MARISA P. DE BRITO

Managing Reverse Logistics or Reversing Logistics Management?

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or
Reversing Logistics Management?

Marisa P. de Brito

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Managing Reverse Logistics
or
Reversing Logistics Management?

Beheersing van retourlogistiek
of
omgekeerde beheersing van logistiek?

Thesis

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by

Marisa Paula de Brito Pereira Maduro

born at Luanda, Angola

Promoters:	Prof.dr.ir. R. Dekker
	Prof.dr. M. B. M. de Koster
Other members:	Prof.dr.ir. J.A.E.E. van Nunen
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	Prof.dr. T. Spengler

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Chapter 1

Introduction

"A long trip starts with the first step"
Lao Tsé

Twenty years ago, supply chains were diligently fine-tuning the logistics from raw materials to the end customer. Today an increasing flow of products is going back in the chain.

Thus, companies have to manage reverse logistics as well. Yet, logistic managers typically think "forward," putting the emphasis on moving the goods to the clients. The issue is, whether or not, companies can go on, and manage reverse logistics, with a purely forward-based thinking. Or, perhaps, there is a need for a considerable share in focus with respect to reverse flows. The question is then: is it a matter of simply managing reverse logistics or of reversing logistics management?

Reverse logistics practices are in the position of being an asset rather than a liability. When a consumer gets rid of a product, this does not mean that the product is valueless. For instance, computers might contain precious metals such as gold, palladium, platinum, and silver, and these materials are still intact when the computer reaches obsolescence. Actually, one metric ton of electronic scrap from personal computers (PC's) has more gold than that extracted from a 17 ton of gold ore. Taking into account that millions of PC's become obsolete every year, it is not surprising that many consider obsolete computers a "Gold Mine" (USGS, 2001). Global Investment Recovery, Inc. is one of the many companies providing services in this area. Global Investment Recovery, Inc. was funded in 1992 and it processes millions of circuit boards every year (see Global Investment Recovery, 2003).

Many other examples can be given, as the role of reverse logistics is increasing in the whole range of industries, covering electronic goods, pharmaceutical products, beverages and so on. For more than a decade, Kodak sells remanufactured single-use photo cameras and ReCellular has a mobile phone remanufacturing business; all sorts of companies handle many of their products in reusable packaging, like Coca-cola (refillable bottles), Philip Morris (pallets), and Estée Lauder's Aveda (merchandize displays), see Kodak, 2003; Recellular, 2003; Coca-cola, 2003; Andriesse, 1999.

Companies are also investing on information technology dedicated to reverse logistics, like Estée Lauder's, which recovered the investment in one year. Other companies, like L'Oreal push high quantities of products to the retailers, because what is not sold can always be brought back (see Meyer, 1999; Coenen, 2000).

Reverse logistics is therefore a key competence in modern supply chains. Accordingly, the importance of reverse logistics is widely recognized. Reverse logistics has renowned professional organizations, like the Reverse Logistics Executive Council (RLEC) in the U.S., which collaborates with academia. In Europe, the European Commission has shown, for long, interest in the development of the field by sponsoring international scientific projects on reverse logistics, such as RevLog and Reloop (see Revlog, 2003; ReLoop, 2003).

This thesis is from the beginning rooted in one of these pan-European projects, namely RevLog, the European Working Group on Reverse Logistics.

This thesis contributes to a better understanding of reverse logistics. We bring insights to reverse logistics decision-making and to the field of reverse logistics as a whole. With respect to the initial question, *is it a matter of simply managing reverse logistics or of reversing logistics management?*, we encourage the reader to bear it in mind along the whole thesis. We will come back to it in the last chapter.

In the next section we put forward the definition and scope of reverse logistics. Then, we review some of the literature on the topic, including key monographs, PhD theses and reviews. After that, we present the structure of the thesis, and we put forward the aims, objectives and the methods employed.

1.1 Reverse Logistics: definition and scope

1.1.1 Definition and a brief history

"In the sweat of your face you shall eat bread
Till you return to the ground,
For out of it you were taken;
For dust you are,
And to dust you shall return."
Genesis 3:19

Though the idea of reverse logistics dates from long ago (as the citation above attests), the naming is difficult to trace with exactness. Though systematically related with recycling, terms like Reverse Channels or Reverse Flow already emerge in scientific literature of the seventies (Guiltinan and Nwokoye, 1974; Ginter and Starling, 1978).

During the eighties, the definition was inspired by the movement of flows against the traditional flows in the supply chain, or as put by Lambert and Stock, 1981 "going the wrong way" (see also Murphy, 1986 and Murphy and Poist, 1989).

In the early nineties, a formal definition of Reverse Logistics was put together by the Council of Logistics Management, stressing the recovery aspects of reverse logistics (Stock, 1992):

"...the term often used to refer to the role of logistics in recycling, waste disposal, and management of hazardous materials; a broader perspective includes all issues relating to logistics activities to be carried out in source reduction, recycling, substitution, reuse of materials and disposal."

The previous definition is rather broad, as it is manifest in the following excerpts "the role of logistics in ... all relating ... activities." (see also Kopicky et al., 1998). Besides this, it has origins in a waste management standpoint. In the same year Pohlen and Farris (1992) define Reverse Logistics, giving again notice of a direction in a distribution channel, as follows:

"...the movement of goods from a consumer towards a producer in a channel of distribution."

Carter and Ellram (1998) keep the concept linked to environmental purposes, as follows: *"the process whereby companies can become environmentally efficient through recycling, reusing, and reducing the amount of materials used."*

At the end of the nineties, Rogers and Tibben-Lembke (1999) portrayed Reverse Logistics by stressing the goal and the intrinsic (logistics) processes:

"The process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal."

The European Working Group on Reverse Logistics, (see De Brito and Dekker, 2004), puts forward the following definition, which is used in this thesis:

"The process of planning, implementing and controlling backward flows of raw materials, in-process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal".

This perspective on Reverse Logistics keeps the essence of the definition as put forward by Rogers and Tibben-Lembke (1999), which is logistics. However it generalizes "point of consumption" to "a manufacturing, distribution or use point" and "point of origin" to "a point of recovery or point of proper disposal." In this way we give margin to return flows that were not consumed first (for instance, stock adjustments due to overstocks or spare parts which were not used). We employ the expression "point of recovery" instead of "point of origin" since flows may go back to other points of recovery than the original (e.g. collected computer chips may enter another chain). Besides this, "point of recovery" stresses the distinction we want to make between reverse logistics and pure waste management activities (see next section). Furthermore, we include the reverse direction through the term "backward flows," to exclude what can be considered as forward recovery. For instance, when a consumer gives his/her personal computer to the neighbor.

In summary, the definition of Reverse Logistics has changed over time, starting with a sense of reverse direction, going through an overemphasis on environmental aspects, coming back to the original pillars of the concept, and finally widening its scope. For other discussions on the evolution of the definition of reverse logistics, we refer to Rogers and Tibben-Lembke (2001) and to Fernandéz (2003).

1.1.2 Delineation and scope

Since Reverse Logistics is a relatively new research and empirical area, the reader may encounter other terms in the literature, like reversed logistics, return logistics and retro logistics or reverse distribution, sometimes referring to roughly the same. In fact, the diversity of definitions with respect to recovery practices is a well-recognized source of misunderstandings both in research as in practice (Melissen and De Ron, 1999).

It is important to observe that Reverse Logistics is different from waste management as the latter mainly refers to collecting and processing products or materials that are to be discarded. The crux in this matter is the definition of waste. This is a major issue, as the term has severe legal consequences, e.g. with respect to regulations on import/export of waste. Reverse Logistics concentrates on those streams where there is some value to be recovered and the outcome enters a (new) supply chain.

Reverse Logistics also differs from Green Logistics as the latter considers environmental aspects to all logistics activities and it has been focused specifically on forward logistic, i.e. from producer to customer (see Rodrigue et al., 2001). The prominent environmental issues in logistics are consumption of nonrenewable natural resources, air emissions, congestion and road usage, noise pollution, and both hazardous and non-hazardous waste disposal (see Camm, 2001).

Industrial Ecology is another field that relates to Reverse Logistics. As explained in Garner and Keoleian (1995), Industrial Ecology is primarily dedicated to the study of the interactions between industrial systems and the environment. The underlying aim is to change the linearity of industrial systems, from raw materials to waste, into a cyclical system, i.e. with product or materials recovery. In the latter, Reverse Logistics undoubtedly plays a major role.

Finally, reverse logistics can be seen as part of Sustainable Development. The latter has been defined by Brundland (1998) in a report to the European Union as "to meet the needs of the present without compromising the ability of future generations to meet their own needs." In fact one could regard Reverse Logistics as the implementation at the company level of processes that guarantee that society uses and re-uses both efficiently and effectively all the value which has been put into products.

The border between Forward Logistics, from raw materials to end user, and Reverse Logistics, from e.g. the end user to recovery or to a new user, is not strictly defined. One can wonder about for instance what "raw materials" are in certain supply chains. For instance, used/recovered glass constitutes considerable material input for new production of glass.

A holistic view on supply chains combining both forward and reverse logistics is embraced by the concept of Closed-Loop Supply Chains (Guide and van Wassenhove, 2003). Recovery practices are framed within the supply chain, and the encircling aspect of the process as a whole is therefore stressed: having either 1) a physical closed-loop: to the original user (see Fleischmann et al., 1997); or 2) a functional closed-loop: to the original functionality; or 3) an open-loop, when neither the original user or original functionality are in the reverse logistics process. The denomination closed-loop supply chains emphasizes the importance of coordinating the forward with the reverse streams.

Reverse Logistics is different but relates with other fields of research such as green logistics and industrial ecology, as discussed above. In the academic world, these fields inhabit separate islands, but they lay in the same sea. The knowledge in each field has been growing quite independently of the knowledge in related fields, but commonalities persist due to the similarities of the overall environment. We believe that we only have to gain by establishing structural links among the fields, even though we have to cross a period of confusion as indicated in the previous section.

1.1.3 The European dimension

In Europe, the European Union has stimulated sustainable development for years, including recovery practices through environmental legislation. Recent developments show that this legislation and its consequences are ever increasing. Priority product flows include: cars (Directive 00/53/EC), electronics (Directive 02/96/EC) and packaging (Directive 99/31/EC). Table 1.1 summarizes the state-of-the-art of recycling quotas (required, realized or expected) in some of the EU countries (see Jordan et al., 2001; European Environmental Agency, 2002; Auto Recycling Nederland, 2003; Arge Altauto, 2003; Doppelt and Nelson, 2001; Europa, 2003).

Though the Member States are also encouraged to introduce prevention and reuse systems, they have some more freedom on this than on the mandatory recycling quotas (Greece, Ireland and Portugal are allowed to set lower targets). Concerning packaging waste, for instance, The Netherlands, Spain and Belgium launched prevention targets (some in the form of covenants), while Denmark, Germany and Portugal introduced reuse targets. Joint recycling-reuse targets are in force in Austria and Finland (the latter also has explicit prevention targets).

The link between reverse logistics activities and employment has not yet been thoroughly investigated. We do know that some of the recovery activities like recycling are labor intensive. Studies have indicated that recycling activities create 5 to 7 times the number of jobs than incineration and more than 10 times than land filling operations. (See Austrian Federal Chamber of

Table 1.1: Recycling quotas in Europe (data collected in 2003 with * being a prognosis).

EU Directive (required quotas)	**France**	**Germany** (realized quotas)	**The Netherlands**
		Cars	
85% (2006)*	-	85% (2002)	85% (2002)
95% (2015)*	-		95% (2007)*
		Electronics	
70%-90% (2006)*	-	-	45%-75% (2002)
		Packaging	
50% (2001)	45% (1998)	65% (1998)	60% (1998)
60% (2006)*			
70% (2011)*			

Labor, 1998a and 1998b; Desproges and David, 1998). The number of people working in recovery activities is estimated to exceed 3 million (see Laxe, 1999). Besides this, the European Commission realizes that recovery activities offer an opportunity to create new distinct jobs, which are not going to be a copy of already existing employment (see Europa, 2003). Furthermore, these jobs are a privileged vehicle for reintegration of workers in professional life. The number of social jobs (state financed) in recycling and reuse has been estimated to surpass 35 000 in Western Europe (see ACRR, 2003).

In Europe, there are initiatives like the Association of Cities and Regions for Recycling (ACRR). Yet, it is lacking a pan-European professional organization dedicated to Reverse Logistics. In contrast, in the U.S., there is the Reverse Logistics Executive Council (RLEC). In addition, other organizations like The American Production and Inventory Control Society (APICS), and The Council of Logistics Management (CLM) are very active on reverse logistics (see as well Section 1.2.1).

Concluding, in Europe reverse logistics related activities play a threefold role for sustainable development: environmentally, economically and socially.

1.2 Literature on Reverse Logistics

This section provides a review of some literature on reverse logistics. We consider key monographs that are important references for the study of reverse logistics, recent PhD theses on the topic, and reviews. Furthermore and to give an idea of opportunities for multidisciplinary reverse logistics studies, we present a snap overview of research in related areas.

1.2.1 Books on reverse logistics

In the nineties, the Council of Logistics Management (CLM) published three relevant studies on reverse logistics. The first one, actually one of the first studies making a thorough exam of reverse logistics, introduced the subject from a waste reduction perspective (Stock, 1992). Based on interviews with US industry and governmental organizations, the author concluded that reverse logistics was still at its very beginning. Accordingly, the companies were rather reactive in dealing with it. Shortly after this first study, CLM published the second study, now dedicated to the opportunities offered by reverse logistics in the context of reuse and recycling (Kopicky et al., 1993). The authors concluded that reverse logistics was evolving very fast with many companies having pioneer programs on waste reduction. After introducing the field, and having showed the opportunities, CLM brought forward a third study dedicated to the implementation and development of reverse logistics (Stock et al., 1998). This study gave form to relevant issues for successful reverse logistics programs, like management and control, measurement and finance.

Kostecki (1998) took a marketing approach to reflect on the optimal use of consumer durable products. The approach linked consumers' preferences and the business challenge of reuse. The book reported on several business examples of product stewardship programmes such as the ones of Kodak and Xerox.

Also in the late nineties, Rogers and Tibben-Lembke (1999) conducted interviews in the U.S. with 150 managers and a survey with hundreds of others. The study focused on the economic and supply chain issues of reverse logistics and how to reduce costs related with product returns.

Three more books are likely to join this year the collection of key-references for reverse logistics research: Guide and van Wassenhove edit a book about Closed-Loop Supply Chains, and the European Working Group on Reverse Logistics, RevLog, brings out two more books, one on quantitative methods and the other on cases from practice (Dekker et al., 2003; Flapper et al., 2003). Next, we describe in more detail the contents of these three books.

Guide and van Wassenhove (2003) closely consider the business aspects of closed-loop supply chains. The book handles subjects such as the recovery options and the relations between parties, namely questions related with contracting. Particular issues include logistics, production planning and inventory control in the supply chain. Other embraced aspects are forecasting, information technology, technology diffusion and product design, where the fulcrum is the customer. From a more business perspective, the economics of closed-loop supply chains and the issue of acquisition management are discussed.

One of the RevLog books is dedicated to quantitative modelling as for aiding reverse logistics decision-making (Dekker et al., 2003). Models are brought together, compared with traditional literature, related to each other and linked to real life examples. The models cover collection, distribution, inventory control, production planning and supply chain management issues. The book embraces particular subjects such as forecasting of returns, network design, vehicle routing, return handling, lot-sizing decisions, co-ordination, environmental and information management. The other RevLog book (Flapper et al., 2003) is on managing closed-loop supply chains and it is a collection of case studies with the respective lessons for managing reverse logistics practices.

1.2.2 PhD theses on reverse logistics

There have been a number of PhD theses on the field of reverse logistics. Next, we describe a sample of those.

Thierry (1995) studied the impact of product recovery management in the electronics and car industries. Special attention was given to the impact on product design, logistics, and relations between actors. The author made use of two real life cases: a copy remanufacturing company and product recovery by the car manufacturer BMW.

Jahre (1995) investigated the performance of collection and recycling systems of household waste, with specific emphasizes on packaging materials. Two main aspects were taken into account: the degree of separation at the source and co-collection. The author employed data provided by the European Recovery and Recycling Association (ERRA).

Van der Laan (1997) analyzed the effects of remanufacturing on inventory control. Special attention went to coordination mechanisms between the manufacturing and remanufacturing operations and to which actions deal to cost-efficiency. The findings were tested with real data from Volkswagen on car parts remanufacturing.

Krikke (1998) addressed the determination of recovery strategies and the logistics network design. For each of the issues, a case study was discussed in detail. On the recovery strategies, for the recycling of computer monitors, the author considerd Roteb, the municipal waste company of the city of Rotterdam, in the Netherlands. On logistics network design, the author dealt with the copier reverse logistics network of the international company Océ, with headquarters in Venlo, the Netherlands.

Fleischmann (2000) dealt with quantitative models for reverse logistics network design and for inventory management with returns. In particular, the thesis inquired under which conditions a network can be split into two separate networks, the forward and the reverse. In addition, the practical issues arising from reverse logistics were illustrated with a case study at IBM.

Beullens (2001) focused on the use of Operations Research (OR) tools for supporting the facility location decision, process planning and vehicle routing in reverse logistics. All the issues were illustrated with real life examples.

Kobeissi (2001) considered the evaluation of options for recovery of end-of-life products. The thesis described the required resources and the different activities of the evaluation process. Also the dissertation of Landrieu (2001) is about end-of-life products. The focus was on the collection strategies, taking into account the product, or the geographic zone of collection. The measures of performance were maximization of profit and the satisfaction of the client. Besides this, particular informational issues were considered as follows: how to integrate information in the collection schemes and what is the impact on efficiency.

Brodin (2002) analyzed the influence of both the product and the relationship between actors on the efficiency of logistics systems for recycling. To do so, the author made use of 1) a case study of the electronics recycling in the Netherlands; 2) a survey of the Swedish recycling market; and 3) interviews with Ericsson, Telia (large customer of telecommunications equipment), Stena Technoworld (recycling company) and Tekpak (a US package producer).

As expected, each of the reviewed PhD dissertation dealt with a set of particular issues within reverse logistics. A diversity of subjects can be found such as recycling systems, inventory control of remanufacturing, recovery strategies, network design and vehicle routing. Furthermore, most of the theses made a link with practice. The theses included studies on the electronics and communication industries (IBM, Ericsson), automobile industry (BMW and Volkswagen), and packaging industry (Tekpak), among others.

1.2.3 Review articles on reverse logistics

Fleischmann et al. (1997) compiled a review on Operations Research (OR) models for reverse logistics. The review is organized in terms of distribution, inventory control and production planning models. The authors pointed out the need for comprehensive approaches, taking into account both the economic and the ecological aspects in the supply chain.

Gungor and Gupta (1999) presented an exhaustive review of more than 300 articles or books on environmentally conscious manufacturing and product recovery. The authors observe that environmental issues are becoming popular among society, governments and industry. In addition, they identify the need to develop both qualitative and quantitative tools to support proper environmental conscious manufacturing decision-making.

Carter and Ellram (1998) put together a review of transportation and packaging, purchasing and other literature on reverse logistics. The authors deduce from the literature that there were both internal and external factors affecting the behavior of organizations with respect to reverse logistics. Next, they build up a model with a combination of determinants for reverse logistics, and based on it they indicate opportunities for future investigation.

Bras and McIntosh (1999) reviewed the literature specifically dedicated to remanufacturing. The authors distinguish between descriptive and developmental work, i.e. work simply meant to characterize the current state and the future of remanufacturing and work aiming at improving remanufacturing aspects. The authors conclude that the work up to then intended: to describe practice; to motivate remanufacturing; to improve product and design for remanufacturing; to learn from traditional manufacturing; and, to improve the process.

De Brito et al. (2003) put forward a review of case studies on reverse logistics, covering various aspects like network design, inventory control and information technology. This review and its findings are central in Chapter 3 of this thesis.

1.2.4 Some literature on areas related to reverse logistics

Here we present a snap overview of other research work that, though it is related with reverse logistics, it is focused mainly on other research area. This gives an idea of the existing opportunities for multidisciplinary reverse logistics studies.

Van Nes (2003) focus on product design as a mean of influencing product lifetime. The author first checks whether, or not, it is desirable to extend the life cycle of products. For most of the products investigated an increase in lifetime is desirable. The next step in the research is directed to provide an understanding of the motivation of consumers to substitute their products. Finally, the author provides insights on how to extend the product lifetime by changing product design.

Beukering (2001) investigates the economic and the environmental importance of recycling for international trade mechanisms. The author discusses the trade of waste paper for recycling in India, the recycling and trade in waste plastics in China and the trade and recycling of truck tyres in Europe.

Hirsch et al. (1998) show how a simulation tool, called LOCOMOTIVE can aid on reverse logistics decision making. The tool is able to simulate the whole life cycle and to assess environmental impacts of different logistics operations within a globally distributed production network. The tool is meant to support middle and upper management, assisting on strategic decision-making.

Stroeker (1995) gives the marketing and economics perspective on second-hand consumer durable goods from. Demographic and lifestyle consumer characteristics are taken into account as context variables as the price structure and the bargaining process in second-hand markets were studied. Furthermore, the author presents a model to predict the purchase of second-hand durable goods.

This section on work related to reverse logistics accommodates studies on research areas such as Design (for end-of-life), Trade (with respect to recycling), Computer Science (simulation tools to support decision-making), and Economics and Marketing (analysis of second-hand markets).

1.3 About the thesis

1.3.1 The structure

Besides the existing areas "affiliated" to reverse logistics, the previous review of literature shows that there are many subjects of research inherent to reverse logistics. The review embraced studies on recovery systems; studies dedicated to a particular form of recovery like recycling, or to a specific decision-area like network design, inventory management or vehicle routing; another set reviewed work was on structuring the field, or on pulling lessons from real-life examples.

The set of topics we could elect to carry out research is very vast. We opted to become engaged with a number of projects, divided in 4 blocks, as follows (see Figure 1.1):

- Part I on the theoretical development of the field;
- Part II on decision-making and return handling;
- Part III on decision-making and inventory management;

- Part IV on the future development of the field.

In the reverse logistics field, return handling is an emerging cluster of knowledge, while inventory management is a well-established cluster of knowledge. Both offer many possibilities for research. As the first gives the opportunity to explore fresh issues, the second poses the challenge of being able to contribute to on-going discussions. This explains our choices of topics for blocks II and III.

Next, we explain more about how this structure was born, which are the aims, what are the particular objectives and which was the employed methodology to achieve them.

1.3.2 The process: aims, objectives and methods

With this doctoral thesis, we committed to make a contribution according to the following two main lines:

- 1) reverse logistics as a research/academic field;
- 2) reverse logistics decision-making and practice.

Next, we present the correspondent aims.

