waste	customers, supermarket stores	supermarket stores and distribution centers	supermarket chain	supermarket chain, collectors, processors, suppliers			
De Koster et al. (2002) / Europe	shoes, sports attributes, waste, advertisement materials	redistribution	products, packaging, distribution items, waste	customers, supermarket stores	supermarket stores and distribution centers	supermarket chain	supermarket chain, special outlets			
De Koster et al. (2002) / Europe	products, coat hangers, racks	redistribution	products, coat hangers, racks, waste	customers, supermarket stores	supermarket stores and distribution centers	supermarket chain	supermarket chain, special outlets			
De Koster et al. (2002) / Europe	products, advertisement materials, containers	redistribution	products, containers, waste	customers, supermarket stores	supermarket stores and distribution centers	supermarket chain	supermarket chain, special outlets			
De Koster et al. (2002) / Europe	consumer goods	redistribution	consumer goods	customers	mail order company	mail order company	same market			
De Koster et al. (2002) / Europe	consumer goods	redistribution	consumer goods	customers	mail order company	mail order company	same market			
De Koster et al. (2002) / Europe	cloths, small appliances	redistribution	cloths, small appliances	customers	mail order company	mail order company	same market			

Dijkhuizen (1997) / Europe	defective parts	remanufacturing	remanufactured parts	customers IBM	IBM	IBM	customers supplying defective parts			
Duhaime et al. (2001) / North-America	distribution items	redistribution	distribution items	Canada Post	Canada Post	Canada Post	Canada Post			
Kleineidam et al. (2000) / Europe	paper	recycling, incineration	materials, energy	households, companies	mainly non-profit organisations	recycler, special collector	pulp industry			
Kroon and Vrijens (1995) / Europe	distribution items	redistribution	distribution items	customers	Nedlloyd	Nedlloyd	customers			
Krikke (1999a) / Europe	copiers	remanufactu ring	remanufactured copiers	Oce national sales organisations	Oce	Oce	Oce national sales organizations			
Louwers et al. (1999) / Europe	carpets	recycling	fibers, filling materials for roads, dams etc	households, companies (e.g. involved in floor covering)	companies involved in floor covering, municipalities, special organization	organization for sorting, fiber producers, cement industry	customers for fibers, cement industry, road and dam builders			
Meijer (1998)/ Europe	scanners, faxes, printers, copiers, toner cartridges packaging	remanufacturing recycling	remanufactured machines, materials	households, companies	dealers, Third party logistics service providers	Canon France (toner cartridges), Canon Scotland (Copiers)	Canon			
Realff et al. (2000) / North-America	Carpeting Mat.	recycling	nylon fibres	business customers	carpet dealers	DuPont				
Spengler et al. (1997) / Europe	by-products steel production	recycling	materials	steel industry	steel industry	steel industry	steel and other industry			
Spengler et al. (1997) / Europe	demolition	recycling	materials	demolition companies	recycler	recycler				
Van Burik (1998) / Europe	car wrecks	recycling	materials, waste	car owner	certified disassembly companies	selected recycle companies				
Van Notten (2000) / Europe	glass	recycling	materials (input for glass industry)	households, companies	specialized companies	glass recycling companies	glass industry			

Table 3. Case studies focussing on Relationships.

Reference / Geographical area	Product-in	Process	Product-out	Supplier (owner/user)	Collector	Processor	Customer			
Bartel (1995) / North-America	toner cartridge	remanufacturing, (parts) retrieval	toner cartridges or parts	customers of Unisys	US postal services		customers Unisys			
Driesch et al. (1998) / Europe	car engines	remanufacturing, refurbishing	car engines	owners of a Mercedes Benz (MB) with an MB engine	Mercdes-Benz dealers	Daimler Chrysler	owners of an MB car	(		
Faria de Almeida and Robertson (1995) / Europe	batteries	Recycling	materials	user battery	shopping malls, stores, mobile collection units, recycling points	specialists	customers materials	Le		
Farrow et al. (2000) / North-America	cardboard boxes	redistribution	Cardboard boxes	Walden Paddlers	New England Foam of Windsor		New England Foam of Windsor			
Guide and Van Wassenhove (2000) / North-America	toner cartridge	remanufacturing	toner cartridges	customers of Xerox	US Postal Services		customers of Xerox			
Guide and Van Wassenhove (2001) / North-America	cellular phones	remanufacturing	cellular phones	cellular airtime providers	ReCellular, third party	ReCellular				
McGavis(1994) / North-America	toner cartridges	recycling	materials	user cartridge	UPS	specialists for different parts	HP			
Vroom et al. (2001) / Europe	PC bottles, crates, pallets	redistribution	PC bottles, crates, pallets	households, supermarkets	supermarkets	Campina	Campina			
Wijshof (1997) / Europe	rockwool produced by Rockwool Lapinus	Recycling	materials (secondary input production rock wool)	building companies, demolishers, other buyers	BFI, Sovabo	Rockwool Lapinus	customers Rockwool Lapinus			
Yender (1998) / Europe	batteries	recycling, reloading	materials, batteries	users batteries	UPS, retailers, municipalities	different specialists		re c		