Aims

To put together the aims we employ two sorts of input: on the one hand, researchers with expertise on reverse logistics; and on the other hand, reverse logistics (related) literature. Both the contact with experienced researchers and a scan of the literature lead to the following conclusions:

- reverse logistics is a young field, growing fast, but with scattered and fragmented theoretical contributions (see e.g. Melissen and Ron, 1999);
- besides this, there is a strong need to better understand reverse logistics decision-making processes and to learn from them;

Aligned with our first main line, *reverse logistics as a research/academic field*, we establish the following aims: to structure reverse logistics as a research field. Furthermore, since reverse logistics is a young field of research, we also plan to look ahead, and to conjecture about the future development of the field. With respect to the second main line, *reverse logistics decision-making*

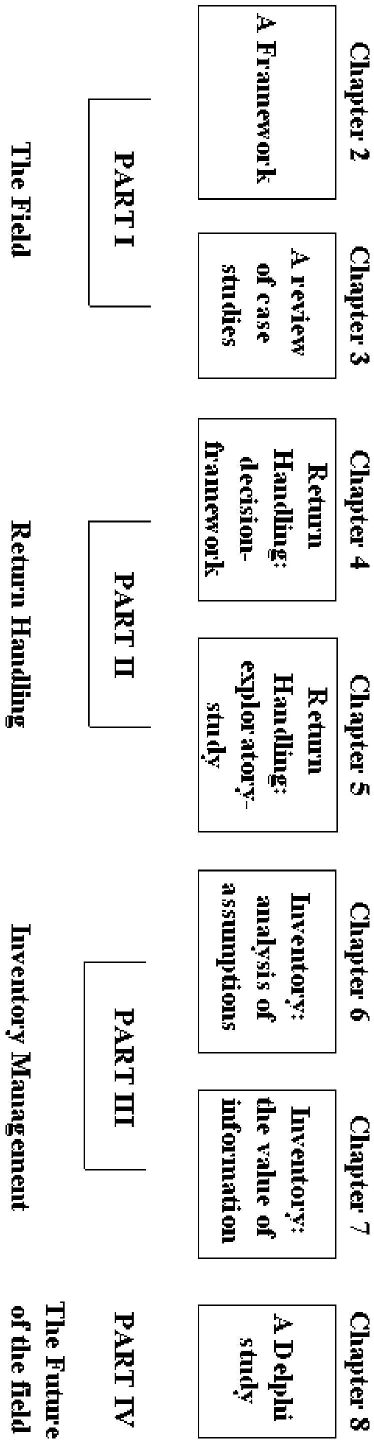


Figure 1.1: The body of the thesis

Table 1.2: List of aims

Guideline 1: *Reverse logistics as a research/academic field*
i) structuring reverse logistics as a research field; ii) conjecturing about the future development of reverse logistics as a research field;
Guideline 2: *Reverse logistics decision-making and practice*
iii) better understanding of reverse logistics practices; iv) structuring and supporting reverse logistics decision-making;

and practice, the following aims are put together: to better understand reverse logistics practices and to structure and support decision-making. Table 1.2 summarizes this.

This exploratory phase of setting the aims is a mean to elaborate the geographic map of our "research expedition". To be more specific on the trail we will walk on, we elaborate specific objectives, which are described next.

Objectives and employed methods

In this design phase, we intensified the contacts with other researchers, as well as the analysis of existing literature. Above all, researchers associated with the RevLog group were of invaluable help (see RevLog, 2003). With this input, we could bring focus to the overall aims, and therefore we are able of specifying the objectives.

Table 1.3 summarizes the collection of research projects we carry out, together with the motivation, the specific objectives, the employed methods, and the key-aims. We refer to the employed methods only briefly, as more details are given in each chapter. The projects are not presented in a strict chronological order.

PART I- The Field

Chapter 2. A framework for Reverse Logistics

While going through the literature, it is clear that there is no formal framework for the field as a whole. The existing contributions have been proposed intentionally for sub-areas of the field, or they were informally presented as a pretext to explain a specific topic. This is not surprising, as reverse logistics is a young field of research. Despite of this fact, the field is growing fast

Table 1.3: Motivation, objectives, methods and aims (by project)

Motivation	Main research objectives	Correspondent aims	Main methods
Part I - The Field			
Chapter 2. A framework for Reverse Logistics			
Structuring the field	To structure the field and to provide an overall understanding of reverse logistics	i)	Review of literature, case studies review & accumulated knowledge
Chapter 3. Reverse Logistics: a review of case studies			
Need to better understand reverse logistics practices	To provide a diversity of reverse logistics activities (and to help constructing the framework)	iii)	Case studies review & content analysis
Part II- Decision Making and Return Handling			
Chapter 4. Return Handling: models for decision-making			
Emerging cluster of knowledge Lack of decision-making models	To put forward the state-of-the-art of models to support return handling	iv)	Critical literature review
Chapter 5. Return Handling: an exploratory study			
Emerging cluster of knowledge Research opportunity	To identify the main factors contributing to whether or not to combine forward and reverse flows during return handling	iii) & iv)	(Comparative) case study research
Part III- Decision Making and Inventory Management			
Chapter 6. Inventory Management: a critical analysis of assumptions			
Lack of empirical evidence to support common assumptions	To inquiry the validity of the common assumptions in the inventory management literature with product returns	iii) & iv)	Literature review and statistical analysis
Chapter 7. Inventory Management with product returns: the value of information			
Literature assumes that more information leads to better forecasts	To assess the impact of (mis)information on inventory management	iv)	Mathematical analysis & simulation
Part IV- The Future of the Field			
Chapter 8. Reverse Logistics research: what does the future bring?			
Reverse logistics is developing fast. A look ahead	To assess which future do academicians expect for reverse logistics as a research field	ii)	Nominal Group Technique & Delphi study

demanding to be formally structured. With this research project, we make a close re-examination of the field and we propose a framework, providing a formal structure and with it an overall understanding about reverse logistics management and decision-making.

To build-up the framework we use three basic inputs: 1) a review of the literature dealing with the organization of the field throughout classifications, 2) an *interactive process* with a review of case studies as a tool to ground the development of the framework in empirical evidence, and 3) generated knowledge.

By the latter we refer to all the knowledge acquired during this doctoral trajectory. The whole process of conducting other research projects provided "data" to build the framework. This "data" takes the form of accumulated knowledge, and it results from collaborating with senior researchers, from attending conferences and from carrying out several other different projects about reverse logistics. Another source of knowledge is non-scientific literature, as well as the unavoidable awareness of real-life reverse logistics situations.

Chapter 2 gives insights on the diversity of reverse logistics systems and on its complexity by putting together a framework for reverse logistics. Reverse logistics is characterized via four basic aspects: *why* companies get involved with reverse logistics and *why* products go back in the supply chain; *how* are products recovered and which are the main recovery options; *what* is actually being returned; and finally, *who* are the main players in a reverse logistics system. More on the methodology behind this research project, can be found in a section of Chapter 2. Another version of this chapter has appeared in De Brito and Dekker (2003).

Please bear in mind that the research projects are not presented in chronological order.

Chapter 3. Reverse Logistics: a review of case studies

The motivation for this research project is in essence the need to better understand reverse logistics practices. One finds however quite some literature on case studies applied to a diversity of industries. This literature is however scattered over journals for very different research communities. Besides this, in countries in the forefront of reverse logistics a substantial number of case studies have been published in other languages than the *lingua franca* and are therefore not accessible for the majority of the research community. To give a fair idea of the diversity of reverse logistics practices, we employ a content analysis of more than sixty real reverse logistics cases. The analysis is based on the framework of Chapter 2. Thus, Chapter 3 is also a life test of the applicability of the framework, and of the completeness of the classifications proposed by the framework. Chapter 3 presents the case studies according the following decision-making focus: Network Structures, Relationships, Inventory Management, and Planning and Control. We remark particular issues and unanswered questions, which we link with a research agenda. For some of these decision making groups, some of the aforementioned questions are predominantly important. We also discuss that and we provide research directions to test these premisses. A previous version of Chapter 3 can be found in De Brito, et al. (2003).

PART II- Decision-making and return handling

Chapter 4. Return Handling: models for decision-making

Return handling is an emerging cluster of knowledge. Since this cluster is in the looming phase, there are not many models supporting decision-making in this area. This motivates an investigation on the opportunities that forward quantitative models for material handling offer for return handling models. To do so, we put together a decision-making framework for return handling and we proceed to a critical analysis of the literature. The chapter reviews the main findings of general material handling literature giving suggestions to adapt such models for return handling. An early version has appeared in De Brito and De Koster (2004).

Chapter 5. Return Handling: an exploratory study

The details of return handling operations have been so far overlooked in the scientific literature. More specifically, there is a need to better understand decision-making regarding the transport, the actual handling and the storage of product returns. In particular, insights are missing on the factors influencing the decision of combining, or not, forward and reverse flows during these processes. Chapter 5 focuses on this by comparing the return handling processes of nine retailer warehouses. The analysis gives insights into critical factors, complicating issues, possible simplifying solutions and practical implications. The chapter ends with a discussion of propositions that can feed future studies on return handling efficiency. This research project was published in the *International Journal of Retail and Distribution Management* (De Koster et al., 2002).

PART III- Decision-making and inventory management

Chapter 6. Inventory Management: a critical analysis of assumptions

In contrast with return handling, inventory management with product returns is, for some time, a well-established cluster of knowledge. Much literature is available on the subject. An analysis of this literature shows that certain assumptions are very often used. At the same time, the trustworthiness of these assumptions has been repeatedly challenged due to the lack of empirical evidence. With this research project we inquire on the validity of the common assumptions, by proceeding to a statistical analysis of real data.

Chapter 6 checks empirically the validity of common assumptions in the literature dealing with inventory control with product returns. This chapter first proposes a general methodology to check the assumptions empirically and then it describes actual practice in companies with respect to information storage on returns and inventory control. Furthermore, the methodology is employed to real data from three companies and the practical implications are discussed. The companies are the European Organization for Nuclear Research (CERN) in Switzerland, and a mail order company and a refinery, both in the Netherlands. The findings have practical relevance, for instance with respect to information management on inventory systems with returns. The findings of this research were earlier published in the *International Journal of Production Economics* (De Brito and Dekker, 2003).

Chapter 7. Inventory Management and product returns: the value of information

Chapter 7 evaluates the impact of misinformation for inventory systems with product returns. If one could exactly know how much is going to be returned and when, one would certainly benefit from incorporating this perfect information a priori in the management of production, inventory, and distribution. In practice, one has to attempt to forecast the timing and the amount of product returns, by hypothesizing about the return flow properties. To do so, historic data on demand and returns can be used. The available literature on information and inventory management with product returns commonly 1) assumes known return probabilities; or 2) considers specific cases where the most-informed method leads to the best forecast. Chapter 7 identifies situations in which the most informed method does not necessarily lead to the best performance, investigating the impact on inventory related costs. See also related publications: De Brito and van der Laan (2003) and Toktay et al. (2004).

PART IV- The future of the field

Chapter 8. Reverse logistics research: what does the future bring?

Since reverse logistics is a rapidly progressing field, with this research project we look ahead and are able to conjecture on the future development of reverse logistics. This project is developed in two phases. The first and exploratory phase employs the Nominal Group Technique. The second is based on a Delphi study with an international panel of academics working on reverse logistics issues. Some of the outcomes are recommendations concerning research and teaching about reverse logistics. In this way, this study assists decision-making concerning proposals, and research priorities with respect to reverse logistics. Furthermore, the chapter reports on the contrasts and/or similarities between the European and North American researchers' perspectives. The exploratory study is also reported in De Brito (2003) and the second part is in De Brito and van Wassenhove (2003).

Finally *Chapter 9* summarizes the main findings, discusses the limitations and proposes guidelines for future research on reverse logistics.

1.3.3 Research paradigms and this thesis

No research is conducted without a set of underlying beliefs, held more or less consciously by the one carrying it out. Besides this, others will also judge his or her research based on a set of own beliefs.

Table 1.4 summarizes the basic beliefs of the four main streams of paradigms, which have been traditionally identified in the literature (for more details see Guba and Lincoln, 1994; Tashakkori and Teddlie, 1998; Healy and Perry, 2000).

Instead of strictly following one paradigm, this research takes a pragmatic approach in the sense that the research question is primordial in each research project, and the method is chosen accordingly. In this context, pragmatism is an attractive paradigm because it welcomes *a priory* any methodology, including mixed methodologies. Besides this, it stays clear of interminable and ineffectual discussions on metaphysical concepts like "truth" or "reality." Furthermore, pragmatism has also been proposed as a departing reference for decision-making in management (see Fontrodona, 2002). Finally it exempts the reader from an in-depth knowledge on extensive criteria to assess the quality of the research. This is because the criterion for assessing the quality of pragmatic inquire relies on asking whether, or not, the employed methods fulfill the objective of answering the research question.

Table 1.4: Basic beliefs of four main research paradigms.

Paradigm /Element	**Ontology**	**Epistemology**	**Main Methodology**
Positivism	Single reality and apprehendable	Researcher and reality are independent (findings are true)	Hypotheses testing
Critical Realism	Single reality but imperfectly apprehendable	Partial objectivism (findings are probably true)	Falsification of hypotheses
Critical theory	Reality is shaped (e.g. by cultural values) and becomes more clear over time	Value-ladenness (findings depend of researchers' values)	Dialogical/ dialectical (researcher changes reality)
Constructivism	There are multiple and constructed realities	researcher and reality are indivisible (created findings)	Hermeneutical/ dialectical (researcher is an active participant in the world being investigated)

Chapter 2

A Framework for Reverse Logistics

"We adore chaos because we love to produce order."
M. C. Escher

2.1 Introduction

The objective of this chapter is to provide an overall understanding of reverse logistics by structuring the field. In fact, we put together a framework for reverse logistics. A framework is "a basic conceptional structure" (see the Merrian Encyclopedia, 2003). Ergo, here we put forward a basic conceptional structure for reverse logistics, i.e. we identify the elementary ingredients (dimensions) of reverse logistics, we structure them, and we describe their relation to each other. With the framework we provide a basic understanding about reverse logistics situations, since we

1. identify the basic dimensions of reverse logistics,
2. classify different types for each dimension (we provide typologies),
3. explain the relations between the basic dimensions of reverse logistics, and
4. illustrate how the characterization of the basic dimensions helps us to identify the problematic issues and the associated decision-making areas of a given reverse logistics situation.

In spite of many genuine efforts, up to now the contributions to organize the field are scattered and fragmented. This is not a surprise, since reverse logistics is a young field of research. Despite of this, the field is growing fast, demanding thus to be formally structured. This is because one cannot provide substantial insights into reverse logistics without first being familiar with its basics elements. Neither a theory on critical factors for successful reverse logistics can be properly developed. Thus, the framework is valuable as

1. a means to provide a holistic view on reverse logistics situations,
2. a tool to characterize the basic features of reverse logistics situations,
3. an instrument to understand the demands of different reverse logistics situations with respect to the type of decisions that are crucial, and as
4. a necessary platform to provide further insights in the field, possibly including the development of theory.

To build the framework we employ three sources of input: *selective literature* that brings structure to the field, a *review of case studies* (Chapter 3 of this thesis), and the *knowledge* on reverse logistics that was *accumulated* throughout the whole PhD trajectory.

To extract data from the inputs, we proceed to a *content analysis* of the aforementioned literature, an *interactive process* with the case study review (which was carried out simultaneously), and a *tacit intellectual record* of the basic dimensions of reverse logistics. The next section describes the methodology in more detail.

Summarizing, the main contributions of this chapter are as follows.

1. We put forward a framework for *reverse logistics as a whole.*
2. We build the framework with an underlying *methodology.*
3. We ground the typologies of the framework in *empirical evidence* (case studies).

The remainder of the chapter is organized as follows. First, we clarify what the methodology behind the project is (Section 2.2). Section 2.3 reviews specific literature that contributes to the organization of the field. Next, Section 2.4 puts together the skeleton of the framework by identifying the basic dimensions of reverse logistics. Section 2.5 provides the “mass” for the skeleton by presenting the typologies for each of the basic dimensions. Section 2.6 articulates the framework by describing the relations between the basic dimensions and showing the research opportunities. Finally, Section 2.7 provides a summary and conclusions.

2.2 Methodology

The overall approach of this research project is very much inline with the principles of *Grounded Theory*. As described in Strauss and Corbin (2000): "Grounded theory is a *general methodology* for developing theory that is grounded in data systematically gathered and analyzed." Furthermore, the authors explain that it is "a way of thinking about and conceptualizing data" and an attempt to generate theory that is *grounded* in the data. We would like to stress that it is *a way of thinking about data*, as well as *a way of conceptualizing data*.

Since Grounded Theory grounds findings on data, it is thus an appropriate methodology to build-up a framework, which is a means to understand the field. To put together the framework, we make use of the following *three* sources of data (see also Figure 2.1).

1. We employ existing literature,
   - to re-examine the field,
   - to identify the basic dimensions of reverse logistics, and
   - to have a start-up for the typologies (when possible).
2. We employ the case study review in an *interactive* way, mainly as
   - a means to empirically ground the typologies,
   - a means to improve the completeness and adequateness of the typologies, and
   - a means to refine the naming of the elements of each of the typologies.
3. We employ the knowledge accumulated during the whole PhD trajectory to strengthen the research with another source of data (triangulation).

The first procedure is rather explicit. In Section 2.3 we explain how the literature leads to the skeleton of the framework, i.e. the basic dimensions.

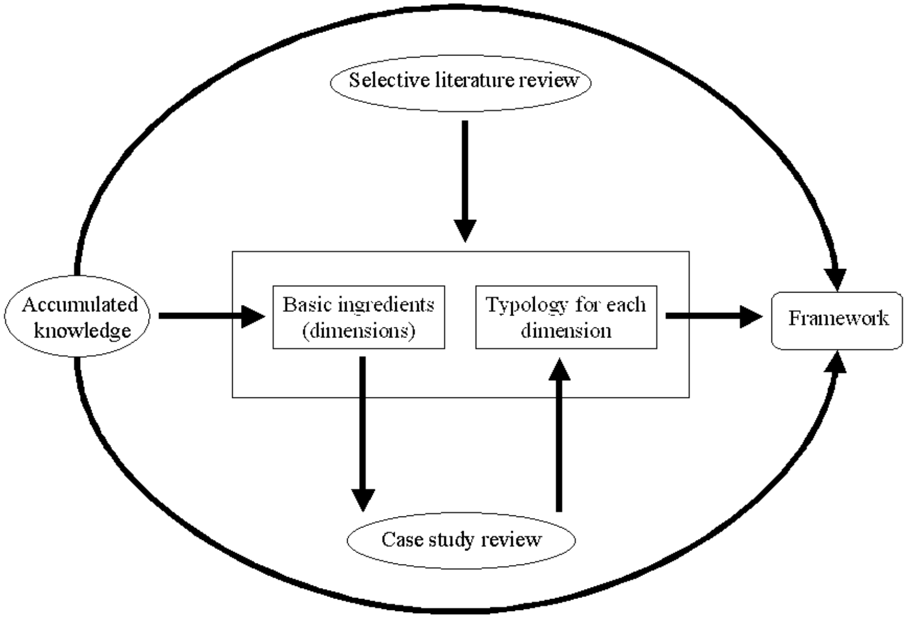


Figure 2.1: Building the framework

While putting forward the typologies (Section 2.5) we state what the contribution is of the classifications in the existing literature. By typology we mean a classification based on types or categories (see Merrian Encyclopedia, 2003).

Let us go into more details regarding the second and the third sets of data. *Interactive process* refers to the progressive interaction and growth of *i*) the framework, and *ii*) the review of the case studies. The analysis of the case studies is based on the framework. Let us recall that the two research projects were carried out simultaneously. The case studies are a tool to put the adequateness of the typologies and its completeness to the test. This allows the framework to be re-shaped and improved, when necessary. Also, the interactive process provides a refinement in the naming of the elements of the typologies. The naming of the elements originally was sometimes unsuitable when faced with a specific case study. By carrying out the projects simultaneously, we could ground the framework on empirical evidence.

Regarding the tacit record of basic dimensions, the whole doctoral trajectory plays a role. It is the result of *i*) cooperation with seniors and young researchers, *ii*) attending conferences, *iii*) carrying out different research projects on reverse logistics, and *iv*) getting information from professional journals on the field, newspapers and internet sites. During the whole PhD-trajectory there was awareness about this being the third source of data for building the framework. It is important to note that this awareness is actually the crux regarding this third source of data, so at all the moments data could be gathered for the project. In addition, notice that a plurality of approaches is employed, known as triangulation.

Triangulation is further achieved by carrying out research projects in two different areas of the field: on the one end, research on an *emerging* cluster of knowledge, and, on the other end, research in a *well-established* cluster of knowledge. The contents of these projects can be found respectively in Part II (Return Handling) and Part III (Inventory Management) of this thesis.

Furthermore, the criteria to choose the structure and to build-up the framework can be summarized as follows (see Tashakkori and Teddlie, 1998; Fleischman and Mumford, 1991).

- The structure has to be based on *primary dimensions* that characterize reverse logistics.
- The framework has to be *parsimonious*, i.e. simplicity will be favored.
- The *internal* validity needs to be preserved by preserving consistency.
- The *construct* validity needs to be preserved. This is taken care of by selecting the basic constructs, i.e. the dimensions of the framework according to their meaningfulness to the understanding of the field.

2.3 Reverse Logistics: a review of literature on theoretical developments

The focus of this section is on literature contributing to structuring the field.

Thierry et al. (1995) describe strategic issues in product recovery management. To facilitate the analysis, the authors first give a list of the options for product recovery management. The options are characterized according to the level of disassembly (product/ module/ part, etc.), the quality required (high/ upgrade to new, etc.), and the resulting product (parts/ modules/ materials, etc.). The paper uses three case studies (BMW, IBM, and an anonymous copier remanufacturer) to illustrate strategic product recovery management. The authors do so by highlighting the changes in operations when the three companies got engaged in recovery.

Fleischmann et al. (1997) present a review on quantitative models for reverse logistics. Before coming to the review itself, the authors put forward a classification of the situations in which reuse occurs. The classification is given according to the following dimensions: motivation for reuse, the type of recovered items, the form of reuse, and the involved actors. The paper then goes over the available models to support reverse distribution, inventory control in systems with return flows and production planning with reuse of parts and materials.

Fuller and Allen (1997) put together a review of several important concepts in the context of recycling of post-consumer solid waste. Thus, a classification of the following recycling systems is given: manufacturer-integrated systems, waste-hauler systems, specialized dealer-processor systems, forward retailer-wholesaler systems, and temporary/facilitator systems. The authors argue that the classification shows that the reverse distribution channels are making a link between the source (post-consumer waste) and the market. The article then continues with a discussion whether, or not, the reviewed variety of systems are likely to be able to deal with the challenges of the future.

Carter and Ellram (1998) review the literature on reverse logistics to identify existing gaps and accordingly to propose an agenda for future investigation. While doing so, the authors identify drivers (regulators, customers, and entrepreneurs), and constraints (such as stakeholder commitment, top management, and vertical integration) regarding reverse logistics. The authors distinguish between internal and external forces, i.e. company factors and the task environment. Then a research agenda is built based on a set of propositions, such as "successful reverse logistics programs require effective policy making," or "top management support is necessary to ensure the continued success of reverse logistics."

Gungor and Gupta (1999) present an extensive review of the literature (more than 300 articles and books) on environmentally conscious manufacturing and product recovery. They subdivide the literature in categories, outlining a framework. The authors look upon product recovery from the point of view of environmentally conscious manufacturing. Both the regulations and the pressure caused by government and customers are mentioned.

Goggin and Browne (2000) suggest a classification for resource recovery, focused on the electronics industry and on products at the end of their life. The classification is given according to the following main lines: generic options, operations (order or planning driven activities), and specific characteristics (input and output complexity; degree of involvement by the OEM; collection, process and distribution complexity; and routing variability). Furthermore the paper discusses electronic equipment manufacturing situations.

The existing categorizations in the field of reverse logistics, are

1. intentionally proposed for a solitarily restricted sub-area of the field, or
2. informally put forward to facilitate the analysis of a specific topic

Implicitly, these categorizations lack generalizability for reverse logistics as a whole, as they constitute partial characterizations of reverse logistics situations. Since, however reverse logistics is not yet a well-structured research area, the aforementioned references are actually important seeds in organizing the field. Next section describes how we use them in more detail.

Ultimately, let us emphasize that, in contrast with the previous literature, this chapter does not focus on any specific form of reverse logistics. Instead, we put forward overall basic dimensions of reverse logistics, such that a framework on reverse logistics *as a whole* is put forward. Besides this, none of the reviewed references explicitly describes which was the methodology to come up with the suggested ingredients and the proposed classifications. Here, we ground the framework on previous knowledge and on empirical evidence, as described in the previous section, and as attested in the next sections.

2.4 Reverse Logistics: the basic dimensions

The reviewed literature brings order with respect to some identified ingredients in the universe of reverse logistics. As the review shows, for some ingredients a typology is given, others are simply used to introduce the analysis. Next we list the ingredients.

- motivation (Fleischmann, 1997)
- drivers (Carter and Ellram, 1998)
- environmental forces (Gungor and Gupta, 1999).

- type of items (Fleischmann, 1997)

- recovery options (Thierry, 1995)
- generic (recovery) options (Goggin and Browne, 2000)
- forms of reuse (Fleischmann, 1997)

- actors (Fleischmann, 1997)
- recycling systems classified according to the actors in the system (Fuller and Allen, 1997)

Some of the ingredients are common to several of the references, though sometimes they are phrased differently. As the above list already suggests, the ingredients can be clustered as follows.