Table 4. Case studies focussing on Inventory Management.

Reference / Geographical area	Product-in	Process	Product-out	Supplier (owner/user)	Collector	Processor	Customer	Ir		
De Brito and Dekker (2003) / Europe	laboratory equipment (15 000 sku)	re-use	same product	internal customers	Customer brings it back	CERN	internal customers	CE		
De Brito and Dekker (2003) / Europe	fashion, electronics and furniture	redistribution	same product	customers	mail-order-company	mail-order company	customers (same chain)	mail- com		
De Brito and Dekker (2003) / Europe	thousands of spare parts	repair, redistribution	same product	maintenance personnel	maintenance brings it back	refinery (as maintenance)	internal customers			
DelCastillo and Cochran (1996) / Central-America	See Table 2 Network Structures									
Diaz and Fu (1997) / South-America	railway spare parts	repair	repaired spare parts	Caracas Subway	Caracas Subway	Caracas Subway	Caracas Subway	Car Sub		
Donker and van der Ploeg (2001) / Europe	circuit boards for telephone-exchanges	repair	repaired circuit boards	telephone companies	Lucent Technologies	Lucent Technologies	telephone companies	Lu Techr		
Fleischmann (2000) / Europe	used/ unused machines	repair, refurbishment	spare parts	business customers,/ retailers		IBM facilities				
Guide and Sri-vastava (1998) North-America	See Table 2 Planning and Control									
Klausner and Hendrickson (2000) / Europe	power tools	remanufacturing recycling	Remanufactured power tools, or materials	customers	dealer, logistics provider	specialized facility		manuf of pow		
Moffat (1992) / Europe	aircraft engine	repair, refurbishing	re-processed aircraft engine	UK Air force	UK Air force	UK Air force	UK Air force	UK A		
Rudi et al. (2000) / Europe	wheel chairs, hearing aids, etc	re-use, refurbishing, recycling, parts retrieval, landfill	re-processed wheel chairs, hearing aids, etc.	users	Technical Aid Center (TAC)	TAC (in some cases recycling center)	people with handicaps	Norw Nat Insu Admin		
Sanders et al. (2000) / Europe	complete products retail	redistribution	same product	customer	third party logistics service provider	Mail Order Company, Wehkamp	Same market	Weh		
Swinkels and Van Esch (1998) / Europe	Beer kegs	redistribution/ re-use	same product	restaurants, bars, etc.	Bavaria, Agents	Bavaria	Bavaria	Ba		
Toktay et al. (2000) / North-America	single-use photo cameras	remanufacturing	same product	consumer	Photo Shops / Retailers	Kodak	Same chain	Kc		
Van der Laan (1997) / Europe	used car parts	remanufacturing	same product	national importer organizations	Volkswagen (Kassel)	Volkswagen (Kassel)	national importer organizations	Volks (Ka		