- drivers (also called ‘motivation’ or ‘environmental forces’)
- type of items
- recovery options (also called ‘forms of reuse’)
- actors

A closer look shows that actually these are answers to the following fundamental questions:

- *why* is there recovery?
- *what* is recovered?
- *how* is the recovery done?
- *who* is doing the recovery?

These fundamental questions constitute basic dimensions of reverse logistics. Yet, the literature does not give a formal classification of answers to all the four questions. Besides this, though there are some formalized classifications that are rather complete, others are not, or the structure behind it was never explained. For instance, the list of recovery options put forward by Thierry et al. (1995) is logically explained, rather complete, and generally accepted. In contrast, the semi-formalized classification of type of items (see Fleischmann et al., 1999) includes only packaging, spare parts, and consumer goods. Industrial goods, and others, are kept out. This is not a surprise, as many authors do not intend to formally structure the field. Besides this, the existing literature does not attempt to ground the classifications in empirical evidence for reverse logistics as a whole.

Section 2.5 provides typologies for the basic dimensions of reverse logistics. There we state what is the contribution from existing classifications, or we logically argue how we arrive to them. To this end, the contribution of the case study review is very important. The framework and the case study review were conducted in parallel interacting continuously with each other. Thus, the typologies evolved through this interactive process. The typologies presented next are in fact the final version. In the process, we strive to balance exhaustiveness with meaningfulness for understanding reverse logistics as a whole.

Before presenting the typologies, however, one can notice that the answer to the first question, *why*, can be given from two perspectives: the companies or the customers. Actually, the perspective of the customer is often informally mentioned in the literature by naming the reverse flows like: end-of-life, end-of-use, and so on. However, this has not been formalized.

Thus, we suggest to split the *why* question into two, as follows.

- Why-returning?
- Why-receiving?

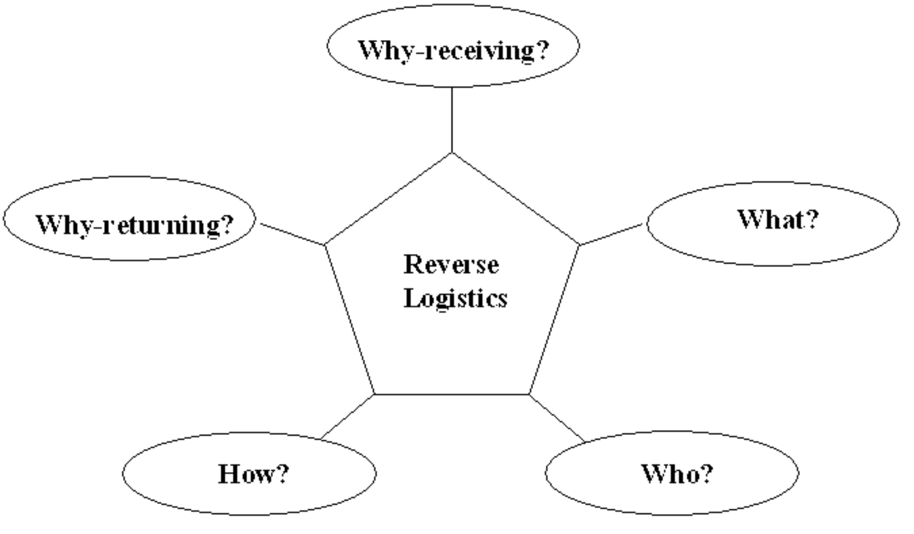


Figure 2.2: The five basic dimensions of reverse logistics.

Summarizing, the skeleton of the framework is given by the following five dimensions (see Figure 2.2):

- Why-receiving?
- Why-returning?

- What?
- How?
- Who?

2.5 Reverse Logistics: why? what? how? who?

This section deals with the fundamentals of reverse logistics by analyzing the topic from five essential viewpoints: *why-returning*, *why-receiving*, *what*, *how* and *who*. For each of these dimensions we provide one or more classification of their elements. This section provides these typologies. In the next section we go into more detail of how the dimensions are interrelated.

The following subsections are considered.

- *Why-receiving*: the forces driving companies and institutions towards reverse logistics.
- *Why-returning*: the reasons why products are returned.
- *What* is being returned: product characteristics and product types.
- *How* are products recovered: processes and recovery options.
- *Who* is doing the recovery: the actors and their roles.

2.5.1 Why-returning: drivers

In the literature of reverse logistics, many authors point out driving factors like economics, environmental legislation and environmental consciousness of consumers (see e.g. RevLog, 2003). Generally, one can say that companies get involved with Reverse Logistics, because *i*) they can profit from it, or *i*) they have to, or *iii*) they feel socially impelled. Accordingly, we organize the the typology driving forces according with the following elements:

- Economics (direct and indirect);
- Legislation;
- Corporate citizenship;

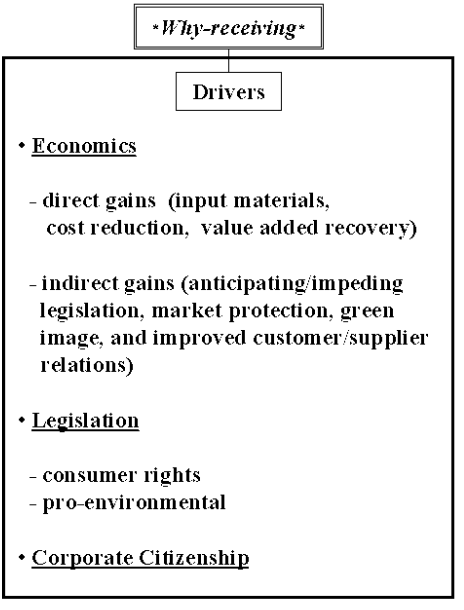


Figure 2.3: Driving triangle for reverse logistics.

Figure 2.3 depicts these three drivers as the driving triangle for Reverse Logistics (compare with Carrol's triple bottom line for corporate social responsibility, Carrol, 1979). Below we go into more detail regarding the three drivers.

Economics

A reverse logistics program can bring direct gains to companies, such as OEM's, by dwindling on the use of raw materials, by adding value with recovery, and by reducing disposal costs. Independent parties have also entered the reverse logistics arena, because of the financial opportunities offered in the dispersed market of superfluous or discarded goods and materials. For example, metal scrap brokers have made fortunes by collecting metal scrap and offering it to steel works, which could reduce their production costs by mingling metal scrap with virgin materials in their process. In the electronics industry, many products have a short life-cycle, but at end-of-life they still have a high intrinsic economic value. For instance, Recellular is a U.S. firm that is taking economic advantage from recovery by trading in refurbished cell phones (see Guide and van Wassenhove, 2001).

Even with no immediate expected profit, an organization can get more involved with reverse logistics because of marketing, competition, and strategic issues, from which indirect gains are expected. For instance, companies may get involved with recovery as a strategic step to get prepared for future legislation (see Louwers et al., 1999) or even to prevent legislation. In face of competition, a company may engage in recovery to prevent other companies from getting their technology, or to prevent them of entering the market. As reported by Dijkhuizen (1997), one of the motives of IBM in getting involved in recovery was to avoid that the brokers would do so.

Recovery can also be part of an image-building operation. For instance, Canon has linked the copier recycling and cartridge recycling programs to the "kyo-sei" philosophy, i.e. cooperative growth, proclaiming that Canon is for "living and working together for the common good" (see Meijer, 1998; Canon, 2003). Recovery can also be used to improve customer's or supplier's relations. An example is a tyre producer who also offers customers rethreading options in order to reduce customer's costs.

Summarizing, the economic driver embraces among others, the following direct and indirect gains:

- Direct gains
  - input materials
  - cost reduction
  - value added recovery
- Indirect gains
  - anticipating/impeding legislation
  - market protection
  - green image
  - improved customer/supplier relations

Legislation

Legislation here refers to any jurisdiction indicating that a company should recover its products or take them back.

In many countries, home-shoppers are legally entitled to return the ordered merchandize (e.g. in the UK, see the Office for Fair Trading, 2003). Furthermore, especially in Europe there has been an increase of environmentally-related legislation, like recycling quotas, packaging regulations and take-back responsibility for manufacturers. For instance, the European Directive on Waste of Electronics and Electrical Equipment (WEEE) was approved by the European Parliament in 2002 and sets the recovery quotas at 70%-90% (see Europa, 2003). In fact, industries, like the electronics and the automobile industry, are under special legal pressure (see Bloemhof-Ruwaard et al., 2004). Sometimes, companies participate "voluntarily" in covenants, either to deal with (or to get prepared for) legislation.

Summarizing, the legal driver embraces the following two elements.

- Consumer rights
- Pro-environmental legislation

Corporate citizenship

Companies use this term 'corporate citizenship' to express that they respect society out of good principles. Note, that there are also other terms used such as social responsibility or ethics. Though the term 'corporate citizenship' many not be generally accepted yet, it fits well our purposes, i.e. it represents when a firm is "feeling" socially impelled to act in certain way (see also Tichy et al., 1997).

In the context of reverse logistics, corporate citizenship concerns a set of values or principles that impels a company or an organization to become responsibly engaged with reverse logistics. For instance, the concern of Paul Farrow, the founder of Walden Paddlers, Inc., with "the velocity at which consumer products travel through the market to the landfill," pushed him to an innovative project of a 100%- recyclable kayak (see, Farrow et al., 2000). Indeed, many firms have extensive programs on responsible corporate citizenship where both social and environmental issues become the priorities (see Shell 2003).

Figure 2.4 summarizes the typology 'drivers' for the dimension 'why-receiving' as described in this section.

Companies are often involved with reverse logistics for a mix of these driving forces and in reality it is sometimes hard to set the boundary. For example, in many countries customers have the right to return products purchased via a distant seller like mail-order-companies or e-tailers. Thus, these companies are legally obliged to give the customer the opportunity to return merchandize. At the same time, this is also perceived as an opportunity to attract customers, bringing potential benefits to the company.

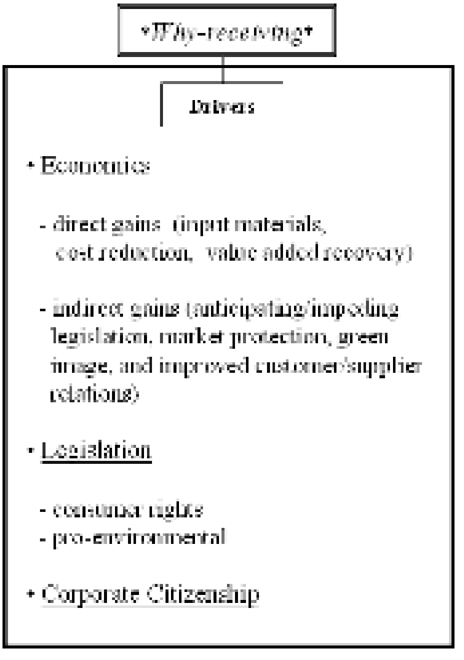


Figure 2.4: The typology 'drivers' for the dimension 'why-receiving'.

2.5.2 Why-returning: return reasons

Roughly speaking, products are returned or discarded because either they do not function properly or because their function is no longer needed. These return reasons are here presented in conformity with the usual supply chain phases: starting with *manufacturing*, going to *distribution* until the products reach the *customer*. Therefore, three groups are differentiated: *manufacturing returns*, *distribution returns* and *customer returns.*

Manufacturing returns

Manufacturing returns are here defined as all those returns for which the need for recovery of components or products is identified during the production phase. This occurs for a variety of reasons. Raw materials may be left over, intermediate or final products may fail quality checks and have to be reworked and products may be left over during production, or by-products may result from production. Raw material surplus and production leftovers represent the 'product not-needed' category, while quality-control returns fit in the 'do-not-function' category.

Summarizing, manufacturing returns include:

- raw material surplus
- quality-control returns
- production leftovers/by-products

Distribution Returns

Distribution/supply returns refers to all those returns that are initiated during the distribution phase. It refers to product recalls, commercial returns, stock adjustments, and functional returns.

Product recalls are products recollected because of safety or health problems with the products, and the manufacturer or a supplier is usually the initiator, and not the customer (see Smith et al., 1996). Product recalls fall in 'distribution returns' as they are usually initiated during this phase and they are anyway specially demanding with respect to distribution.

B2B commercial returns are all those returns for which a buyer has a contractual option to return products to the seller (see a review of supply chain contracts at e.g. Tsay et al., 1999). This can refer to wrong/damaged deliveries, or to unsold products that retailers or distributors return to, e.g. the wholesaler or manufacturer. The latter include outdated products, i.e.

those products for which the shelf life is too short and may no longer be sold (e.g. pharmaceutical products and food).

Stock adjustments occur when an actor in the chain re-distributes stocks. For instance stock adjustments also occur between warehouses or shops for instance in the case of seasonal products (see De Koster et al., 2002). Thus, stock adjustments occur within a company while commercial returns involve more than one company alone.

Finally, there are products for which their inherent function makes them go back and forward in the chain. We suggest to call these as ‘functional returns’. An obvious example is distribution carriers like pallets: their function is to carry other products and they can serve this purpose several times (see e.g Kroon and Vrijens, 1995 and Duhaime et al., 2000).

Summarizing, distribution returns comprehend:

- product recalls,
- B2B commercial returns (e.g. unsold products, wrong deliveries,)
- stock adjustments, and
- functional returns (distribution items/carriers/packaging).

Customer Returns

The third group consists of customer returns, i.e. those returns initiated once the product has reached the final customer. Again, there is a variety of reasons to return the products, viz.

- B2C commercial returns (reimbursement/other guarantees),
- warranty returns,
- service returns (repairs, spare-parts, etc.),
- end-of-use returns, and
- end-of-life returns.

As much as possible, the reasons have been listed according to the life cycle of a product. B2C commercial returns, like reimbursement guarantees, give customers the opportunity to change their minds about purchasing when their needs or expectations are not met (usually shortly after having received/acquired the product). The list of underlying causes is long. For instance, with respect to clothes dissatisfaction it may be due to size, color, fabric's properties, and so forth. Independent of the underlying causes, when a customer returns a new product, benefiting from a money-back-guarantee or an equivalent, we are in the presence of B2C commercial returns. The next two reasons, warranty and service returns, refer mostly to an incorrect functioning of the product during use, or to a service that is associated with the product and from which the customer can benefit.

Initially, customers benefiting from a warranty can return products that do not (seem to) meet the promised quality standards. Sometimes, these returns can be repaired. Otherwise, a customer may get a new product or his/her money back after which the returned product can be recovered. After the warranty period has expired, customers can still benefit from maintenance or repair services, but they no longer have the right to get a substitute product for free. Products can be repaired at the customer's site or sent back for repair. In the former case, returns commonly occur in the form of spare-parts, since in advance it is hard to know precisely which components are going to be needed for the repair.

End-of-use returns refer to those situations where the user has a return opportunity at a certain life stage of the product. This refers to leased products and returnable containers like bottles, but also to returns to second-hand markets as the one of Bibliofind, a division of Amazon.com for used books (see Amazon.com, online).

Finally, end-of-life returns refer to those returns for which the product as such is at the end of its economic or physical life. They are either returned to the OEM because of legal product-take-back obligations, or other companies like brokers, collect them for value-added recovery (see Section 2.5.4).

Figure 2.5 summarizes the typology 'return reasons' for reverse logistics in the three stages of a supply chain: manufacturing, distribution, and customer. One should note however that the distinction between these three stages might be factitious. In practice it is not always easy to pinpoint exactly where manufacturing ends and distribution starts, as value may be added when some sort of distribution has already begun.

2.5.3 What: types and characteristics

A third viewpoint on reverse logistics can be obtained by considering what is actually being discarded or returned. Standard logistics product properties, such as size, weight, value, easiness of transportation and so on, play also a role for reverse logistics.

Figure 2.5: The typology 'return reasons' for the dimension 'why-returning'.

Furthermore, we identify three product characteristics that seem relevant to the organization and to the profitability of reverse logistics systems, viz.

- composition;
  - homogeneity
  - disassembility
  - testability
- deterioration
  - economical
  - physical
- use-pattern
  - location
  - intensity
  - duration
  - bulk use vs. individual

Composition

As highlighted by Gungor and Gupta (1999), product composition in terms of the number of components and of materials is one of the many aspects to keep in mind while designing products for recovery. Not only the number, but also how the materials and components are put together, will affect the easiness of disassembling, and re-processing them, and therefore the economics of reverse logistics activities (Goggin and Browne, 2000 discuss product complexity). The same holds for testability (e.g. in case of the recovery of mobile phones). The presence of hazardous materials is also of prime relevance, as it demands special treatment. The material heterogeneity of the product can play a role in recovery, where one may try to separate streams of materials (see also Krikke et al., 1999b). The size of the product has also been pointed out as a significant factor for recovery systems (see Goggin and Browne, 2000). One can imagine e.g. the impact of this aspect on transportation. Summing up, the intrinsic characteristics of a product, like homogeneity, disassembility and testability, are decisive for the recovery, since they affect the economics of the whole process.

Deterioration

Next, product and materials undergo deterioration processes, viz. physical (homogeneous or not) and economic. This strongly affects the recovery option. Several questions have to be asked in order to evaluate the recovery potential of a product: does the product age during use? (intrinsic deterioration); do all parts age equally, or not? (homogeneity of deterioration); does the value of the product decline fast? (economic deterioration). Deterioration eventually causes a non-functioning status of the product, but also determines whether there is enough functionality left to make further use of the product, either as a whole or as parts.

In fact, products may become obsolete because their functionality becomes outdated due to the introduction of new products in the market, as it happens with computers. This will restrict the recovery options that are economically viable. The same can be said for the intrinsic deterioration and whether or not it is homogeneous. If a product is consumed totally during use, such as gasoline, or if it ages fast, like a battery, or if some parts are very sensitive to deterioration, reuse of the product as such is out of the question. If however, only a part of the product deteriorates, then other recovery options like repair, or parts retrieval and replacement, may be considered.

Use-pattern

The product use pattern, with respect to location, intensity, and duration of use, is an important group of characteristics as it affects for instance the collection phase (see Section 2.5.4). It will make a difference whether the end-user is an individual or an institution (bulk-use), demanding different locations for collection or different degrees of effort from the end-user (e.g. bring the product to a collection-point), see also Chapter 3. The use can also be less or more intensive. Let us consider the case of leased medical equipment, which is commonly used for a small time period, and it is likely to be leased again after proper operations like sterilization. Time is not the only component describing intensity of use, but also the degree of consumption during use. Consider for instance the example of reading a book. Quite often one reads a book only once after the purchase and keeps it, but does not do anything more with it. This has stimulated Amazon.com to start her successful second-hand trading of books.

The characteristics of the product are related with the type of product in question. The product type in fact gives the first global impression on the potential status of the product when it reaches recovery. Zhiquiang (2003) uses for instance a typology for products in order to sketch the planning of reverse logistics activities. Fleischmann et al. (1997) distinguish the following types: spare parts, packaging, and consumer goods. A natural addition is the class of industrial goods, which in general are more complex and have a different use pattern than consumer goods. Furthermore, by looking at the United Nations (UN) classification of products (see UN, 2003), and at the relevant characteristics for reverse logistics (as described previously) we have to discriminate a few more classes of products, like: ores, oils, and chemicals; civil objects, and other transportable materials. Everyone knows that civil objects have a long useful life. Besides this, recovery has to be mostly in-site as objects like bridges and roads are not easily removed and transported, though there are cases where this has happened. Ores, oils, and chemicals are a special category due to their common hazardous composition needing specialized handling during any recovery process. Finally, a separate category is of other materials, such as pulp, glass, and scraps. In sum, the following main product categories can be discriminated:

- civil objects (buildings, dikes, bridges, roads, etc.),
- consumer goods (apparel, furniture, and a vast variety of goods),
- industrial goods (e.g. military and professional equipment, etc.),
- ores, oils, and chemicals,
- packaging and distribution items (like product carriers),
- spare-parts, and
- other materials (like pulp, glass, and scraps).

Figure 2.6 summarizes the typologies 'product characteristics' and 'product types' for the *what* dimension.

2.5.4 How: processes and recovery options

This section deals with how reverse logistics works in practice, i.e. *how* is value recovered from products.

Recovery is actually only one of the activities of reverse logistics. Other processes include collection, inspection/testing selection, and sorting. Collection refers to bringing the products from the customer to a point of recovery. At this point the products are inspected, i.e. their quality is assessed and a decision is made on the type of recovery. Products can then be sorted and routed according to the recovery decision. Thus, we have:

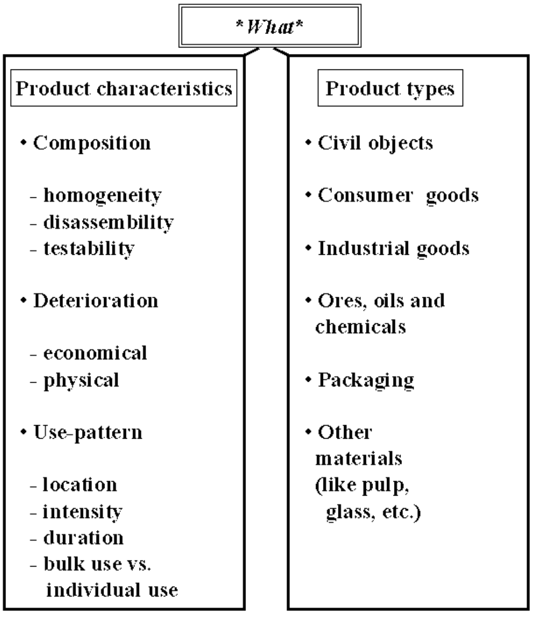


Figure 2.6: The typologies 'product characteristics' and 'product types' for the dimension 'what'.

- collection,
- inspection/ testing,
- selection,
- sorting, and
- recovery itself.

If the quality is "as-good-as-new," products can be fed into the market almost immediately through direct recovery. If not, other types of recovery may be involved but now demanding more action, i.e. a form of re-processing. Thus, we distinguish two groups of recovery, which we discuss next (Thierry et al., 1995 have used the term 'direct reuse' and Fleischman et al., 1997 employed the term ' reused directly').

- Direct Recovery
- Process Recovery

Direct Recovery

Note that re-use, re-sale and re-distribution are slightly different. Re-sale applies to situations where the product is sold again. Re-use is a situation in which the product is used again, but there is no purchase, e.g. unused spare parts. Re-distribution refers to products like carriers, that are simply distributed again and again. Direct recovery involves the three following options:

- Re-use
- Re-sale
- Re-distribution

Process Recovery

Process recovery can involve several operations such as cleaning, disassembling, and re-assembling. In spite of the detailed operations, *process recovery* can be said to occur at different *levels* as explained next. For complete definitions, please see Thierry et al. (1995). For more on recovery/re-processing levels, please have a look at Fleischmann et al. (1997), and Goggin and Browne, (2000).

A product can be recovered as a whole, by being repaired at a product level (repair). At module level, the product, e.g. a large installation, building, or other civil object, can get upgraded (refurbishment). In the case of component recovery, products are dismantled and used and new parts can be used either in the manufacturing of the same products or of different products (remanufacturing). Re-processing may involve a guided selection process of parts for recovery (retrieval). In the case of material recovery, products are usually grinded and their materials are sorted out and grouped according to quality criteria, so recycled materials can be raw material input for industry, such as paper pulp and glass (recycling). Finally, in energy recovery products are burned and the released energy is captured (incineration). If none of these recovery processes occur, products are likely to go to landfill.

Summarizing, process recovery includes the following recovery options:

- repair (at product level),
- refurbishing (at module level),
- remanufacturing (at component level),
- retrieval (at part level),
- recycling (material level), and
- incineration (energy level).

Figure 2.7 gives the typologies 'processes' and 'recovery options' for the dimension 'how'.

Figure 2.8 represents recovery options ordered regarding the level of recovery (product as a whole; module; component; part; material; or, energy level). This figure is in the form of an inverted pyramid, since repair and refurbishing are forms of recovery at a more global level (at the top of the pyramid), while recycling and incineration are forms of recovery in a more specific content level (at the bottom of the pyramid). Please note that returns in any stage of the supply chain (*manufacturing*, *distribution* and *customer*) can be recovered according to options from the top to the the bottom of the pyramid.

One can find overall similarities between the inverted pyramid of Figure 2.8 and Lansink's waste hierarchy introduced in 1979 by this Dutch member of parliament, being: prevention, re-use, recycling, and proper disposal (see VVAV, 2003).

At first, one may think that recovery options at the top of the pyramid are of high value and more environmentally friendly than options close to the

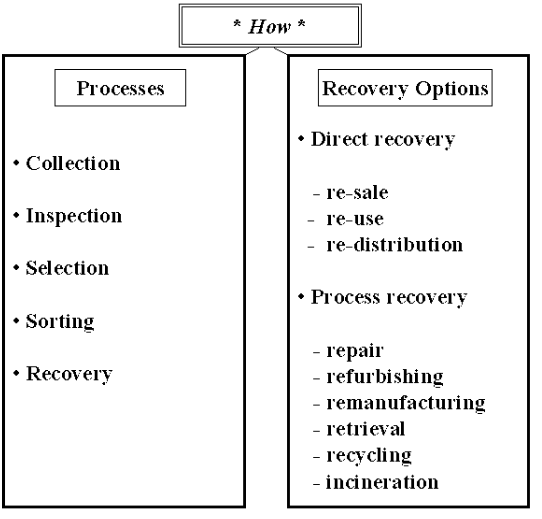


Figure 2.7: The typologies 'processes' and 'recovery options' for the dimension 'how'.

bottom, which apparently recover less value from the products. It is important to stress, however, that both thoughts are not necessarily true. Originally, the Lansink's hierarchy was put together regarding the environmental friendliness of the recovery option. Yet, the hierarchy is not entirely true even with respect to environmental friendliness. For instance, in the case of paper recycling versus land filling, one may go against recycling by arguing that paper is biodegradable and therefore land filling may require less energy than the de-inking and the bleaching processes necessary for recycling. With respect to the economic value of each recovery option, this depends for instance on the existence of a matching market. This is because after recovery, products, materials, and energy can go again to the market (see Figure 2.9). Thus, it is possible that a used product has essentially no market value as such, but is very valuable as a collection of spare parts.

Nonetheless, with respect to process recovery and if there is a market for all the options, one is likely to select the options from top to bottom (see Figure 2.9). This of course, if the product has enough quality to be done so. The return reason plays a role here. If a customer is returning the product because it needs to be 'restored to working condition' (service returns), direct recovery is very unlikely. Note as well that the lines in the figure separate recovery options that very much affect different parts of the organization. Direct recovery mainly affects distribution, the middle group

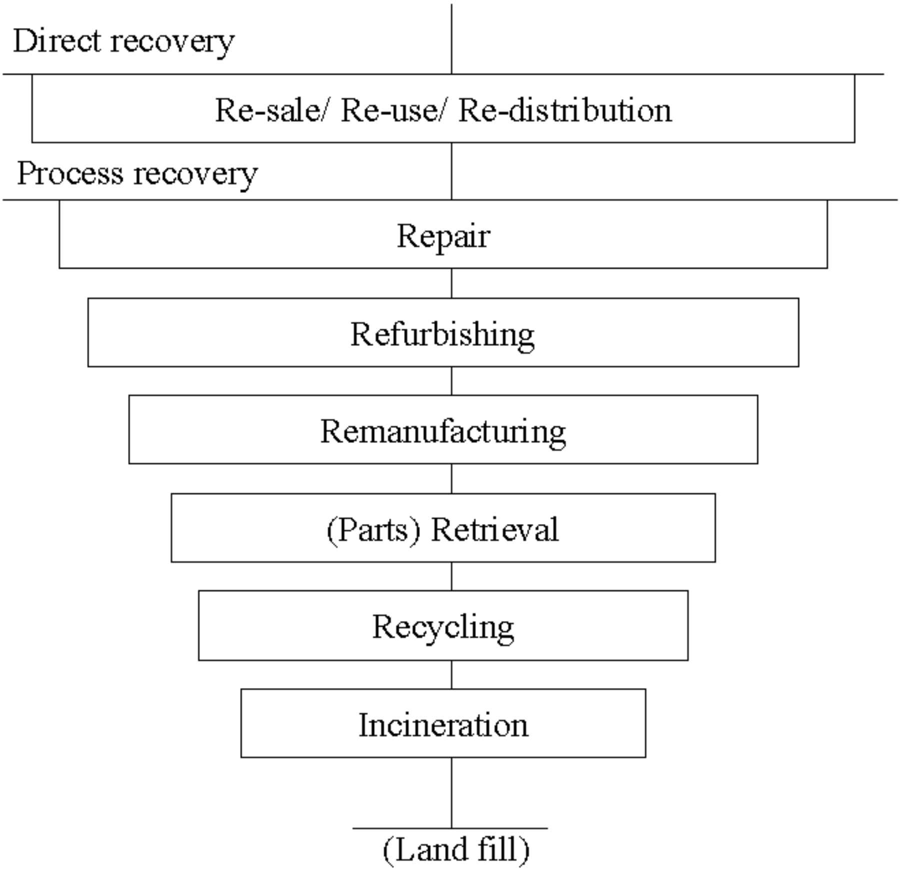


Figure 2.8: Recovery option inverted pyramid

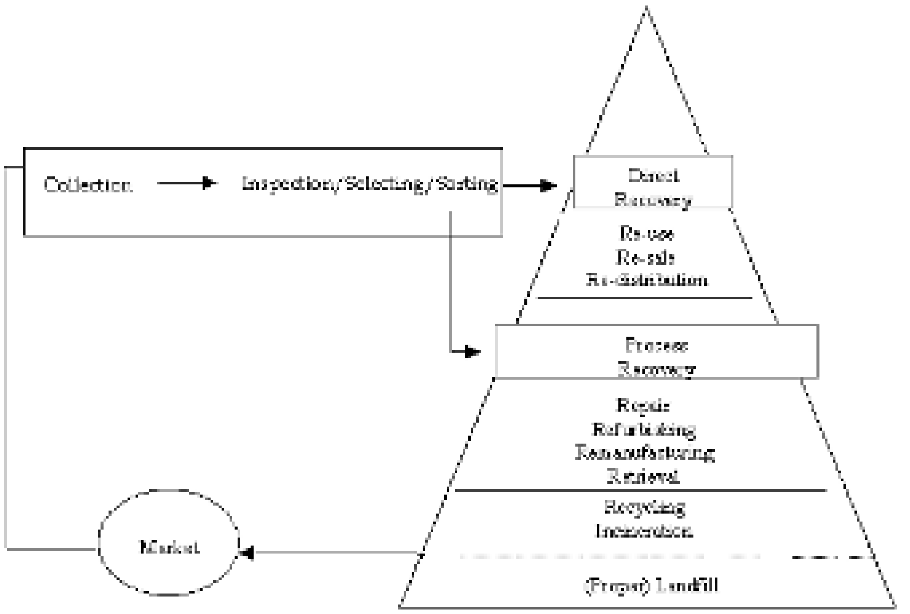


Figure 2.9: Reverse logistics processes

affects production planning, and the third group is most likely outsourced by the organization. So, also depending of the recovery option, there are opportunities in the reverse logistics arena for certain type of players. This is further illustrated in Section 2.6.

2.5.5 Who: actors and roles

Essentially, the following players are the most crucial (see also the viewpoint of Fuller and Allen, 1997):

- forward supply chain actors, (supplier, manufacturer, wholesaler, retailer, and sector organizations),
- specialized reverse chain players (such as jobbers, recycling specialists, dedicated sector organizations or foundations, pool operators, etc.),
- governmental institutions (EU, national governments, etc.), and
- opportunistic players (such as a charity organization).

These players can have the following roles:

- managing/organizing
- executing
- accommodating

Figure 2.10 gives the typologies 'actors' and 'roles' for the dimension 'who'.

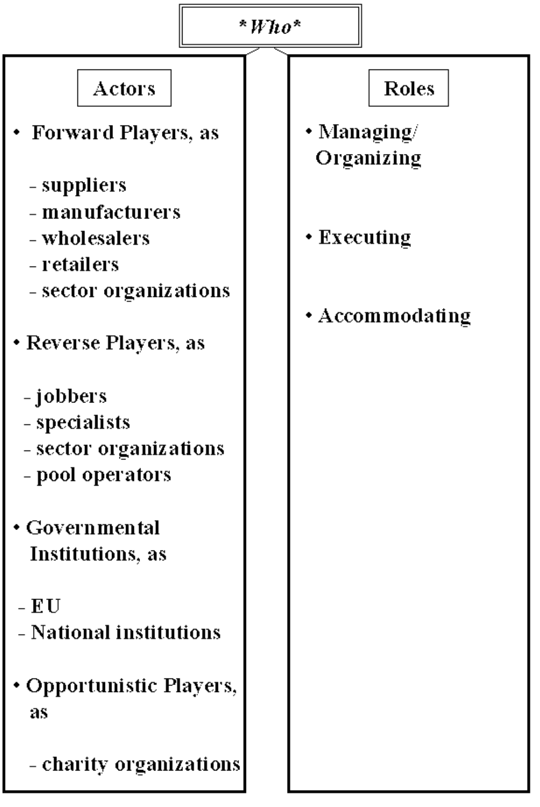


Figure 2.10: The typologies 'actors' and 'roles' for the dimension 'who'.

At the managing level, parties are responsible for (organizing) the reverse chain/network. Other players simply execute activities in the network. The final role to add is the accommodator role, performed by both the sender/giver and the future client (the market), without whom recovery would not make much sense (see also Figure 2.11). The group of actors involved in reverse logistic activities, such as collection and processing, are commonly independent intermediaries, specific recovery companies (e.g. jobbers), reverse logistic service providers, municipalities taking care of waste collection, and public-private foundations created to take care of recovery. Each actor has different objectives, e.g. a manufacturer may do recycling in order to prevent jobbers reselling his products at a lower price (see Section 2.5.1). Furthermore, the various parties may compete with each other.

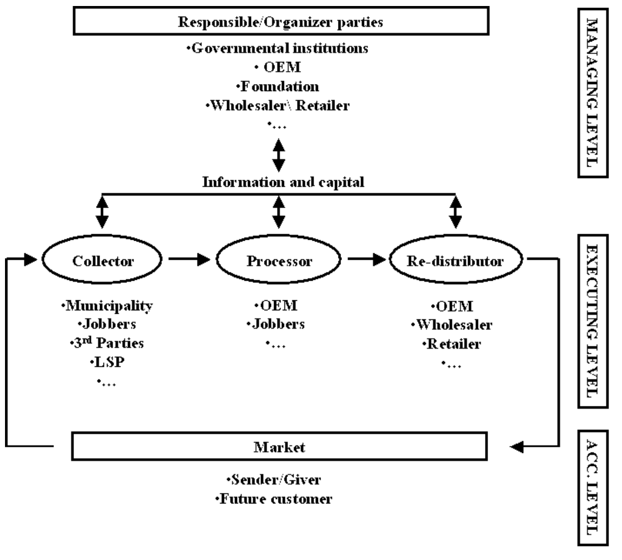


Figure 2.11: Who is who in reverse logistics

Figure 2.11 gives an overall view on the type of players and their roles. The parties at the top of the picture are responsible (or made responsible by legislation) and/or they organize the network. They are from the forward chain, like the OEM, or they are governmental entities like the European Union. At the execution level, there are collectors, processors, and re-distributors, which can be different parties. Between the managing and the execution level, there are exchanges of information and capital.

2.6 The framework

In Section 2.4 we constructed the skeleton of the framework, by identifying its five main dimensions: the return reasons (*why-returning*), driving forces (*why-receiving*), the type of products and their characteristics (*what*), the recovery processes and recovery options (*how*), and the actors involved and their roles (*who*). In addition, we provided "mass for the skeleton" by putting forward a typology for each of the dimensions, in the previous section.

A detailed investigation of how reverse logistics situations are affected by these five dimensions is not yet available in the literature. However, in order to determine the situation itself, the combination of these dimensions is crucial.

In a product recovery setting, product type and return reason are exogenous entities, and they work as inputs. Given these inputs one has to decide on how to recover and who is responsible for what. These decisions are also influenced by the product recovery drivers. Figure 2.12 gives a schematic representation of the relations between the five dimensions of the framework.

The elements in the typologies of input dimensions, such as *why-returning*, are related with the elements of the output dimensions, such as *how-recovery options*. Different return reasons, product characteristics, and different drivers seem many times to lead to different recovery options and actors (see Chapter 3). Many factors play a role, however, and firms may end up with different options. Thus, the same relations are not going to hold always. Nonetheless, below we give a number of typical situations. For each situation, we use the framework to identify the problematic issues and the associated decision-making areas.

By-product returns

Let us consider a typical situation of by-products in the pharmaceutical industry (see e.g. Inderfurth et al., 2004). During the manufacturing process, chemical by-products are released (*why-returning* and *what-type*). These by-products contain valuable substances that can again serve as input to the production process. So, the manufacturer can directly gain from recovering these substances (*why-receiving*). Please note that in this specific case, the sender and receiver is one and the same organization, i.e. the manufacturer.

After retrieval the valuable substances are used again in the production process (*how-recovery option*). However, the by-products deteriorate rapidly (*what-characteristics*). This has an immediate impact on the way that processes are organized. For instance, recovery is integrated with production in the same production plant (*how-processes* and *who*). As a consequence, both production and retrieval of substances compete for physical space and manpower.

It is clear that the input dimensions, *why-returning* and *what*, have an impact on the *how* and on the *who*. Furthermore, the combination of elements defines the problematic issues and the associated decision-making areas. In this case, coordination of production and retrieval operations is clearly essential. Figure 2.13 summarizes the above.

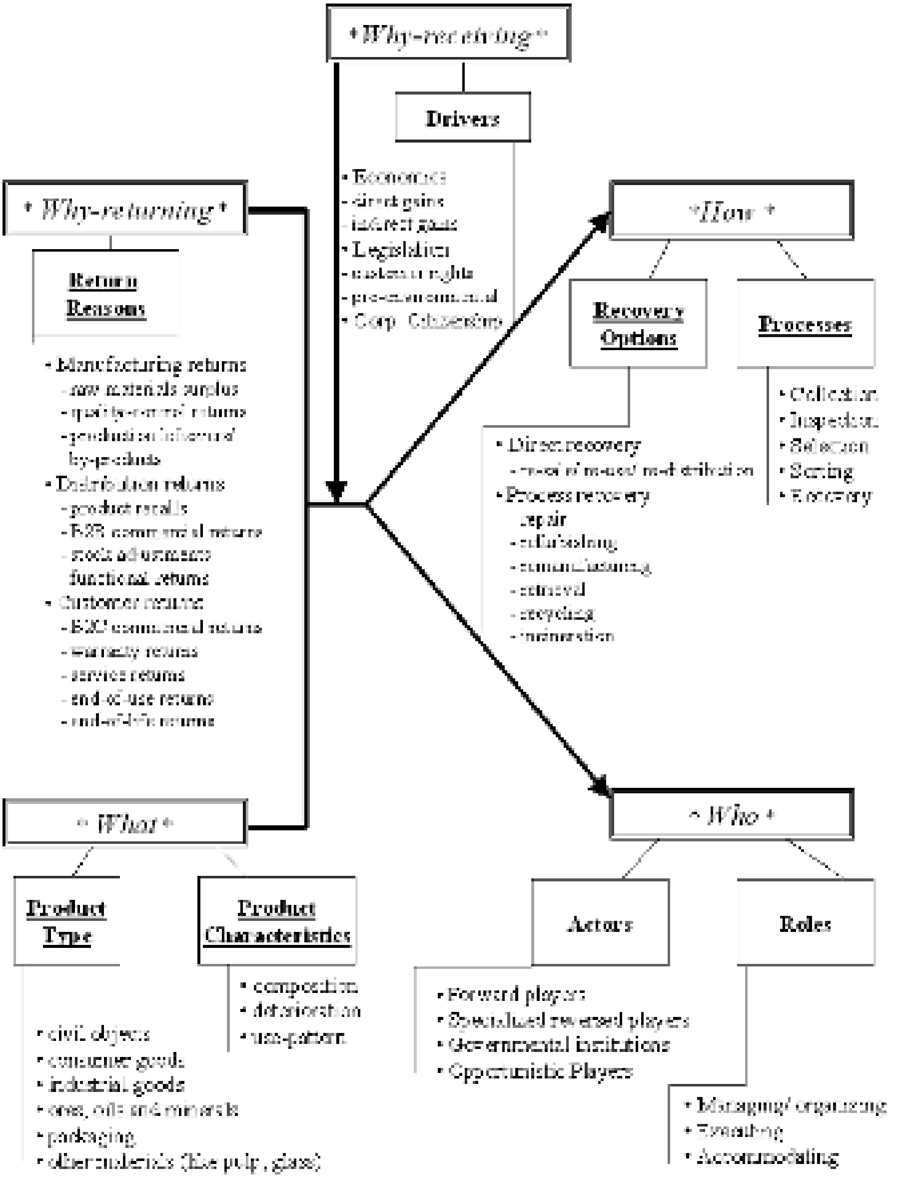


Figure 2.12: A framework for reverse logistics.

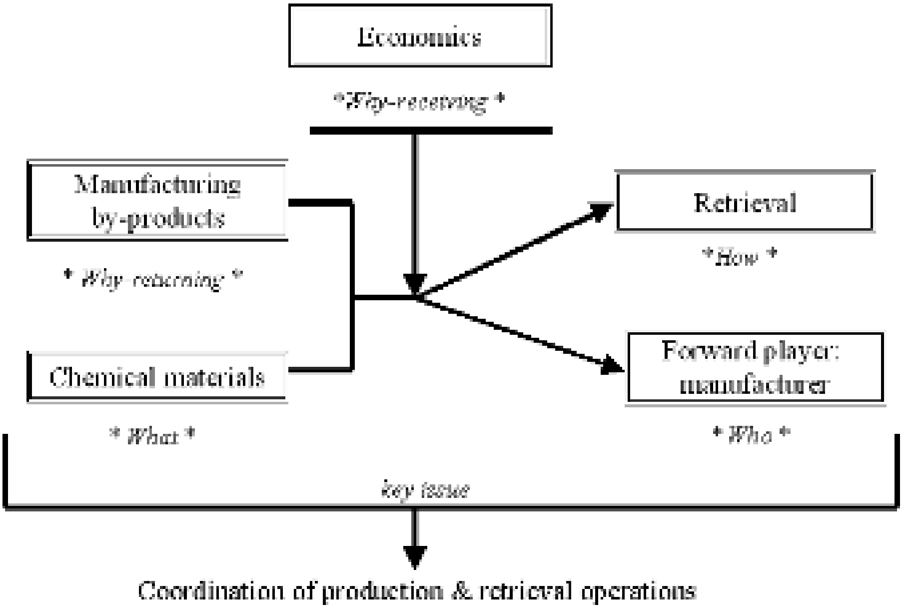


Figure 2.13: Illustrative example of by-product returns.

Functional returns

Functional returns are products that return due to their inherent function, like distribution items (*why-returning* and *what-type*). A typical industry where this type of returns occurs is the beverage industry.

A distribution item usually can be re-distributed several times, since it was designed to be robust enough to protect product integrity in the first place (*what-characteristics*). This makes re-distribution a natural and economically viable recovery option (*how*). The drivers for recovery are economics and possibly, also legislation in the form of recovery quotas, like it happens in Europe (*why-receiving*).

Since the inherent function of distribution items is to go back and forward in the chain, containers are carefully checked and cleaned, so they can be safely redistributed (*how-processes*). Moreover, many actors are involved. Typically, distribution items are pooled with several organizations. Thus forward players as well as pool operators are usually involved (*who*).

Sometimes even parties from competing supply chains are involved. In this setting, keeping control over the distribution items is problematic. One of the issues is preventing leakage, i.e. preventing that items get lost or are stolen throughout the chain. Note that the forward distribution depends heavily on the availability of serviceable distribution items. So, one of the key-issues is data collection (how many items are where) and forecasting how many items come back when (see Figure 2.14).

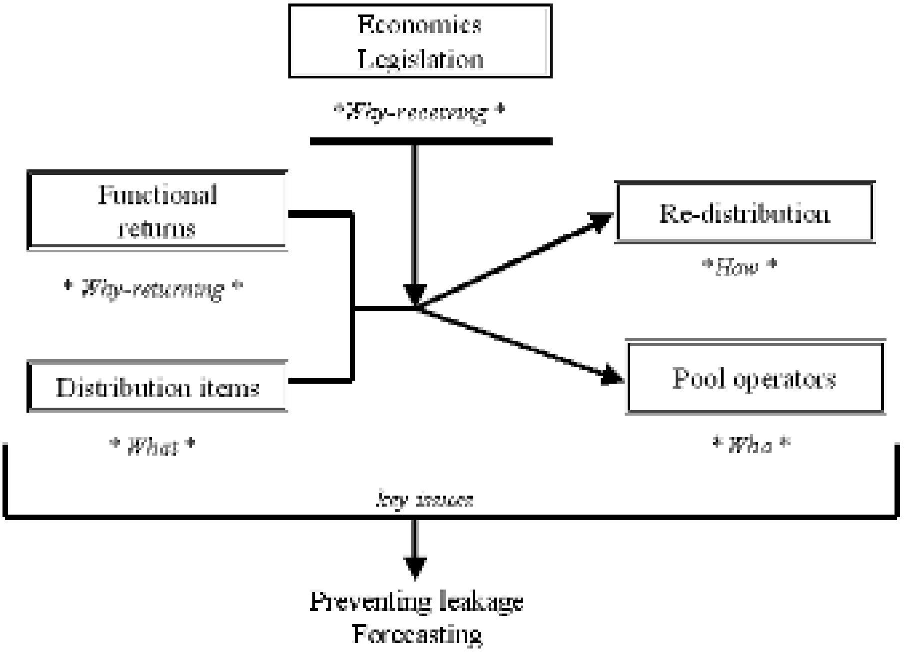


Figure 2.14: Illustrative example of functional returns.

B2C commercial returns (reimbursements)

Let us consider the catalogue retail industry (see also Chapters 4 and 5, where the catalogue retail industry is described in more detail).

After receiving the ordered product, the customer has a limited amount of time to return it and claim reimbursement (*why-returning*). The industry offers reimbursements. This is because, on the one hand, companies want to improve customer relations, and, on the other hand, there is legal enforcement (*why-receiving*). In principle, consumer goods like apparel (for which the catalogue industry is huge) do not physically deteriorate in the meantime, but due to seasonality the products suffer from economic deterioration (*what*).

A natural choice for recovery is direct recovery, by re-selling them. The *what-characteristics* affect directly the way the company is going to organize it. For instance, fashion apparel has to be re-sold during the same season due to seasonal deterioration. Therefore, speed in re-selling is very important (*how*). The products are likely to be brought back to the warehouse so its integrity is checked and the products can be re-packaged (*how-processes*). Thus, at least some actors of the forward chain are also involved in the reverse chain (*who-actors*).

Considering the above, a crucial decision-making area is return handling with the following being one of the issues: do the forward and reverse processes (transportation, warehousing activities, etc.) need to be combined or not? (see Figure 2.15). Chapter 5 further investigates this issue.