Table 5. Case studies focussing on Planning and Control

Reference / Geographical area	**Product-in**	**Process**	**Product-out**	**Supplier (owner/user)**	**Collector**	**Processor**	**Customer**			
Andriesse (1999) / Europe	pallets	redistribution	pallets	suppliers Philip Morris Holland	Philip Morris Holland	Philip Morris Holland	suppliers Philip Morris Holland	P		
Bakkers and Ploos van Amstel Jr . (2000) / Europe	PVC lamellas	recycling	PVC material	households, companies	distributors lamellas	Ortes Lecluyse	Ortes Lecluyse	Ort		
Bartels (1998) / Europe	See Table 2 Network Structure									
Bentley et al. (1986) / North-America	subway cars / transit cars	repair, refurbishing	repaired, refurbished cars	NY City et al.		Morrison-Knudsen Company	NYCity et al.	Morr		
Del Castillo and Cochran (1996) / Central-America	See Table 2 Network Structures									
Duhaime et al. (2001) / North-America	See Table 2 Network Structures									
Driesch et al. (1998) / Europe	See Table 3 Relationships									
Guide and Spencer (1997), Guide et al (1997), Guide and Srivastava (1998) / North-America	aircraft, engines, avionics equipment	remanufacturing	remanufactured aircraft, engines, avionics equipment	US Air Force	US Air Force	US Air Force	US Air Force	U		
Gupta and Chakraborty (1994) / Asia	scrap production glass	recycling	Materials for glass production	producer glass	producer glass	producer glass	producer glass	pro		
Klausner and Hendrickson (2000) / Europe	See Table 4 Inventory Management									
Krikke et al. (1999b) / Europe	PC monitors	parts retrieval, recycling	Parts, materials	PC owners/ users	Roteb (municipal waste company)		secondary markets	Rot was		
Robinson (1992) / North-America	diesel engine components	remanufacturing	remanufactured diesel engine components			Detroit Diesel remanufacturer West		De ren		
Schinkel (2000) / Europe	gypsum	recycling	gypsum	building companies	third party LSP	producers gypsum products	customers producers gypsum products	Org l gyp		

Simons (1998) / Europe	parts of sheets (external), production scrap (internal)	recycling	materials	building companies (external), Trespa (internal)	third party LSP, building companies, demolishers	Trespa	Builders			
Simons (1998) / Europe	pallets	redistribution	pallets	builders, demolishers	third party LSP, building companies, demolishers	Trespa	Trespa			
Spengler et al. (1997) / Europe	See Table 2 Network Structures									
Teunter et al. (2000) / Europe	by-products	re-use	materials	Schering AG	Schering AG	Schering AG	Schering AG	S		
't Slot and Ploos van Amstel (1999) / Europe	white and brown goods	recycling	materials	households	municipalities, retailers	recycler	users materials	g		
Thomas Jr (1997) / North-America	airplane engines	remanufacturing	airplane engines				Pratt & Hitney aircraft West Virginia	Pr ai		
Tucker et al. (2000) / Europe	See Table 3 Relationships									
Ubbens (2000) / Europe	metal cans for drinks, food	recycling	materials	households etc	municipalities (via household waste)	recyclers	metal industries	S		
Van Donk (1999) / Europe	leftovers from building activities	recycling		buidling companies	special collectors					
Van Notten (2000) / Europe	See Table 2 Network Structures									
Wijshof (1997) / Europe	See Table 2 Network Structures									

Table 6. Case studies focusing on Information and Technology

Reference / Geographical area	**Product-in**	**Process**	**Product-out**	**Supplier (owner/user)**	**Collector**	**Processor**	**Customer**			
Nagel and Meyer (1999) / Europe	refrigerators	Remanufacturin g, recycling	plastics; metals	end-of-life user	dealer; service provider	recycling plant				
Nagel and Meyer (1999) / Europe	computers	parts retrieval	computer components	End-of-life user	VOBIS (retailer)	Covertronic (recycler)		C		
Meyer (1999) / North-America	cosmetics	resale	cosmetics	customer	Estee Lauder	Estee Lauder	same chain, employees	Es		
Farrow et al. (2000) / North-America	post-consumer plastics	recycling	plastics	households, companies	supplier of recycled resins	manufacturer kayak	buyers kayak	Wal		
Linton and Jonhson (2000) / North-America	circuit boards	remanufacturing	circuit boards	customer	customer Service (NN)	customer Service (NN)	same chain	Nor		
Klausner et al. (1998, 2000) / Europe	See Table 4 Inventory Management									
Maslennikova and Foley (2000) / Europe	Recycled materials; Xerox products	refurbishing, recycling	reprocessed Xerox products	customer	Xerox Europe, Ltd. Service engineers	Xerox Europe, Ltd.	same chain	Xero		

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