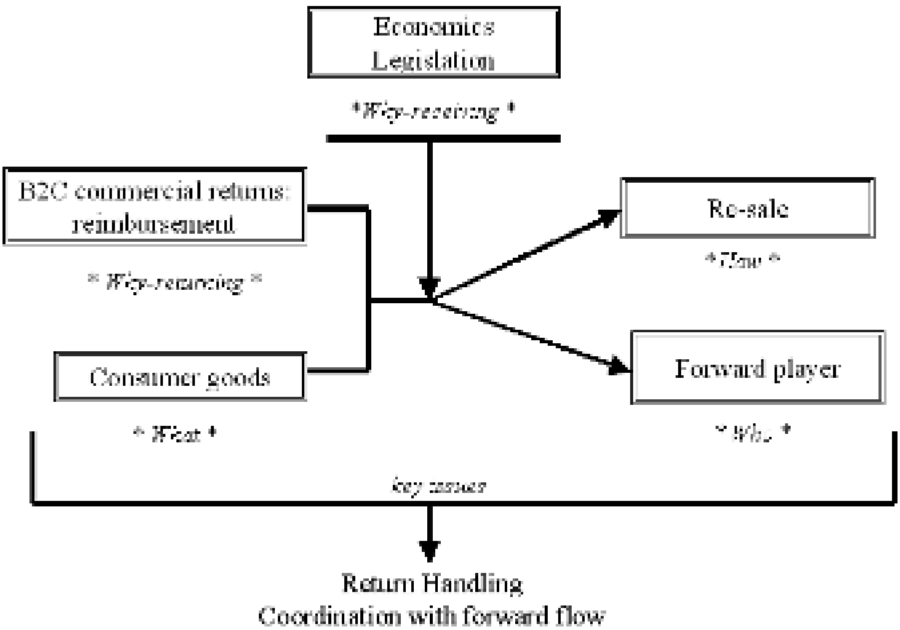


Figure 2.15: Illustrative example of reimbursement returns.

Service returns

In many B2B businesses, the original equipment manufacturer provides after-sales service on valuable industrial products like e.g. aircrafts (*why-returning* and *what*). After-sales service contracts are often very profitable, since this service is very critical to maintain industrial systems and contracts are often negotiated for the long-term (*why receiving*).

When a customer calls for an after-sales service due to a mal-function of the equipment, a service engineer is sent to bring the equipment back to working order, i.e. to repair it (*who* and *how-recovery option*). In order to deal with the particular problem the engineer brings an inventory of tools and spare parts.

A likely outcome is that some parts need to be replaced during the service. Depending on their condition, replaced parts are returned for recovery. The spare-parts that are not used by the engineer are returned and directly restocked in the warehouse for spare parts (*how*).

Since we are dealing with industrial goods, service is very critical, and therefore fast response times are crucial. This opens up opportunities for 3PL's such as fast-courier services (*who*). It also puts major importance on decision-making areas such as network design (centralization vs. decentralization, network coverage) and inventory management such as inventory deployment and accessibility (see Figure 2.16).

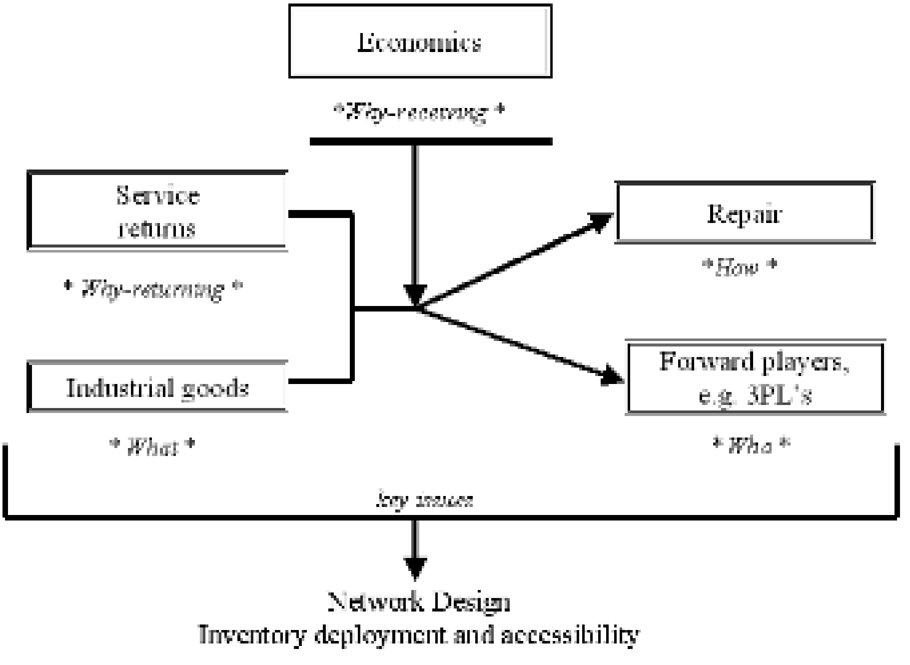


Figure 2.16: Illustrative example of service returns.

End-of-use returns

Consider the B2B leasing of industrial goods such as copiers (*what-type*). Normally, after a lease contract expires, the copier is returned (*why-returning*).

Since these copiers are designed to be very durable, returned copiers are likely to represent a high value (*what-characteristics*).

With these product characteristics, there is an excellent opportunity for obtaining economic gain from remanufacturing (*why-receiving* and *how-recovery option*). Typically, the recovery is done by the original manufacturer (*who*), since they have the know-how and the resources to deal with these complex machines. Since the recovery is done by the original manufacturer, it is natural to integrate the recovery with the production processes.

The questions are however to determine the the degree of integration and how to do this efficiently. There is also a quality issue. Remanufacturing is defined as 'the process that turns a product into as-good-as-new condition'. Thus, how far should disassembly and recovery efforts go, so sufficient quality is guaranteed, but without wasting resources? In addition, the recovery process would be more efficient in presence of design for remanufacturing (see Figure 2.17).

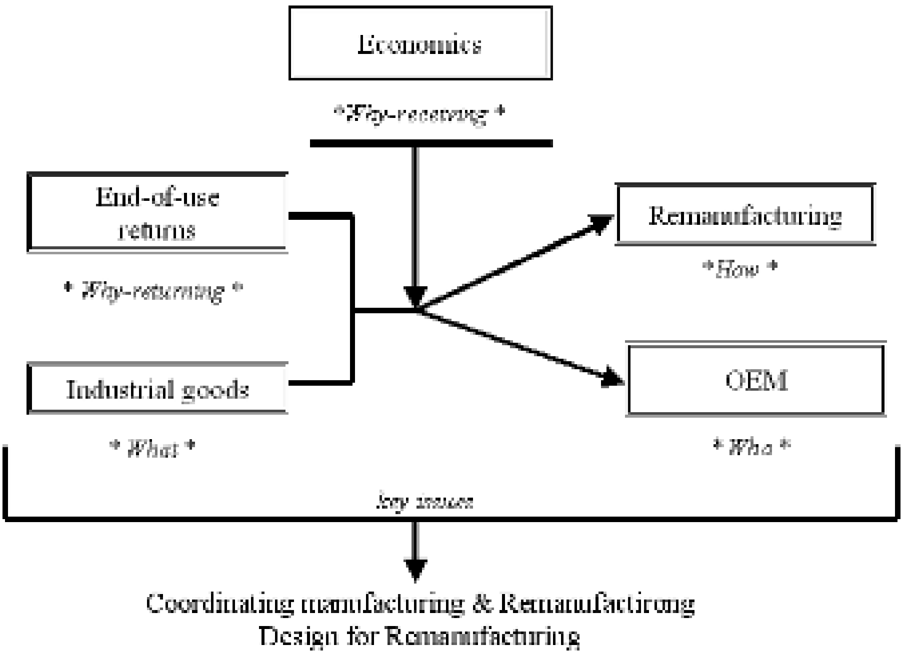


Figure 2.17: Illustrative example of end-of-use returns.

End-of-life returns

Consider a well-known closed-loop recovery system, i.e. the paper industry. Paper that is collected at the end-of-life can serve as pulp input for the industry itself (*what* and *why-returning*). So, the industry has a direct economic gain from the recovery of paper. In Europe, legislation is also a driver as the paper industry is pushed to increase the percentage of paper recovered (*why-receiving*). Since paper is a material, obviously, the only way to recover it at the same time that serves as input for the paper industry, is recycling (*who* and *how-recovery option*).

In paper-recycling, speed is not so much an issue, since we deal with a material that does not deteriorate quickly. Therefore inventories and the recycling process can be centralized. There is, however, a need for big investments in recycling technology. Huge quantities need to be collected in order to take advantage of economies of scale.

Acquisition *is* an issue, since you need the collaboration of the end-user to separate the paper from the waste stream. Furthermore, the geographic spread of paper-use calls for a very fine-branched network, which requires even more investments (see Figure2.18).

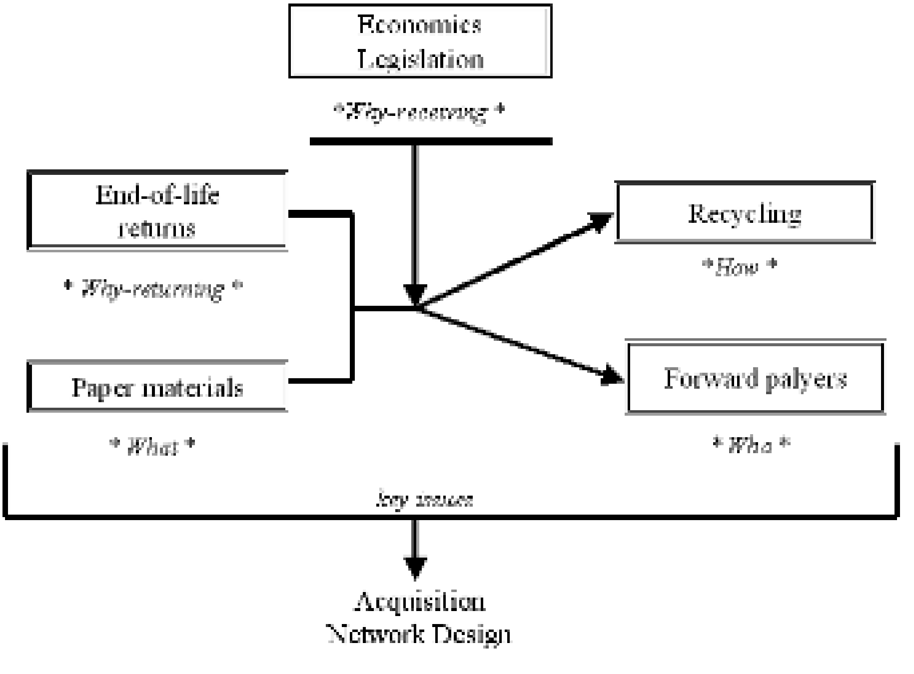


Figure 2.18: Illustrative example of end-of-life returns.

Above, we illustrated with typical situations that filling the five dimensions of the framework with information helps to identify the problematic issues and the associated decision-making areas. The exact influence and relations of the five dimensions of the framework presented here (*why-receiving*, *why-returning*, *how*, *what* and *who*) is still an open question that requires more investigation. There are nonetheless some leads in the literature, which we discuss next.

Goggin and Browne (2000) developed typologies to assist to determine the recovery level (in their case, remanufacturing, component recovery, and material recovery) from product characteristics, like input product complexity and output product complexity, together with some other factors. The product complexity is defined after the number of levels and constituents in the Bill of Materials describing the product. Future research can extend this type of research. The authors restricted themselves to one kind of consumer goods (electronic products) and two recovery options (reuse and refurbishing). Future studies can embrace more recovery options and more product types, covering a diversity of reverse logistics systems.

Krikke et al. (2003) study how value can be regained from returns. The authors identify seven typical returns. They characterize them according to the 1) features of the product (obsolescence, complexity, and remaining lifetime), 2) the influence of legislation, 3) the most associated recovery option, and 4) market characteristics. Then, the authors try to match each reverse flow with a specific type of reverse chain. They characterize this reverse chains to 1) the main driver, 2) degree of centralization, 3) type of processes, and 4) the IT support. The main conclusion is that integration with the forward chain provides the best opportunities, in particular when based on modular reuse. The framework proposed in this chapter can be used in similar studies.

Chapter 3 indicates that per decision-making area, certain dimensions of the framework have a predominant role in identifying the problematic issues. The chapter puts forward the following predominant relations:

- Networks ⇔ Recovery option (*How*) and type of Actors (*Who*)
- Relationships ⇔ Actors (*Who*)
- Inventory Management ⇔ Return reason (*Why-returning*) and Product type (*What*)
- Production Planning ⇔ Recovery option (*How*) and type of Actors (*Who*)

If one wants to get more in-depth details, build-up theory, or explain phenomena, one has to go into more depth regarding some aspects of the framework.

2.7 Summary and conclusions

This chapter provided a framework for reverse logistics directly contributing to

- structuring the field and
- providing an overall understanding of reverse logistics issues.

Five key dimensions were considered, with their respective typologies (see also Figures 2.4, 2.5, 2.6, 2.7 and 2.10):

1. *Why-receiving?*, i.e. why companies get involved reverse logistics (drivers),
2. *Why-returning?*, i.e. the reasons for products being returned (return reasons),
3. *How?*, i.e. how is recovery carried out (processes and recovery options),
4. *What?*, i.e. what is being returned (product characteristics and product types)
5. *Who?*, i.e. who is doing the recovery (actors and their roles).

Finally, we have pointed out that the five dimensions and the typologies of the reverse logistics framework not only give context to reverse logistics situations. Also their combination determines to a large extent the kind of issues that arise in implementing, monitoring, and managing such situations. This was illustrated with a collection of typical reverse logistics situations.

The framework is also a means to raise questions. For instance, the precise influence of the five dimensions of the framework presented here (*why-receiving*, (*why-returning*, *how*, *what* and *who*) is still an open question that requires more investigation. Some of the work going in this direction, such as Goggin and Browne (2000) can be extended by taking into account more product types and return options. The typologies presented in this chapter can provide a basis for this.

Furthermore, Chapter 3, a review of more than sixty case studies, touches upon this issue. There, the framework is used to facilitate the analysis, shedding more light on the relations between the five dimensions, and on their importance with respect to characterizing reverse logistics situations.

We are confident that the framework presented here is going to be a platform for making further progress in the field, by inspiring hypotheses that, once tested, can provide the roots for reverse logistics theory.

Chapter 3

Reverse Logistics: a review of case studies

"Practice is everything"

Periander

3.1 Introduction

This chapter reviews more than 60 case studies on the field of reverse logistics, giving a fair idea of the diversity of reverse logistics practices. The review not only gives an overview of real life situations, but it is also a source of case support for researchers. This is important because one cannot provide proper insights into reverse logistics without being familiar with how firms are dealing with it in practice, what are the trade-offs during decision-making, how decisions are being supported, and so on.

Field studies and surveys can be extremely helpful in getting this knowledge. At the end of the nineties, Rogers and Tibben-Lembke (1999) presented a broad collection of reverse logistics business practices, giving special attention to the U.S. experience, in which the authors carried out a comprehensive questionnaire. One year later, Guide (2000) published a study on research needs based on an extensive survey within the remanufacturing industry in the U.S. Also, quite some case studies on reverse logistics have been described in the literature dealing with different industries, recovery options and drivers. This literature is however scattered over journals for very different research communities. Besides this, in countries in the forefront of reverse logistics a substantial number of case studies have been published in other languages than the *lingua franca* and are therefore not accessible for the majority of the research community. This chapter can also be used as a check list for researchers willing to conduct (comparative) case studies.

The analysis of the case studies is based on the framework of Chapter 2. Concisely, according to the framework, a first characterization of reverse logistics situations starts with answering the following questions: *what*?, *how*?, *who*?, and *why*?. I.e., *what* products/materials are being returned? *how* are they being recovered?, *who* is involved?, and *why* is all this happening?

Actually the two research projects, the framework and the case studies review were carried out in parallel, and in an *interactive* way. The analysis of the case studies is facilitated by the framework. At the same time, the case studies put the adequateness of the typologies and its completeness at test, leading to a refinement of the framework when necessary. So, on the one hand, the case studies review is a means to ground the framework on empirical evidence, and on the other hand, the framework is a means to "see through" the case studies. The framework of Chapter 2 constitutes the "last words" of the interaction between this research work and the framework.

We present the case studies according to the following decision-making areas, widely used in Operations Management: Network Structures, Relationships, Inventory Management, and Planning and Control. For each section we describe and organize the cases and we put forward preliminary insights as well as research gaps, which we link with a research agenda. For some of the decision-making areas, some of the dimensions of the framework are predominantly important. We also discuss this and we provide research directions to further investigate this, by indicating the kind of elements that could be considered in more detail, depending on the decision-making area.

The remainder of the chapter is organized as follows. Section 3.2 describes the methodology employed for finding and classifying the case studies. Section 3.3 provides statistics regarding the type of industry, the product and the geographic area of the cases. After that, Sections 3.4 to 3.8 present the case studies, and preliminary insights related to the state of the art of research in the field. Section 3.9 presents the overall insights of this review. Finally in Section 3.10 we present the conclusions and we put forward research directions. An earlier version of this work has been reported in De Brito et al. (2003).

3.2 Methodology

"Case study" here means a close analysis of the practice (in scientific literature), together with the circumstances and its characteristics leading to an understanding of the situation within its own context (see Stake, 1995). Note that this definition rules out mere examples that are short on details. The approach also excludes the pure description of business practice in professional magazines. We do not contest the usefulness of professional magazines in learning about reverse logistics practice (see e.g. Duijker et al., 1994-2000). However, articles in professional magazines more likely than scientific literature include immaterial content and are biased with promotional aims. Thus, our main source of literature is scientific literature. Yet, we includ refereed professional literature like the Handbook of reverse logistics (Van Goor et al., 1994-).

The search procedure was as follows. The search was carried out by three researchers, one junior and two seniors. We inspected the Science Citation, and the ABI/Inform online libraries, using the combination of key words listed in Table 3.1.

Table 3.1: Key words used for the search of case studies

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	(commercial) Return
Defective	Reassembly	Reuse/ re-use
Disassembly	Rebuild	Reutilization
Dismantling	Recalls	Reusable
Disposal	Reclaim	Reverse logistics
Downgrading	Reclamation	Rework
Energy recovery	Reconditioning	Salvage
Environment	Re-consumption	Secondary (market)
Garbage	Recovery (product, 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

We also survey literature that is especially dedicated to the topic, like the proceedings of renowned conferences, namely the APICS Reman and IEEE on Electronics and the Environment (see APICS, 2003, and IEEE, 2003).

The main search took place in early 2001 and continued till end 2002. Note that we report only on the literature that fit the case study criteria, i.e. leading to an understanding of reverse logistics issues, through a close analysis of a real case.

To give the reader the overall reverse logistics context, we gathered, for each case study, information on the five dimensions of reverse logistics, i.e. *what*, *how*, *who*, and *why-returning*, *why-receiving* as introduced in Chapter 2.

In order to be engaged in, 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. Relevant issues here concern measures to ensure that the actors involved follow a certain behavior. At the operational level, inventories and the recovery activities have to be managed and controlled (see Ganeshan et al., 1999; Fleischmann et al, 1997). Information and communication technologies play an important role to achieve this. Thus, we present the case studies according to the following decision-making focus: Network Structures, Relationships, Inventory Management, and Planning and Control. Furthermore, there is an overview of Information and Technology (IT) for reverse logistics. By IT we denote technological means to process and transmit information (see IT definitions by OECD, 2003, and NAICS, 2003). If a case focuses on multiple decisions, then the case study is discussed in more than one section. With our search procedure, we found 26 case studies on Network Structures,10 cases on Relationships, 14 cases on Inventory Management, 25 cases on Production Planning and Control, and 7 cases dedicated to IT issues.

3.3 Statistics

We have found more than sixty cases involving reverse logistics. Using the United Nations classifications for Industry (see http://esa.un.org), roughly 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 (see Table 3.2).

We also use here the United Nations classifications for Products (see http://esa.un.org). In Chapter 2 we actually expanded this classification (*what-types*) as for thorough research, a more detailed typology is necessary. For an overall perspective, we state here the statistics according to the United

Table 3.2: United Nations classifications for Industry (see http://esa.un.org)

A-Agriculture, hunting and forestry
B-Fishing
C-Mining and quarrying
D-Manufacturing
E-Electricity, gas and water supply
F-Construction
G-Wholesale and retail trade
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

Nations classification. We observe that almost half of them deal with metal products, machinery and equipment. Around 30% of the products being processed fall in the category of *other transportable goods* like wood, paper and plastic products. Around 20% concern food, beverages, tobaccos, textiles and apparel. Less than 10% fall in the category ores and minerals. Not surprisingly, these numbers show that the majority of the cases are on products with high value (see Table 3.3).

Table 3.3: United Nations classifications for Product (see http://esa.un.org)

1-Ores and minerals;
2-Food products, beverages, tobaccos; textiles, apparel and leather products
3-Other transportable goods, except metal products, machinery and equipment (e.g. wood, paper and plastic products)
4- Metal products, machinery and equipment

The majority of the cases are from Europe. In fact, we report on 1 case from South America ([79]), 2 cases from Asia ([46]; [134]), 17 case reports from North America , ([16], [22], [76], [86], [95], [124], [128], [127], [129], [130], [175], [185], [189], [209], [215] [249], [256]) and more than 40 cases from Europe (note that some cases relate to more than one geographic area). The unequal distribution of cases over geographic areas corresponds to the uneven past development of reverse logistics research and practice in the different continents. Next, we discuss the cases listed by subject.

3.4 Case studies on Reverse Logistics Networks

A main activity in reverse logistics is the collection of the products to be recovered and the redistribution of the processed goods (see Section 3.2). Although this problem apparently resembles the standard forward distribution problem, there are also some differences. There are usually many points from which goods need to be collected. In other words, the one-to-many structure that characterizes the forward distribution of goods becomes a many-to-one instead (Fleischmann et al., 2000). Besides this, cooperation of the sender is much more needed and the goods tend to have a lower value than in forward distribution. 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 (see also Fleischmann et al., 2004).

3.4.1 The case studies

We report on 26 case studies, which are summarized in Table 3.4.

Below we discuss the cases organized according to the recovery option. This is a common way of organizing the discussion of reverse logistics networks (see Fleischmann et al., 1999).

The most often described recovery option is direct recovery, either re-distribution or re-sale (12 cases), followed by recycling (11 cases, of which 8 describe public networks and 3 private networks), and then remanufacturing (3 cases).

Networks for re-distribution/re-sale (12 cases)

Containers, packaging and refillable bottles are typical items which can be re-used without extensive recovery operations. In the industrial market these items are exchanged between several companies. Three cases were found.

Kroon and Vrijens [166] 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 and the locations of the depots of the containers.

Del Castillo and Cochran [76] 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.

Table 3.4: Case Studies on Reverse Logistics Networks

Reference	Product(in)	Recovery option	Product(out)	Sender	Collector	Processor	Future customer	Organizer/ Respons.	Return reason	Drivers
[166] (Europe)	dist. items	re-distribut.	(product-in)	customers	Nedloyd	Nedloyd	same market		functional	economics
[76] (N.A.)	distribut. items	(product-in)	retailers	EMSA	EMSA	original chain	EMSA		functional	economics
[86] (N.A.)	distribut. items	re-distribut.	distribut. items	Canada Post	Canada Post	Canada Post	Canada Post	Canada Post	functional	economics
[65] (3 cases, Europe)	distr. items other mater.	re-distribut., recycling	distr. items materials	supermarkets	food chain	food chain specialist	supermarkets	food chain	functional, end-of-life	economics
[65] (3 cases, Europe)	cons. goods dist. items other mater.	re-sale	cons. goods stores	stores chain	stores chain	store chain	stores chain	stores chain	stock adj., functional end-of-use	economics
[65] (3 cases, Eur.)	cons. goods	re-sale	cons. goods	customers company	mail order company	mail order company	customers	mail order company	reimbursement	economics (legislation)
[164] (Europe)	ind. goods	remanufact.	(product-in)	local filial	Oce	Oce	same & new	Oce	end-of-use	economics
[186] (Europe)	ind. & cons. goods	remanufact., recycling	(product-in) materials	households, companies	specialized 3rd parties	Canon (F & UK)	Canon (F & UK)	Canon (F & UK)	end-of-life, end-of-use	economics (image)
[80] (Europe)	spare parts	remanufact.	spare parts	customer	return centre	return centre	same customer	IBM	service	economics, legislation
[17] (Europe)	chemicals (batteries)	recycling	other mater.	households, companies	municipalities, retailers,	specialized companies	-	Organiz. of importers	end-of-life (+incentives)	legislation
[67] (Europe)	cons. goods: white goods	recycling	materials	households	municipalities	specialized retailers	companies companies	Organiz. of electronics (NL)	end-of-life (+ no disposal costs)	legislation
[274] (Europe)	dist. items (glass)	recycling	other mater. (glass)	households, firms	specialized players	specialized players	glass industry	Glass Foundation	end-of-life	legislation
[263] (Europe)	other mater. (car wrecks)	recycling	other mater.	car owner	certified disassemblers	selected recyclers	glass industry	Car Foundation (NL)	end-of-life	legislation economics
[15] (Europe)	other mater. (construction)	recycling	other mater. (sand)	waste processors	Recyclers consortium	Recyclers consortium	Dep. of Public Works	Recyclers consortium	end-of-life	legislation
[157] (Europe)	other mater. (paper)	recycling vs. incineration	materials or energy	households, businesses	opportunistic players	specialized	pulp industry	consortium Governm.	end-of-life	legislation economics
[46] (Asia)	other mater. (waste)	recycling	materials	households	public authority	public authority	-	Kaohsiung's municipality	end-of-life	(corporate) citizenship
[178] (Eur. & N.A.)	cons. goods (carpets)	recycling	fibers, materials	households, companies	municipalities, specialists	professional organization	road, dam builders	carpet industry	end-of-life	economics (legislation)
[209] (N.A.)	cons. goods carpets	recycling	other mater. nylon fibres	business customers	carpet dealers	Dupont		Dupont	end-of-life	economics
[234] (Europe)	other mater. steel scraps	recycling	other mater. (steel)	steel industry	steel industry	steel industry	steel & other industry	industry government	manufacturing by-products	corporate citizenship
[234] (Europe)	other mater. (construction)	recycling	materials	households players	demolition recycler	specialized	industry	government	end-of-life	corporate citizenship

Duhaime et al. [86] 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 3.6.

De Koster et al. [65] describe return handling operations of three food retailers, three department chains, and three mail-order companies (see Chapter 5).

Networks for remanufacturing (3 cases)

Remanufacturing is typically applied to complex equipment or machinery with many modules and parts. It is usually a labor-intensive activity, which requires much testing. Fleischmann et al. (2000) 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. We found the following cases.

Krikke et al. [164] 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 [186] discusses the remanufacturing of used scanners, printers, copiers, faxes at Canon.

Dijkhuizen [80] discusses the remanufacturing network of IBM. He deals with the problem of where to re-process the products: in each country, or centrally at one place in Europe.

Networks for Recycling (11 cases)

One can distinguish two types of networks depending on the organizer/ responsible party, viz. private and public. Fleischmann et al. (1999) and Goggin and Browne (2000) have also made this kind of differentiation while classifying networks for recovery.

Public Networks (7 cases)

There are several papers describing the set-up and organization of recycling networks in The Netherlands.

Bartels [17] describes the Dutch nationwide system for the recycling of batteries. Since 1995, it is legally required that all Dutch battery manufacturers and importers have the batteries they sell retrieved and recycled. Stichting Batterijen (Stibat), was put together to make possible for Dutch battery manufacturers and importers to fulfil these legal requirements. Stibat is a non-profit organization, of which batteries manufacturers and importers are members. The Stibat Plan describing how batteries are collected and processed was approved by the Dutch ministry of Environment (VROM).

De Koster et al. [67] 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, such as a video recorder. The authors also describe the details of network for end-of-life large white goods in De Koster et al. (2003). The consumer pays a disposal fee when purchasing the good, and the sector organization is responsible for "distributing" the money among the parties involved.

Van Notten [274] explains the glass recycling system in the Netherlands. The rules are legally established by the Dutch Ministry for the Environment (VROM). The glass industry formed a Glass Recycling Foundation to deal with them. The authors discuss the bring and pickup systems for the collection of glass scrap from households.

Van Burik [263] describes the car-recycling nation-wide scheme in the Netherlands. Again a society, Auto Recycling Nederland (ARN) was raised by the car manufacturers, importers, and other players in the network of the car industry to address car recycling. A tax on new purchased cars, paid by the consumer to the car importer is used to pay for the recycling. Discarded cars are first assembled at car dismantling centers. Resulting materials are collected and centrally recycled. Recycling companies are paid for processing volumes.

Barros et al [15] discuss the design of a network for the recycling of sand case that comes free during the sieving of building waste, in the Netherlands. Sand recycling in large-scale infrastructure projects, e.g. road construction, is considered a potential alternative to land fill and furthermore aligned with environmental legislation. The Department of Public Works is responsible for the destination of the recycled sand, since it coordinates large-scale infrastructure projects. As the Dutch government aims to increase the recycling quota of building waste from 70% to 90%, a consortium of construction waste processing companies is interested in improving efficiency in the sand-recycling network. The main problem tackled in the paper is the determination of the number and location of depots of the sand.

Kleineidam et al. [157] consider the structure of the recycling network of the paper industry in the Netherlands. Paper recycling in the Netherlands is bounded by the rules put down by the Dutch Ministry for the Environment (VROM). Companies selling or importing paper and cardboard in/to the Dutch market are members of the Dutch Corporation of Paper Recycling. This corporation is in charge of the control mechanisms. The recycling system resembles a close-loop, with used paper being collected, processed, and turned into pulp, which is raw material for the paper industry. Paper from households is mainly collected by a network kept up by non-profit organizations. The authors investigate the dynamic behavior of the chain and use it to evaluate the system. In the analysis, both incineration costs and paper taxes are considered.

Chang and Wei [46] discuss the recycling network for household waste of the city of Kaohsiung in Taiwan, Waste management is maneuvered by the Environmental Protection Bureau of the city. This bureau has the challenge to have in place an effective planning recycling program. The authors deal with the allocation of the recycling drop-off stations.

Private Networks (4 cases)

Louwers et al. [178] discuss the set up of a carpet recycling system. It concerns a special type of carpets, of which the output is used as feedstock in the chemical industry. Both the organization and the collection network are discussed. Realff et al. [209] discuss a similar network, using the same technology, but now in the U.S.

Spengler et al. [234] discuss two cases, one for recycling building debris and one for the recycling of by products in the German steel industry. The authors consider the effect of various variables, like the cooperation between companies.

3.4.2 Preliminary insights

The outline of the previous section is organized around two dimensions of the framework, as follows: the *how* and the *who* (see Chapter 2). In more detail, we presented cases for

- Networks for re-distribution/re-sale,
- Networks for remanufacturing,
- Networks for Recycling - *Public Networks*,
- Networks for Recycling - *Private Networks*.

Typologies of the *how* and the *who*, also have been (more or less consciously) employed in previous literature to distinguish reverse logistics networks (see Fleischmann et al., 1999; Goggin and Browne, 2000; Fleishmann et al., 2000; and Fleischman et al., 2004). Thus, the *how* and the *who* are two prominent elements when one characterizes reverse logistics networks. We come back to this on Section 3.9.

In general, within reverse logistics networks, the models to determine the location of facilities are based on deterministic integer programming models (Fleischman et al., 2004). However, it is commonly accepted that reverse logistics is characterized by much more uncertainty than in forward logistics (see Dekker et al., 2004). With this in mind, there is space for stochastic programming modelling with respect to reverse logistics network design (see e.g. Listes and Dekker 2001).

3.5 Case studies on Reverse Logistics Relationships

It is typical for reverse logistics that several parties are involved, such as the sender of the product, the collector, the processor and the organizer/initiator (see Chapter 2). To stimulate/enforce a certain behavior of their partners, parties in the reverse chain make use of various incentive tools. In this subsection we discuss our findings with respect to the tools that are used in practice to stimulate/enforce a desired behavior of partners in the context of product recovery. A summary of the cases is provided in Table 3.5.

A distinction should be made between two categories of incentives to stimulate/enforce a certain behavior of other players in the supply chain:

1. incentives to acquire products for recovery, and
2. incentives to force others to accept the products a company wants to get rid of.

To be more concrete, two examples follow: in the first situation, a producer of toner cartridges may be interested in getting back its empty cartridges; in the second situation, a company buying chemical raw materials in kegs, may wish that a supplier takes back these kegs (avoiding in this way potentially high disposal costs, once the kegs are empty). Accordingly, these companies are looking for incentives to make “their wishes come true” but against the lowest costs.

The cases embrace incentives regarding functional returns, service returns, end-of-use returns and end-of-life returns.

3.5.1 The case studies

We have found ten cases illustrating the employment of eight different incentive tools, as follows:

1) *Deposit fee*: This fee may concern the product itself or the distribution item like a bottle, box, and pallet. An example of the former is the deposit

Table 3.5: Case Studies on Relationships

Reference	Product(in)	Recovery option	Product(out)	Sender	Collector	Processor	Future customer	Organizer	Return reason	Drivers
[16] (N.A.)	cons. goods (toner cartridges)	remanufact., (parts) retrieval	(product-in)	customers of Unysis	U.S. postal service		customers of Unysis	Unysis	end-of-use (+ price)	economics (customer relations
[85] (Europe)	ind. goods (car engines)	remanufact., refurbishing	ind. goods	owners of Mercedes- -Benz engine	Mercedes -Benz dealers	Daimler- Chrysler	owner of Mercedes- Benz cars	Daimler- Chrysler (Mercedes- Benz)	service (trade-in)	economics (+ customer relations)
[94] (Europe)	Chemicals (batteries)	recycling	other mater.user	mobile of batteries	specialists units, stores, malls	customers	City of for raw other mater.	end-of-life Leicester (UK)	(+ info.)	
[95] (N.A.)	other mater. (plastic scraps)	recycling (+ DfX, innovation)	(100% recycled) kayak	consumers	supplier of recycled	Kayak's manufacturer resins	recreational kayak	Walden Paddlers market	end-of-life	corporate citizenship
[129] (N.A.)	cons. goods (toner cartridges)	remanufact.	(product-in)	customers of Xerox	U.S. postal service		customers of Xerox	Xerox	end-of-use (+ price)	economics
[130] (N.A.)	cons. goods (cellular phones)	remanufact.	(product-in)	cellular airtime providers	Recellular (specialist)	Recellular (specialist)			end-of-use (+price, ...)	economics
[185] (N.A.)	cons. goods (toner cartridges)	recycling	other mater.	users of toner cartridges	UPS	several specialists	HP	HP	end-of-use (+donation by HP to WWF)	economics (+ to put jobbers out of market
[277] (Europe)	dist. items (PC bottles, crates)	re-distribut.	(product-in)	distribution centres of supermarkets	Campina	Campina	Campina	Campina	functional (+ deposit fee)	economics
[282] (Europe)	other mater. (rock wool)	recycling	other mater.	demolishers, building suppliers	3rd party logistics industry	building industry provider	RockWool	RockWool	end-of-life (+buy) back)	economics (+ green image)
[284] (Europe)	Chemicals (batteries)	recycling	Chemicals	households, companies municipalities	UPS, retailers,	several specialists corporation			end-of-life (+ price)	

fee that has to be paid when renting a car, whereas an example of the latter is the deposit fee on certain bottles from glass and PET bottles (*functional returns*), see e.g. Vroom et al [277].

2) *Buy back option*: At the moment that a product is sold, the buyer is offered the possibility to sell back the product on a later moment in time. Some conditions can be imposed, such as kilometers driven.

For instance, Ford has a program called *Options*, which gives the client some advantages in exchanging his/her car, after two years, for another new car Ford (*end-of-use returns*).

Rockwool Lapinus, the Dutch subsidiary of the Danish Rockwool Company, gives the client the opportunity to return rock wool for free or for a lower price than he/she would else have to pay to get rid of it (*end-of-life returns*), see Wijshof [282]. Numerous examples of buy back options for unused products (*commercial returns*) are presented in the literature, where no explicit attention is paid to what happens to these products thereafter (see e.g. Tsay (2001)).

3) *Trade-in*: One can only get a new product if a used one 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, [85]). Owners of a Mercedes-Benz (MB) passenger car or small van with an MB engine can go to an authorized MB dealer in order to have their present engine replaced by a reconditioned engine (*service returns*). The MB dealer removes the engine and sends it to the central parts Distribution Center (DC) of the center of Daimler-benz motor recycling (DB-MTR). From this DC, a 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.

4) *Acquisition price*: This is paid to the sender/giver when he or she delivers a product for recovery. Some suppliers for toner cartridges, including UNISYS, deliver their cartridge in a box that can be returned for free to them either by post (Bartel [16]) or via another third party logistics service provider like Hewlett Packard or Xerox do (see McGavis [185], Guide and van Wassenhove, [129]). Recellular, a U.S. cellular phone remanufacturer is also very active in setting prices to buy used mobile phones in the B2B environment (see Guide and van Wassenhove [130]). These are cases of *end-of-use returns*.

Also manufacturers of batteries use this type of incentive, see Yender [284]. Another example is Varta, the German battery manufacturer, that pays 50p in the UK for every returned rechargeable battery (*end-of-life returns*) send to a collection point (see Faria de Almeida and Robertson [94]).

5) *Supplying timely and clear information about the recovery program*: How important this incentive is, is illustrated by a pilot system for the collection of different types of batteries in Denmark and Germany (*end-of-life returns*), where it turned out that it was too difficult for a number of suppliers to understand clearly which type of battery they have (see Faria de Almeida and Robertson [94]).

6) *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 her supplier, New England Foam of Windsor, to take back their cardboard boxes (*end-of-life returns*), see Farrow and Johnson. [95].

7) *Environmental responsibility*: The idea is to appeal to the consumer's environmental responsibility. This incentive is likely to require a lot of advertising, and its reliability is questionable, as is illustrated by the collection of toner cartridges (*end-of-use returns*), by Hewlett Packard (see McGavis [185]).

8) *Social responsibility*: The idea is to appeal to charity donors. Basically, it works as follows: for each product received for recovery, a non-profit organization receives an amount of money. This incentive was used by Hewlett Packard in the beginning of the nineties but it did not result in a satisfying number of returns (McGavis, [185]). A drawback of this incentive is that the company is going to accept the products without any guarantee of quality. This also applies to the previous tool, i.e. appealing for the consumers'environmental responsibility.

Very recently, this incentive was revived by Recellular (see Recellular, 2003) in the U.S. and by the retailer chain Tesco in the U.K. (see Tesco, 2003), to acquire used mobile phones. All these are examples of *end-of-use returns*.

3.5.2 Preliminary Insights

Among the ten cases, there are quite different incentive tools:

1) Deposit fees (Vroom et al.[277]),
2) Buy back options (Wijshof [282])
3) Trade-in (Driesch et al, [85]),
4) Acquisition price (Faria de Almeida and Robertson [94], Bartel [16], McGavis [185], Guide and van Wassenhove [130], [129]; Yender [284]),

5) Timely and clear information (Faria de Almeida and Robertson [94]),
6) Power (Farrow and Johnson [95]),
7) Environmental responsibility (McGavis [185]), and
8) Social responsibility (McGavis [185])

In the beginning of this section we distinguished two type of incentives:

1) incentives to acquire products for recovery, and
2) incentives to force others to accept the products a company wants to get rid of.

Actually only one among the ten cases found was on the latter type of incentive. This is the case of Walden Paddlers using its *power* to force its supplier of foam to take back the cardboard boxes (see Farrow and Johnson [95]). Besides this, not all the other cases are examples of incentives exclusively dedicated to acquire products for recovery. Many of the tools are also meant to keep customers. One example is the *buy back option* offered by Ford (www.ford.nl), when the customer buys another new Ford after 2 years. Another example is the case of the engine *trade-in* option offered by Daimler Chrysler (Driesch et al [85]). Other tools are not directly coupled to a selling activity and they can involve more than just own customers. For instance, a gift to a non-profit organization (see McGavis [185]) as used by Tesco to get back used mobile phones. Or, *deposit fees* on beverages, where customers from one shop may return the empty bottles in another shop. Actually, the latter seems to be the only incentive that is specific for product recovery. Other incentives can serve other objectives than recovery alone.

Next, we make some observations regarding the incentives in the cases and the return reason *why-returning*. The cases do not report on manufacturing returns. These are usually handled internally, or they are not a matter of acquisition anyway. A similar argument can be used for the absence of stock adjustments. None of the cases include product recalls, as in this situation safety is a key-issue thus the parties involved have to take their responsibility. Regarding B2B and B2C commercial returns, these are documented in the literature on contracts for unused products with a return option (see Anupindi and Bassok, 1999; Corbett and Tang, 1999; Debo et al., 2004; Tsay et al., 1999; Tsay, 2001; Lariviere, 1999). The cases presented here embraced incentives to acquire products from functional, service, end-of-use and end-of-life returns (see Table 3.6). The table shows that for several return reasons, it seems to exist different incentives to choose from.

Although all the aforementioned incentives can be found in practice, there are no models in the literature supporting *the choice of incentive*. The litera-

Table 3.6: Case studies: return-reason vs. incentive

Cases	**Return Reason**	**Incentives**
	Acquisition	
[277]	Functional	Deposit fee
[85]	Service	Trade-in
[16]	End-of-use	Acquisition Price
[185]	End-of-use	Acquisition Price, Environmental Responsibility & Social Responsability
[129]	End-of-use	Acquisition Price
[130]	End-of-use	Acquisition Price
[282]	End-of-life	Buy back option
[284]	End-of-life	Acquisition Price
[94]	End-of-life	Acquisition Price & supplying timely and clear information
	Disposition	
[95]	End-of-life	Power

ture deals with one or more aspects of those mentioned above. For instance, 1) literature on sales contracts with return options for unused products; and 2) research on the optimal acquisition price to realize a certain flow of products. The prime focus of the first group of literature is on what may be gained by both sellers and customers by allowing customers to order more under certain return options. Usually a fixed sales price is assumed for the products that are taken back by the seller. Besides this, most of the literature on contracts with a return option concern unused products (see Anupindi and Bassok, 1999; Corbett and Tang, 1999; Debo et al., 2004; Tsay et al., 1999; Tsay, 2001; Lariviere, 1999 [171]).

Klausner and Hendrickson (2000) present a mathematical model that might be used for estimating the acquisition 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.

This aforementioned literature can be used as a starting point to construct a model to support the choice of which incentive to choose, under which conditions.

Another research opportunity is searching explanatory variables with respect to *the choice of incentive*. To start with, we suggest mapping *who is* *who* in each network. This is because an important factor in choosing between incentive tools is to be informed on the alternatives that other players have and the costs associated with them. Therefore, the type of players and their interrelations are likely to determine the type of incentive tools employed.

3.6 Case studies on Inventory Management

The 14 cases on inventory management within reverse logistics are given in Table 3.6. They can be classified according to the return reasons (see Section 3.2). We did not find cases for all the return reasons. We did find cases for functional returns, 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. They differ mainly in the contractual side and accordingly one cannot expect many publications with an inventory management focus. Stock adjustments are somewhat similar to some of B2B commercial returns (bulk returns) and might even not be distinguished from them in the case descriptions. Below we go over the cases in more detail.

3.6.1 The case studies

Functional returns (2 cases)

This category corresponds to distribution items, that is, products like containers, bottles, railcars and crates, which are used for distribution purposes. On this we report two cases, viz. Swinkels and van Esch [242] and Del Castillo and Cochran [76]. Here the location of the distribution items is a major issue in the inventory decision.

Del Castillo and Cochran [76] 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 [242] describe how the optimal stock of refillable beer kegs is determined within Bavaria, a Dutch beer brewery.

Table 3.7: Case Studies on Inventory Management

Reference	Product(in)	Recovery option	Product(out)	Sender	Collector	Processor	Future customer	Organizer	Return reason	Drivers
[59] (Europe)	ind.goods	re-use	ind.goods	internal customers	customer (bring-back)	CERN	internal customers	CERN	reiumbursement, end-of-use	economics
[59] (Europe)	cons. goods	re-sale	cons. goods	customers	mail order company	mail order company	customers (same market)	mail order company	reimbursement	economics, legislation
[59] (Europe)	spare parts (refinary)	repair, re-use	spare parts	service engineers	service engineers	Refinery	internal customer		service	economics
[76] (N.A.)	distribut. items	re-distribut.	(product-in)	retailers	Coca-Cola chain	Coca-Cola	original chain	Coca Cola	functional	economics
[79] (S.A.)	spare parts (railways)	repair	spare parts	Caracas subway	Caracas subway	Caracas subway	Caracas subway	Caracas subway	service	economics
[82] (Europe)	spare parts (telephones)	repair	spare parts	telephone companies	Lucent Technologies Nederland	Lucent Technologies Nederland	same chain	Lucent Technologies Nederland	service	economics
[101] (Europe)	ind. goods (IBM)	repair, refurbish.	ind. goods spare-parts	business customers		IBM			end-of-life etc.	economics
[154] (Europe)	cons. goods (power tools)	remanufact., recycling	(product-in) other mater.	customers	specialized party	specialized facility		manufacturers	end-of-life	economics (pro-active)
[192] (Europe)	ind. goods (aircraft engine)	repair, refurbishing	ind. goods	UK Air Force	UK Air Force	UK Air Force	UK Air Force	UK Air Force	service	economics
[222] (Europe)	cons. goods (aid equip.)	reuse, refurbish., retrieval,...	(product-in)	users	Norwegian Technical Aid Centers (TAC)	TAC or specialized player	same market	Norwegian National Insurance Administration	end-of-use service	economics, corporate citizenship
[223] (Europe)	cons. goods	re-sale	cons. goods	customer	3rd party log. provider	Wehkamp (catalogue)	same market	Wehkamp	reimbursement	economics (legislation)
[242] (Europe)	distribut. items (beer kegs)	re-distribut.	distribut. items customers	business agents	Bavaria Bavaria	Bavaria	Bavaria		functional	economics
[256] (Europe, N.A.)	cons. goods (single-use photo cameras)	remanufact.	cons. goods	consumer retailers	photo shops, other	Kodak	same chain	Kodak	service	economics
[266] (Europe)	spare parts (cars)	remanufact.	spare parts	Importer organizations	Volkswagen (in Kassel)	Volkswagen (in Kassel)	Importer organizations	Volkswagen (in Kassel)	service	economics

Commercial returns (3 cases)

Commercial returns occur in a B2B or in a B2C setting (see Section 3.2), where the buyer has a right to return the product, usually within a certain period. In the B2B setting, there are all kind of contracts lowering the risk of e.g. the retailer by giving him the opportunity to return what is not sold. In this situations, returns are likely to be in bulk and at the end of a season. In the B2C setting, consumers are given, or they have by law, the right to return a product if the product does not really meets his/her expectations.

Sanders et al. [223] 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: seasonal and non-seasonal products. For the first, the company employs an amended version of the newsboy model taking into account returns. For the latter, the inventory management is done according to an (R, S) policy.

De Brito and Dekker [59] 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 (see Chapter 6). Two cases of commercial returns are considered, viz. a mail order company and and the warehouse at the center for nuclear research, CERN.

Service return (6 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 one that failed is discarded. Secondly, if one needs a continuous functioning of the product or system, one may directly restore functionality by replacing a spare 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.

Díaz and Fu [79] study a 2-echelon repairable item inventory model with limited repair capacity. For several classes of arrival processes they develop an 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 [82] 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 be fulfilled from stock) and there is no budget restriction for service parts.

Moffat [192] 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 [266] describes the remanufacturing chain of engines and automotive parts for Volkswagen. It is somewhat similar to the engine remanufacturing case with Mercedes Benz in the previous section (see Driesch et al. [85]).

A special example of service returns is the one described by Toktay et al. [256] on Kodak's single use camera. Customers return it, so they can develop the film. 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.

De Brito and Dekker [59] investigate the distribution of the return lag, i.e. the time between the purchase and the return of an item for a spare parts warehouse at a petrochemical plant.

End-of-use returns (1 case)

This return reason concerns items that are only temporarily with the user. The product may e.g. be leased or rented.

Rudi et al. [222] 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 (2 cases)

Fleischmann [101] describes the dismantling of computers at the end of their life-cycle into useable spare parts with IBM. This source nicely combines with return obligations and it is 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 the content of the computers, as well as, an insufficient information system to handle the operations.

Klausner and Hendrickson [154] 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.

3.6.2 Preliminary Insights

We have grouped the presentation of the cases according to the *why-returning* typology, i.e. according to the return reason as follows:

- Functional returns,
- Commercial returns,
- Service returns,
- End-of-use,
- End-of-life

This is because this seems a natural way of grouping and discriminating the reverse logistics issues raising from each inventory system. Other authors have done roughly the same (see Dekker and van der Laan, 2003).

Many have defended that product data are essential for efficient handling of returns. For instance, Kokkinaki et al. (2004) provide an example of the value of information for disassembly. Other authors have investigated the impact of data, with respect to returns, on inventory management performance (Kelle and Silver, 1989 ; Toktay et al., 2000; De Brito and Van der Laan, 2003). Yet, there is still 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, techniques to forecast return behavior would have to be enriched with broader explanatory variables. We refer to Toktay (2003) for a discussion of factors influencing returns, which are potential explanatory variables in advanced forecasting models.

Concluding, it remains to be investigated in which degree inventory systems' characteristics like timing, quality and degree of control, are determined by the return reason *why-returning*, as well as on the type of product (*what*).

3.7 Case studies on Planning and Control of recovery activities

This subsection deals with the planning and control of the recovery activities, i.e. collection for recovery and the recovery itself.

Part of the planning and control of product recovery concerns the planning and control of supply of goods to be recovered in which incentives play an important contextual role. This important aspect has already been dealt with in subsection 3.5. In this subsection the 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 the planning of activities, such as on lot sizes, re-processing priorities and scheduling.

The 23 case studies on planning and control of product recovery activities that we found in the literature (see Table 3.8) can be subdivided into case studies dealing specifically with:

1) collection for recovery (13 cases), and
2) recovery itself (9 cases).

The cases are succinctly presented in Table 3.7.

3.7.1 The case studies

Collection for recovery (13 cases)

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.

Andriesse [6] describes the Packaging Return System of Philip Morris for reusable pallets and sheets used to cover pallets. Philip Morris Holland BV and most of its suppliers agreed that the lot size for returning reusable pallets should be a full truck.

Del Castillo and Cochran [76] 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. First the final customers return the bottles to the stores, which return them to the depots.

Duhaime et al [86] 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 [154] mention the lot size used for the collection of power tools by Robert Bosch GmbH.

Table 3.8: Case Studies on Production, Planning and Control

Reference	Product(in)	Recovery option	Product(out)	Sender	Collector	Processor	Future	Organizer customer	Return reason	Drivers
[6] (Europe)	distr. items (pallets)	re-distribut.	distr. items	suppliers	Philip Morris	Philip Morris	suppliers	Philip Morris	functional	legislation
[14] (Europe)	cons. goods (PVC lamellas)	recycling (PVC)	other mater.	households, firms	distributors of lamellas	Ortes Lecluyse	Ortes Lecluyse		end-of-life	economics (image)
[17]	see table 3.4									
[22] (N.A.)	ind. goods (subway)	repair, refurbishing	(product-in)	NY City, Chic. Tr.		M.-K. Chic. Tr.	NY City,	M.-K.	service	economics
[76]	see table 3.7									
[86]	see Table 3.4									
[85]	see Table 3.5									
[124] [128] [127]	ind. goods (aircraft equipment	remanufact.	(product-in)	Air force	Air force overhaul/repair Depot	US Navy	Air force	Air force		
[134] (Asia)	other mater. (glass scrap)	recycling	other mater. (glass)	Producer of glass	Producer of glass	Producer of glass	Producer of glass	Producer of glass	manufacturing leftovers	economics
[154]	see Table 3.7									
[165] (Europe)	cons. goods (PC monitors)	retrieval, recycling	parts & other mater.	consumers	Municipal	Waste Company	Secondary markets	Municipal Waste Company		legislation economics
[215] (N.A.)	spare parts (engines)	remanufact.	(product-in)			Detroit Diesel		Detroit Diesel		
[225] (Europe)	other mater. (gypsum)	recycling	gypsum	building companies	3rd party LSP	producers (gypsum)	customers (gypsum)	organiz. of producers	end-of-life	legislation
[229] (Europe)	other mater. (wood)	recycling	(product-in)	Trespa (buildings)	3rd LSP, demolishers	Trespa	Builders	Trespa	manufacturing leftovers	economics (legislation)
[229] (Europe)	dist. items (pallets)	re-distribut.	(product-in)	builders, demolishers	3rd LSP, demolishers	Trespa	Trespa	Trespa		economics, legislation
[234]	see Table 3.4									
[246] (Europe)	... chemicals (pharmaceut.)	retrieval	... chemicals (pharmaceut.)	(manufacturing process)	(manufacturing process)	Schering AG (pharmaceut.)	(manufacturing process	Schering AG	manufacturing by-products	
[243] (Europe)	cons. goods (white & brown)	recycling	other mater.	households retailers	municipalities,	recycler	users of other mater.	government	end-of-life	corporate citizenship
[249] (N.A.)	ind. goods aircraft engine	remanufact.	ind. goods				Pratt&Hitney	Pratt&Hitney		
[260] (Europe)	dist.items (tin plate)	recycling	other mater. (tin)	households, etc.	municipalities	specialized player	Metal industries	Stichting		legislation
[270] (Europe)	other mater. (construction)	recycling	other mater.	construction firms	specialized players				manufacturing leftovers	corp. citiz. legislation
[274]	see Table 3.4									
[282]	see Table 3.4									

Bartels [17] 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 call one of the contracted collectors to collect the batteries, what has to happen within one month.

Van Donk [270] describes the system set up by Nelis Utiliteitsbouw B.V., a Dutch construction company. The system has as objective to raise the level of reuse of different types of materials by separating them at the building locations. Among other things, 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 recycling company is called who replaces the filled container by an empty one.

Van Notten [274] 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 [225] describes the Dutch nation wide system for the recycling of gypsum. Attention is paid to the actual collection of gypsum via special containers and bags.

'T Slot and Ploos van Amstel [243] describe the pilot project in the region of Eindhoven, the Netherlands preceding 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 [260] 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 [282] 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.

Simons [229] describes the recycling system set up by Trespa International B.V. This company is a producer of sheets made from resins and wood fibers, which are used in the building industry. The recycling system was established to recycle(or alternatively to incinerate) these sheets, or parts of them. Attention is paid to the collection of leftover sheets at building sites. 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 (3rd LSP's).

Bakkers and Ploos van Amstel Jr [14] describe the recycling system setup by Ortes Lecluyse, a Dutch producer of PVC window blinds. Attention is paid to the sizes of the containers used for collection and to the frequency for emptying these containers. The containers are located at their direct customers, and they are collected once a week, when new window blinds are delivered.

Recovery itself (9 cases)

Two cases have been found on disassembly that 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. [165] discuss the disassembly of PC monitors, where it appears difficult to determine in advance the level of disassembly. This is due to the heterogeneity of the products to be recovered. Kobeissi (2001) determines the optimal disassembly plan for washing machines.

Bentley et al [22] mention that Morrison-Knudsen uses MRP II to plan the remanufacturing of subway/transit overhaul, but the authors do not explain exactly how. The latter also holds for Robinson [215] who mentions the use of MRP by Detroit Diesel Remanufacturing West, that remanufactures Detroit Diesel engines.

Driesch et al [85] describe the car engine recovery network set up by Mercedes-Benz For Europe, including the actual planning and control of the recovery activities in the plant in Berlin. Among other things 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. No further details are given, nor is explained how these lot sizes have been determined.

Guide and Spencer [124] and Guide and Srivastava [125], [126] discuss a method for rough cut capacity planning to the Air Force overhaul depot. Guide and Srivastava [127] discuss 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. [249] 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. The bottleneck is the engine reassembly. Buffer time is used to protect this activity form variations in foregoing activities. This time is determined via Linear Progamming, but no formulas are given.

Spengler et al. [234] discuss an Mixed Integer Linear Programming model used for the planning of processing components arising from the dismantling of buildings in the Upper Rhine Valley.

Next there are two case studies where the resources used for production are also partly used for processing as described.

Gupta and Chakraborty [134] 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 [246] describe the mathematical model presently used by Schering AG, a German producer of pharmaceutical products, including the re-processing of by-products.

3.7.2 Preliminary Insights

The case studies on planning and control of product recovery activities that we found in literature can be subdivided into case studies dealing with:

- collection for recovery (13 cases)

  - separate collection for recovery (Andriesse [6], Del Castillo and Cochran [76], Duhaime et al [86], Klausner and Hendrickson [154], Bartels [17], Van Donk [270], Van Notten [274], Schinkel [225], 't Slot and Ploos van Amstel [243], Ubbens [260], and Wijshof [282]).

  - combined collection and distribution (Simons [229], Bakkers and Ploos van Amstel Jr [14]).

- recovery (9 cases)

  - separate recovery (Krikke et al. [165], Bakkers and Ploos [14], Bentley et al. [22], Robison [215], Guide and Spencer [124]; Guide and Srivastava [125]- [126]-Guide and Srivastava [127], Thomas Jr, [249], Spengler et al. [234]).

  - recovery combined with production (Gupta and Chakraborty [134], Teunter et al. [246]).

Quite a number of planning and control concepts for product recovery have been presented in academic literature. However, the supply of recoverables is often assumed to be autonomous, except for some literature on repair (for an overview see e.g. Guide and Srivastava, 1997b) and remanufacturing (see Guide, 2000; Guide et al., 2001; Guide and van Wassenhove, 2001; Minner and Kiesmüller, 2002). No direct relation between sold/leased and recovered products is assumed. Besides this, uncertainty has been incorporated only 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 has hardly been taken into account (for an exception, see Souza et al, 2002)

Planning and control is all about deciding on how things are going to be done and by whom. These are stressed aspects in the case studies. Naturally, the most relevant elements of the framework for this decision-area are likely to be precisely the *how* and the *who*. This poses a research opportunity. We come back to it on Section 3.9.

3.8 Case studies on IT for Reverse Logistics

We have found six cases concentrating on various applications of IT for reverse logistics activities (see Table 3.9). IT is used to support reverse logistics during different stages of the life cycle of a product, namely manufacturing, distribution and customer (see Kokkinaki et al., 2004 and Hendrickson et al, 2003).

3.8.1 The case studies

Manufacturing (2 cases)

Regarding the phase of product development and 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 defect, i.e. in case of 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 for Xerox Europe as reported by Maslennikova and Foley [183]. Xerox has an extensive Design-for-the-Environment program in place. 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 is the case for Walden Paddlers, who launched a 100% recycled kayak project (Farrow et al. [95]). The project had to rely much on computer experiments as no available design then 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 (3 cases)

Landers et al. [169] 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 IT leads to an improvement in stock levels, routing and picking processes when compared with the pre-IT scenario. Xerox (Maslennikova and Foley [183]) uses bar code labels to track packaging material with the aim of achieving resources' preservation.

Fraunhofer IML has developed software to embed data on recovery processes as reported in Nagel and Meyer [201]. 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%.

Customer (4 cases)

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 (see Maslennikova and Foley [183]). 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.

In the case of Nortel Networks, a Decision Support System (DSS) was developed to assist remanufacturing (see Linton and Jonhson, [175]). The tool permits to apprehend the interrelations between the production and the remanufacturing of products. By this means both processes can be better planned and controlled resulting in a more efficient allocation of resources.

Estée Lauder is another firm that has developed specialized software to handle product returns (see Meyer [189]). The system checks the cosmetic items for expiration date and damages. In this way 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 IT in one year's time.

Table 3.9: Case Studies on IT

Reference	(product-in)	Recovery option	Product(out)	Sender	Collector	Processor	Customer	Organizer	Return reason	Drivers
[201] (Europe)	cons. goods refrigerators	remanufact., recycling	product(in) materials	end-of-life user	forward & specialized	recovery plant			end-of-life	legislation economics
[201] (Europe)	cons. goods computers	(parts) retrieval	end-of-life user	VOBIS (retailer)	Covertronic (specialist)		Covertronic ((specialist)		end-of-life	economics
[189] (N.A.)	cons. goods cosmetics	re-sale	(product-in)	customer	Estée Lauder	Estée Lauder	same market or employees	Estée Lauder	reimbursement	legislation economics
[95] (N.A.)	o. materials (plastic scraps)	recycling (+ DfX, innovation)	(100% recycled) kayak	consumers	supplier of recycled	Kayak's manufacturer resins	recreational kayak market	Walden Paddlers	end-of-life	corporate citizenship
[175] (N.A.)	ind. goods (circuit boards)	remanufact.	ind. goods	customer of Nortel	customer service of Nortel	customer service	(closed-loop)	Nortel Networks	service	economics
[154], [155] (Europe)	cons. goods (power tools)	remanufact., recycling	cons. goods o. materials	customers	specialized party	specialized facility		manufacturers	end-of-life	economics (pro-active)
[183] (Europe)	cons. goods (Xerox)	refurbish., recycling, (+ DfX)	(product-in)	customer	Service Engineers (Xerox Europe)	Xerox Europe	(same chain)	Xerox Europe	service	economics legislation

Nagel and Meyer [201] 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 Electronic Data Loggers (EDL, see also EUREKA, 2003). 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 a certain product without first investing resources in disassembling and testing components. Klausner et al. [155] have investigated the benefits of collecting information via this chip technology in electric motors. Likewise Simon et al. (2001) apply both steady state and transient models to evaluate the benefits of using a data logger in washing machines.

3.8.2 Preliminary Insights

Table 3.10 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 improvements for reverse logistics. E.g., Xerox (Maslennikova and Foley [183]) has an integrated solution for reverse logistics from product development to recovery or proper disposal. Furthermore, all the case studies provide in one way or another an evaluation on the benefits of IT. However, the investments on such technologies or on gathering information are not reported, except for the Estée Lauder case (Meyer [189]) and partially for Walden Paddlers (Farrow and Jonhson [95]). The real benefit of IT investment is therefore difficult to assess as the case studies stress the benefits while the investments and operational costs are left out. In face of limited investment capacity, it would be helpful to know in which phase the investment would have most earnings. In addition, if alternative technologies are available, one can 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 literature is an excellent starting point, as the potential advantages or bottlenecks of some type of information are partially analyzed: 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 Ketzen-

Table 3.10: Case studies: IT tools, requirements and benefits for reverse logistics

IT Tool	Information's requirements	Type of support	Life cycle phase
EDL for electric motors reuse [154], [155]	Info. on potential cost savings)	Reuse decisions through	Customer
DSS for end-of-use [201]	Info. on operations' costs and recycling revenues	Cost optimization, facilities location, vehicle routing, etc.	Customer Distribution
Computer's configuration reader [201]	Info. on operations' costs &recycling revenues	"Setting buy-back price"	Customer Distribution,
Software specialized on return handling [189]	Product's expiration data, damage check	Recovery-related decisions	Customer
DSS for remanufacturing [175]	In-depth information on processes	Remanufacturing -related decisions	Customer
DfX, remote maintenance, etc. (X=Recyclability) [183]	Recovery options, environment's sustainability, and so forth.	Extensive data-base on products	All phases
DfX (X=Recyclability) [95]	Further separation of resins;	Developing a 100% recycled (& recyclable) Kayak	Manufacturing

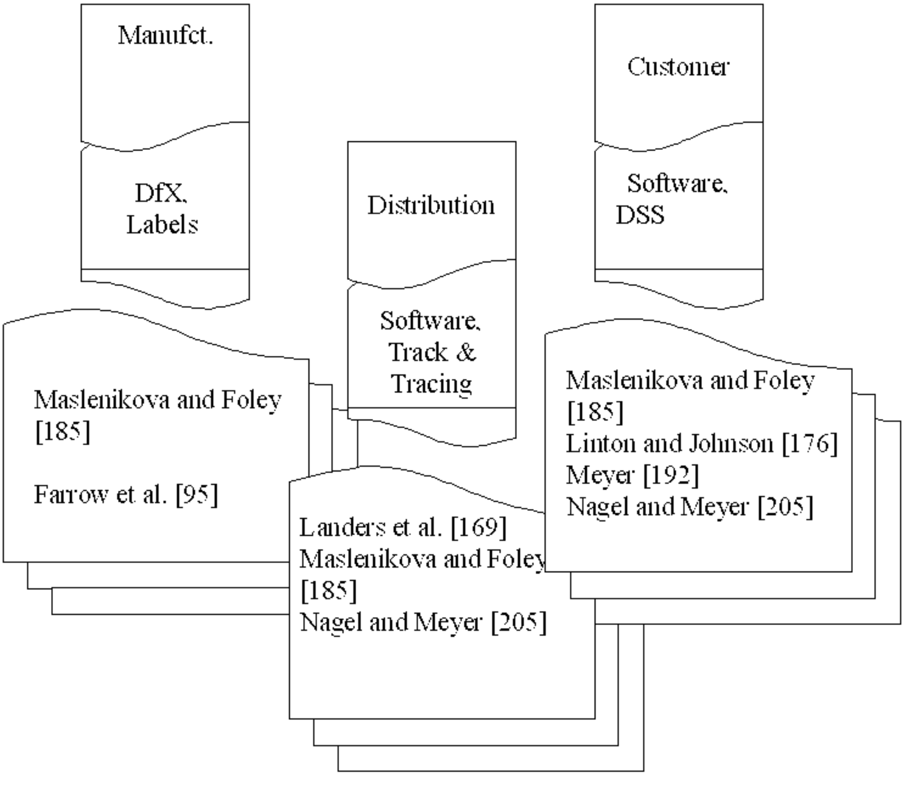


Figure 3.1: IT support for Reverse Logistics in different phases of the life-cycle of the product.

berg(2003), Kiesmuller (2003), and [254]Toktay (2003).

Besides investments, IT tools are very demanding regarding data on reverse logistic processes and associated costs and earnings. This data is however often not available. Nagel and Meyer [201] declare that the lack of information is a bottleneck, which complicates the management of recycling systems. Furthermore, on the Nortel Networks case the DSS could not be designed as desired due to a shortage of data on customer's returns (see Linton and Jonhson [175]). Besides this, to acquire and to manage the data is very expensive.

3.9 Overall insights

The framework presents a structuring and classification of reverse logistics. In our opinion the typologies in the framework are not only useful for describing reverse logistics but also to establish relations between attributes of reverse logistics. Below we present some findings.

Table 3.11 presents the cases organized by return reason (*Why-returning*) and the recovery option (*How*). No cases of recalls were found. This is not surprising, since these cases are not typically documented in Operations Management literature.

From the above table we make now some observations and remarks about the return reason and the recovery option.

- Among the return flows that may occur during manufacturing, there are three cases of manufacturing leftovers, and two cases of manufacturing by-products. They are all associated with materials or chemicals and therefore the corresponding recovery option is recycling.

- The B2C commercial returns are associated with re-sale and with direct re-use. The latter is a form of internal returns, as the customers belong to the same organization as the supplier of the products.

- Functional returns, by definition, are re-distributed. This actually justifies the element 're-distribution' in the recovery option typology (*How*) that we suggested in the framework of Chapter 2.

- Service returns are mainly associated with repair, and to a lower degree refurbishing, and remanufacturing. Let us recall that service returns occur in the first place, because customers need it to be serviced. This usually means 'restore it to working order'.

Table 3.11: The cases: return reasons vs. recovery options

Return Reason	Recovery Option	Total	The cases
End-of-life	Recycling	23	[14], [15], [46], [65] (3 cases), [69], [94], [95], [154]–[155], [157], [178], [165], [186], [201], [225], [209], [234], [243], [263], [274], [282], [284],
	Remanufact.	2	[154]–[155], [201]
	Retrieval	1	[201]
	Incineration	1	[157]
Service	Repair	7	[22], [57], [79], [82], [101], [124]–[127]–[128], [192]
	Refurbishing	5	[22], [85], [101], [183], [192]
	Remanufact.	5	[80], [85], [175], [256], [266]
	Reuse	1	[57]
	Recycling	1	[183]
Functional	Re-distribution	11	[6], [65] (3 cases), [76], [6], [86], [166], [229], [242], [277]
End-of-use	Remanufact.	6	[16], [85], [130], [123], [164], [186]
	Retrieval	3	[16], [85], [165]
	Recycling	1	[17]
	Reuse	1	[57]
B2C commercial returns	Re-sale	5	[65] (3 cases), [223], [189]
	Re-use	1	[57]
Manufacturing Left-overs	Recycling	3	[134], [229], [270]
Manufacturing by-product	Recycling	2	[234], [246]

- End-of-use returns appear with various options, although remanufacturing is the more dominant one. This is not surprising, since typically there is enough value to recover to make remanufacturing attractive.

- In contrast, end-of-life returns are highly correlated with recycling. This is not surprising, as at the end of the product's life, there is less value to recover than in earlier stages. Please note, however, that if products or their modules would be designed for remanufacturing, this option would likely be more attractive, even at the end of life.

Table 3.12: The cases: drivers vs. return reasons

Driver	**Return Reason**	**Total**	**The cases**
Economics	Recycling	16	[201], [155]-[154], [178], [185], [186], [183], [209], [263],[282], [157], [65] (3 cases), [225], [134], [14]
	Remanufacturing	10	[16], [85], [123], [130], [164], [154]–[155], [175], [186], [256], [266]
	Redistribution	9	[65] (3 cases), [76], [86], [166], [229], [242], [277]
	Repair	6	[22], [57], [79], [82], [101], [192]
	Re-sale	6	[57], [65] (3 cases), [189], [223]
	Refurbishing	5	[22], [85], [101], [183], [192]
	Retrieval	2	[16], [201]
	Re-use	1	[57]
	Incineration	1	[157]
Legislation	Recycling	12	[15], [17], [69], [157], [165], [183], [201], [225], [260], [263], [270], [274]
	Re-sale	3	[57], [189], [223]
	Re-distribution	2	[6], [229]
	Retrieval	1	[165]
	Remanufacturing	1	[80]
	Refurbishing	1	[183]
	Incineration	1	[157]
Corporate Citizenship	Recycling	5	[46], [95], [234], [243], [270]

Table 3.12 exhibits the cases organized by driver vs. recovery option.

- Economics is associated with all recovery options, of which recycling and remanufacturing are the most documented ones. This shows that in principle all recovery options have the potential of being economically viable.

- Legislation appears to be mainly associated with recycling. Some of the cases are associated with re-sale. In those cases, legislation gives customers the right to return purchased products. The above raises the question whether environmental legislation is not able to stimulate other forms of recovery. As we stated before, if design for recovery would be more common, other recovery options than recycling would likely be more attractive. Concluding, there is indeed an opportunity to stimulate other forms of recovery through legislation. For instance, legislation could also pro-actively focus on product design issues, rather than dealing with recovery in a reactive way.

- There are not so many cases where the driver is corporate citizenship, but all of them appear consistently associated with recycling. They can be divided into community services and private initiatives.

For each of the decision-making areas, such as Networks, Relationships, etc., some of the dimensions of the framework (see Chapter 2) are predominantly important. These were mentioned at the end of each section under the preliminary insights. These dimensions are more or less consciously emphasized in the case studies presented here. We believe that this is because these dimensions predominantly affect the organization of reverse logistics within each of the discussed areas. We summarize the predominant dimensions per decision-making area in Table 3.13.

To further investigate these relations, we suggest a dedicated case study analysis. In such research, one may also consider to add typologies per dimension or to go into more depth regarding sub-characteristics of the typologies in the framework. Please recall that the framework was constructed to be parsimonious and to facilitate a holistic view of reverse logistics. The last column of Table 3.13 exhibits the kinds of elements that could be considered in more detail, depending on the decision-making area. Furthermore, we also put forward what kind of variables can be added in relation to a given typology.

Table 3.13: The kind of elements to be considered in more detail

Decision making area	Dominant dimensions	Additional elements
Networks	How & Who	Value of the product;
Relationships	Who	The type of relation between the parties; Degree of control in acquisition;
Inventory Management	Why-returning & What	Why-returning + used vs. not; What -characteristics (in detail);
Production planning	How & Who	How-processes (in detail); Degree of involvement of the sender (bring and pickup systems); combined with forward, vs. not;

3.10 Summary and research opportunities

We have found more than sixty cases involving reverse logistics. Roughly 60% of the cases are in the manufacturing category, about 20% are within wholesale and retail trade and about 10% in construction.

Almost half of the cases deal with metal products, machinery and equipment. Around 30% of the products being processed are materials like paper and plastic. Around 20% concern food, beverages, tobaccos, textiles or 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.

With this review we

1. give a substantial overview of the diversity of real life reverse logistics situations, and

2. provide a reference guide for researchers that look for case support.

We observed a lack of cases on reimbursement returns. However, the growth of the catalogue industry including e-catalogues is posing new challenges. Ergo, field research in this area is likely to grow as well.

The analysis of the cases was based in the framework for reverse logistics proposed in Chapter 2. Thus, for each case study we answered the following questions:

- *what* products/materials are being returned?

- *why* are they returned?
- *why* is the company involved in recovery?
- *how* are the products being recovered?
- *who* are the parties involved?

This review was also a means to improve the quality of the framework (Chapter 2). Both projects were carried out simultaneously and in an *interactive* way. This means that on the one hand, the case studies review is a means to ground the framework on empirical evidence, and on the other hand, the framework is a means to further analyze the case studies. The analysis of the case studies allowed us to establish relations between attributes of reverse logistics. We come back to this later in this section.

We presented the case studies according to the following decision-making focus: Network Structures, Relationships, Inventory Management, and Planning and Control. We remarked particular issues and latent questions, for which we proposed topics for future research. For each group, some of the aforementioned questions gain a dominant role, as summarized below. Furthermore, there was an overview of Information and Technology (IT) for reverse logistics.

Reverse Logistics Networks

The section on Reverse Logistics Network Structures was organized around the typologies on the *how* and the *who* (see Section 2). In more detail, we presented cases for

- Networks for Re-distribution/Re-sale,
- Networks for Remanufacturing,
- Networks for Recycling - *Public Networks*,
- Networks for Recycling - *Private Networks*.

Here, most of the cases fell under 'Re-distribution' and 'Recycling - *Public Networks*'. Only a few cases relate to private networks, but at this time we do not know to which degree private networks for recycling are successful.

Reverse Logistics Relationships

The cases report quite different incentive tools to stimulate/enforce a certain behavior of other players in the supply chain (see Section 3.5):

- Deposit fees
- Buy back options
- Trade-in
- Acquisition price
- Timely and clear information
- Power
- Environmental responsibility
- Social responsibility

Some incentives are also part of sales contracts, while others require the customer to buy another product in exchange. There are also tools that are not directly coupled to a selling activity like a gift to a non-profit organization. Furthermore, it seems that only *deposit fees* are specific for product recovery. The other mentioned tools are also used to attract or keep customers in general.

Inventory Management for Reverse Logistics

We have grouped the presentation of the cases according to the *why-returning* typology. The cases covered:

- Functional returns,
- Commercial returns,
- Service returns,
- End-of-use,
- End-of-life

We did not find cases for all the return reasons. Omissions can mainly be explained, because some return reasons are treated in different contexts, like production planning (see Section 3.6).

One of the complicating factors in Inventory Management is the uncertainty in the quality of reverse flows. Many have defended that product data are essential for the efficient handling of returns. This offers various research opportunities (see the next section).

Planning and Control for Reverse Logistics

We found case studies on Planning and Control of product recovery in the following categories:

- collection for recovery
    - separate collection for recovery
    - combined collection and distribution
- recovery
    - separate recovery
    - recovery combined with production

In the literature, the supply of recoverables is often assumed to be autonomous, except for some literature on repair and remanufacturing. Besides this, uncertainty has been incorporated only as far as the arrival of products for recovery and the duration of recovery related activities are concerned. Uncertainty with respect to the result of the processing activities has hardly been taken into account. In practice, however, there is a lot of yield uncertainty.

IT for Reverse Logistics

We found cases reporting evidence that IT can be used in the following stages of the life-cycle of a product:

- Manufacturing
    - dfX
    - labels
- Distribution
    - software
    - track & tracing
- Customer
    - software
    - decision support systems

The technology to process and transmit information seems to be available with promising benefits for reverse logistics. The cases show, though, that the lack of appropriate data is still *the* bottleneck in the implementation of decision support systems.

For each of the above decision-making areas, some of the dimensions of the framework (see Chapter 2) are predominantly important (see Sections 3.4–3.8). We summarize the predominant dimensions per decision-making area as follows

- Networks ⇔ Recovery option (*How*) and Actor (*Who*)
- Relationships ⇔ Actor (*Who*)
- Inventory Management ⇔ Return reason (*Why-returning*) and Product type (*What*)
- Production Planning ⇔ Recovery option (*How*) and Actor (*Who*)

In the next section we give directions to explore this further.

Besides the analysis per decision-making area, we also presented the cases organized by return reason (*why-returning*) vs. recovery option (*how*), and the cases organized by driver vs. recovery option (see Section 3.9). This analysis revealed some relations and issues. For instance, end-of-life returns appear to be highly correlated with recycling. If products or their modules would be designed for remanufacturing, however, remanufacturing would likely be more attractive, even at the end of life. The main driver for recycling is legislation. Actually, current legislation does not seem to be able to stimulate other forms of recovery. However, if legislation would also pro-actively focus on product design issues, rather than dealing with recovery in a reactive way, other recovery options than recycling would likely be more stimulated.

3.10.1 Research opportunities

If one wants to get more in-depth details, build-up theory, or explain phenomena, one has to go into more depth regarding some aspects of the framework. In Table 3.13 we put forward the kind of elements that can be considered to further analyze the prominent dimensions of the framework per decision making area. In order to do this, a dedicated case study analysis should be conducted. Next we continue with specific research opportunities regarding the various decision making areas.

Reverse Logistics Networks

Commonly, the models to determine the location of reverse logistic facilities are based on deterministic integer programming models. However, it is commonly accepted that reverse logistics is characterized by much more uncertainty than in forward logistics. With this in mind, there is room for other tools like stochastic programming modelling for reverse logistics network design.

Reverse Logistics Relationships

We pointed out the lack of literature supporting the *choice of incentive*. Fortunately, there is plenty of literature that can be used as a starting point. For instance, 1) literature on sales contracts with return options for unused products, and 2) research on the optimal acquisition price to realize a certain flow of products.

Inventory Management for Reverse Logistics

Knowledge about returns is seen to be essential for efficient inventory management of returns. With respect to modelling, it is critical to question the validity of the common assumptions in the literature (see Chapter 6). Furthermore, it is important to investigate the impact on inventory management of having *a priori* information on product returns (see Chapter 7). Moreover, specialized forecasting techniques should be developed to deal with this issue.

Planning and Control for Reverse Logistics

In the literature, uncertainty with respect to recovery yield has hardly been taken into account. In future research, yield uncertainty should be modelled explicitly. Furthermore, return handling operations have been so far overlooked in the scientific literature (see Chapter 4). On this, Chapter 5 provides insights regarding splitting vs. combining forward and reverse flows during transport, actual handling and the storage.

IT for Reverse Logistics

Almost all the cases that focus on IT report on the benefits only, while disregarding the required investment. It is important to broaden such partially sighted reports.

In face of limited investment capacity, it would be helpful to know in which phase the investment would have most earnings. In addition, when alternative technologies are available, one can investigate which one is best. To do so, one has to take into account the costs and benefits of collecting and managing data and the costs of investing and managing the technology.

The majority of the case studies deal with one aspect of a real reverse logistics situation but they do not give the overall business environment, which makes insights rather one-dimensional. Thus, there is a need for conducting more integral case study research, by mapping the business context together with more broad information on critical factors, trade-offs and implications.

Besides this, the lack of theory for reverse logistics (see Dowlatshahi, 2000) or even for supply chain management (Croom et al., 2000) adds to companies' inability of knowing what matters in reverse logistics. Therefore the development of theory should be on top of the research agenda to support reverse logistics decisions.

Chapter 4

Return Handling: decision-making and quantitative support

Consistently wise decisions can only be made
by those whose wisdom is constantly challenged.

Theodore C. Sorensen

4.1 Introduction

Return rates can be very high and very costly if not handled properly (see Meyer, 1999 and Morphy, 2001). In spite of this, some managers have disregarded product returns or they handle returns extemporarily (see Meyer, 1999). The fact that quantitative methods barely exist to support return handling decisions adds to this. In this chapter those issues are bridged, as we

- put together a decision-framework for return handling, and
- identify models to support the decision-making process.

With respect to the second item, we often depart from existing quantitative models on general material handling. This is because of the lack of quantitative methods dedicated to return handling.

The remainder of the chapter is organized as follows. First, Section 4.2 gives a brief review of the return handling operations. Section 4.3 provides an illustrative example. Subsequently, in Section 4.4 we put forward a decision-making framework for return handling. After that, Section 4.5 identifies opportunities to support warehousing decisions with quantitative models. Section 4.6 draws some overall conclusions.

This research was reported in De Brito and De Koster (2004).

4.2 Return Handling

Different actors in the supply chain face various return flow types (see the framework in Chapter 2). Independently of the return flow type, the following warehousing processes can be distinguished (see Figure 4.1):

- Receipt,
- Inspection, sorting & other handling,
- (Interim/Stock) Storage,
- Shipping.

Here we do not consider the last process in detail, since shipping is similar to forward flows. In general, operations can differ per return type (see Chapter 2 for a description of return processes and operations). For instance products that come back in an as-good-as-new state can be restocked to be sold again (see De Brito and Dekker, 2003), while end-of-life products may only need interim storage until they are sold to a recycling company.

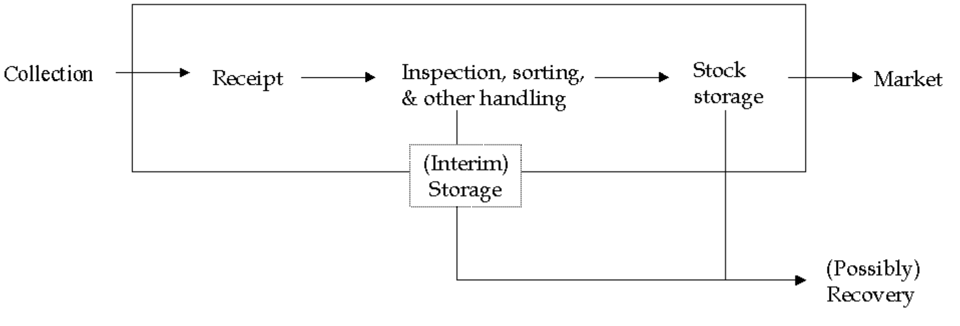


Figure 4.1: Return handling in the warehouse.

Material handling is among the most recent research issues within reverse logistics, which in itself is a relatively new topic. Therefore, material handling aspects (e.g. receipt, and storage) have not been dealt with in the literature in great detail.

Yet, the coercion of re-use and recycling quotas in Europe (see EUROPA, 2003) has served as impetus for specific research on subsequent consequences for return handling. For instance, Anderson et al. (1999) have investigated how firms are coping with EU legislation for packaging recovery and Fernie and Hart (2001) have considered the required assets to carry out the European packaging regulations.

Furthermore, very recently, De Koster et al. (2002) investigated and discussed the return operations of nine retailers. This research is also reported in Chapter 5.

4.3 Return Handling: an illustrative case

This section illustrates the return handling process throughout the operations of a catalog company, here named CTC. Similar operations hold for mail order companies in general (see also Chapter 5). We employ the framework of Chapter 2 to generally structure the description of the case.

What, why, who and how?

The assortment consists of thousands of *consumer goods*, as fashion and hardware articles. There are two selling seasons per year with different assortments. The peak in demand is during the first weeks of the season, when the new catalogue is out. Return rates in catalog business are usually large (see Meyer, 1999). For CTC they vary from a few percent (mainly warranty returns for furniture and large appliances), to larger percentages for small appliances, and to much larger for fashion.

A main driver behind the returns is home-shopping legislation (*consumer rights legislation*). Therefore, CTC allows customers to return products. Apart from legislation, accepting returns at no cost to the customer is seen as an important service element (*improved customer relations*).

Telephone operators sometimes stimulate customers to order more fashion products than they really need (e.g. by suggesting to order the item in multiple sizes). They do this to increase the probability that the customer will keep at least one of the items. This will however cause the customer to return the sizes that do not fit. This is not per se a drawback if one understands the following arguments. Return transportation and handling costs are free to the customer. This also holds for the delivery cost, unless the customer buys at least one item. Thus, to suggest multiple sizes may still lead to lower costs for CTC than when the customer places multiple orders of one unit each, keeping only one of them.

The home delivery of customer orders is outsourced to a Third Party Logistics Provider (3PL) with a very dense network. When a customer wants to return an item, CTC informs the 3PL, which schedules the pick-up in a route carried out in the area of the customer (*who-actors*). If such a route is not planned yet, the pick-up is delayed, or the customer can decide to bring it to a nearby post office and send it back herself. Pick-ups go back again via the sorting centers with large trucks to CTC. The same trucks are used for pick-ups of the new orders at CTC's warehouse.

The return handling operations of the warehouse of fashion and small appliances is further described in more detail. The focus is on collection, inspection and recovery (storing for re-sale) (*how-processes*).

- *Collection* of returns at customers has been integrated with the distribution of products to customers. The same third party logistics company carries out both processes and the route planning is based on both types of orders, although return collection has a slightly lower priority. Even the return drop-offs at CTC are integrated: the truck that brings returned items also collects new orders for distribution.

- Returned products are *inspected* and the receipt is confirmed in the information system, where it is decided whether the client should be credited or not (based on the condition of the product, payments made, and date of original purchase). The products are labelled, which permits to trace the number of times each one of them were returned. Such a label is however disguised so the customer cannot detect whether, or not, she is receiving a product that was once returned by another customer.

- Returned products with a 'as-good-as-new' status are *re-sold*. They are first consolidated with new products on a location in a forward pick area, whereas newly purchased items are *stored* in a reserved area. Other than 'as-good-as-new' products are either returned to vendors or to brokers.

Considering additional decisions made by CTC to control the returns, here follow some observations:

- The return handling process is completely separated from the regular receipts of suppliers, with dedicated workstations and handling equipment like conveyors. For administrative handling, a tailor-made software module is used.

- The forward storage differs from the regular receipts. For regular receipts, one product carrier (usually a pallet) consists of one product. Returns on the other hand are regularly brought to the storage area in rolling bins.

- In the picking process, no explicit priority is given to returned items.

4.4 Return Handling: a framework of decisions

In the last section, the company CTC served to illustrate some of the return handling related decisions. This section formally addresses the decision-making process according to:

- long-term decisions

- medium-term decisions

- short-term decisions

Table 4.1 provides an overview of the decision-making process. One should note that the decision topics have many interdependencies. In practice, when deliberating over a decision, the whole set of decisions should be kept in mind.

4.4.1 Long-term decisions

In supply chain management, the design of the supply chain is often considered to be a strategic, or long-term, decision (see Ganeshan et al., 1999). Analogously we consider here that the design of the warehouse is a long-term decision for return handling. Intimately related to design decisions is the outsourcing decision, which is therefore also considered to be a long-term one.

Facility Layout & Design

Facility layout and design is essentially a long-term decision regarding warehousing. Companies have to ensure that sufficient storage and handling capacity is going to be allowed for return handling and, additionally, how the space in the facility is going to be organized. For instance, companies have to decide if a facility dedicated to return handling is preferable, or, if returns are going to be handled in a separate area of the warehouse facility. By integrating return and forward handling, resources can be shared on the one hand, but on the other hand handling complexity increases.

In the illustrative example, returns were handled in the same facility, but in a separate area dedicated to returns. Actually, this is observed in retailers of other industries as well, as reported in the comparative study of Chapter 5. From the analysis there, a threshold on return volume is likely to determine whether, or not, returns are allocated to a separate area: above the threshold it is more efficient to handle returns in a dedicated area. In practice, one even finds companies with a separate facility dedicated to returns, such as Quelle in Germany, Sears and Kmart in the US, which all have to deal with huge amount of returns (Chain Store Age, 2002).

Fleischmann et al. (2004) further explains how the decision of opening a separate facility for return handling is affected by the amount and type of returns. An obvious trade off is between investments and capacity for return handling. In addition, the location of a return handling area within a facility affects the internal handling systems and therefore the related costs.

Concluding, return handling should be explicitly taken into account during the design of the warehouse.

Outsourcing

In the illustrative case, CTC keeps the warehousing operations in-house. In this case, outsourcing would be difficult since the activities take place within the warehouse and are closely related with order picking and storage activities.

A determinant factor is whether, or not, the return process can be clearly separated from the forward process. If so, return handling may be outsourced. Examples include Albert Heijn (the return warehouse in Pijnacker, the Netherlands) and Sears and Kmart in the US, where the returns are handled by Genco (see De Koster and Neuteboom, 2001; Chain Store Age, 2002).

Other determinant factors are the value and type of product as well as the availability of experienced third parties. At this moment such companies are emerging. Examples include Genco and Universal Solutions Incorporated (see e.g. Chain Store Age, 2002). The advantage of outsourcing is that one can focus on its own competence and let other matters to proper professionals. On the other hand, when outsourcing, a company will always lose a certain degree of control over the return handling operations.

Long-term decisions
• Facility layout & design - physical facilities for return handling • Outsourcing - Outsourcing of return handling operations (transportation and warehousing)
Medium-term decisions
• Integrated operations - return policy (rules and responsibilities) - reusable packaging • Inventory Management - storage policy of returned products • Internal (return) transportation - type of distribution items (product carriers) - automatization of vehicles - type of vehicles • Information Systems - IT systems to support the return handling - type of information
Short-term decisions
• Inventory, storage and order picking - controlling return storage - storage of returns vs. order picking • Vehicle planning and scheduling - route selection

Table 4.1: A framework of decisions for return handling.

4.4.2 Medium-term decisions

Often, medium-term decisions concern integrated operations, transportation, and information systems (see Ganeshan et al., 1999). In addition, we make a distinction between inventory management (medium-term) and inventory control (short-term). The latter is considered in the next section.

Integrated Operations

Here we consider mainly two sets of decisions,with respect to *i)* return policy, and *ii)* reusable packaging.

Actors in the chain are assigned with responsibilities for returns. In the case of chain stores, either a central facility (often the distribution center) collects and processes the products and materials that have been returned from the stores, or the stores take care of it themselves.

According to IGD (2002), in the UK all major food retailers recycle packaging materials in a central facility: either a distribution center or a separate recycling unit. Actors in the chain also have to establish whether different types of returns incur different levels of accountability. For instance, the manufacturer takes the responsibility for all the processes related with end-of-life returns but no responsibility for reimbursement returns.

Another issue to decide upon is the rules for the return policy. For instance, stores have to know which products can or must be returned to the warehouse, in which situations, or how to grant permission for this. In the illustrative example, the mail-order-company does not have much freedom with respect to the return policy, as it is a legal requirement to allow for returns.

The urge to reduce packaging materials leads to the decision whether, or not, packaging materials are going to be replaced by reusable packages. Reusable packages will demand a higher initial investment, but have the inherent benefit of the repetitive use. Many industries choose to reduce packaging waste by using standardized boxes (Schiffeleers, 2001), or by replacing packaging materials by other materials involving less material handling.

Some retailers opt to start recycling their own packaging materials. Albert Heijn, for example, recycles wrap foil into plastic bags, integrating the forward and reverse flows for a practical purpose. Yet, this demands changes in its operations as follows. Stores have to separate the wrap foil, to put it in roll cages, and store it until collection. After recycling by a third party, bags are re-sent to the warehouse to be integrated with the distribution.

Inventory Management

Returned products may have a quality status that differs from new ones. Depending on the status and the timing, they may be, or not, sold in the same market. Both newly supplied and as-good-as-new returned merchandize are going to be stored for future sales as long as the season runs and taking into account the shelf life of the product. The two streams can be stored separately or the merchandize can be consolidated in the same location.

In the case of CTC, returned items are stored together with new merchandize. In the comparative analysis of Chapter 5, other retailers than mail-order-companies have mixed and hybrid storage policies. For instance, one retailer would first store returns at a separate location and consolidate them only when the location's capacity would be exceeded. The analysis led to the conclusion that separate storage policies are mainly found among retailers that wish for a high degree of control over returns. Returns can be consolidated if the future market is the same as for newly supplied merchandize. The 'future market' is also a critical factor for other returns than the 'as-good-as-new' ones. Unsold products are usually consolidated in interim storage locations per vendor or potential 'customer'. A well-known example is unsold books that go back to their respective publishers. End-of-life returns are also usually separated and held together by potential brokers.

Internal (return) transport

An important issue in internal transport is the choice of reusable transport carriers. Choosing the type depends on the willingness of the parties in the chain to adopt one of the available standards. This is usually a complex process, where power and trust play a major role. Once a standard is in place, the decision that is left to take is the amount needed. Product carriers require collection, transportation back to the warehouse, checking, storage, and possibly cleaning before being used again. In order to limit the amount of product carriers needed, they should rotate rapidly. Since the timing and quality of such returns are difficult to anticipate, many companies have searched for ways to reduce such uncertainty.

Carriers can also leak from the system. A way to monitor this is to invest on tracking and tracing systems. Chapter 3 reviews incentive tools to persuade parties behaving in a desired way. A common incentive is to charge a deposit fee between the different parties in the chain, especially if the material has some intrinsic value. Each receiver must pay this fee to its supplier or a central party (see Lüstrenbach, 1993 for a review of systems for returnable carriers). Often, when multiple companies participate in such networks, there is a central organization that tracks the ownership of carriers and registers financial transactions. The deposit fee not only prevents items from being lost but it also provides a natural mechanism to motivate careful handling and therefore a minimum quality is ensured per returned item, as transactions have to be tracked.

Several international pools for pallets exist in Europe, like Deutsche Bahn (DB) and Chep. Many manufacturers supply their products on such pallets. In the case that the reusable packaging can be shared between different users, the benefits can sometimes be huge, since large savings can be achieved in the numbers needed (Koehorst et al., 1999). For this reason, in the Netherlands and in the UK food retailers have switched to reusable container systems (IGD, 2002). In food retailing, reusable crates are mostly used for product categories such as produce and chilled, where warehouse stocks are small and sales volumes are high. This means the crates are used intensively, reducing the cost per trip. However, wholesalers and retailers with many suppliers and different pallet types have considerable work in handling, sorting and storing pallets returned from their customers (retail organizations or stores). In the case of large return volumes, mechanization or automation may become economically attractive. Choices to be made are the degree of mechanization and the appropriate equipment for internal transport and storage.

Information Systems

One has to determine which information system is going to be used to register product returns. Kokinakki et al. (2004) examine the overall needs and existing supporting technology for managing information in the reverse logistics context.

Commercial software particularly designed for supporting return handling is lacking (Caldwell, 1999). The commonly used ERP packages generally lack the ability to properly deal with returns (De Kool, 2002). At this stage decision-makers may consider the in-house development of dedicated software. This has been the case at CTC and Estée Lauder (see Meyer, 1999). In the latter case, the specialized software system checks returns for expiration date and damages, speeding up return handling. Besides this, the software is linked to an automatic sorting system, which has lowered labor costs.

In general, the type and the horizon of information to be registered has to be determined, as well as how decisions with respect to returns can be supported. Also attention can be given to potential abusive returns (see Schmidt et al, 1999) and how this affects warehousing operations.

In the case of CTC, though law enforces accepting returns, returned merchandize is first checked and only then it is decided whether or not the client should be credited for it.

4.4.3 Short-term decisions

Inventory, storage, order picking, and vehicle planning and scheduling

When storing returns, this has to be planned in coordination with forward operations such as order picking and internal transport. In the case of CTC, it is crucial to put returns back in inventory timely to prevent stock-outs. Another aspect is the organization of the picking process. In the case of CTC no explicit priority is given to returned items over regular stock. There are, however, cases where priority to returns might be given (see Chapter 5).

The former discussion put together a decision framework of long-, medium-, and short-term warehousing decisions with respect to return handling.

Long-term decisions embrace facility design and outsourcing. At a more tactical level, one finds the topics of integrated operations, inventory management, internal (return) transport, and information systems. Within a shorter horizon, one has also the control of inventory and order picking, and the planning and scheduling of vehicles for internal transport.

The discussion tackled one topic at a time, but the complete framework has to be taken into account at any decision instant. Subsequent decisions are circumscribed by previous decision-making. E.g., the layout of a warehouse restricts the possibilities regarding order picking and storing. Or, if part of the warehouse is likely to be outsourced, the facility design should take this into account.

The remainder of this chapter brings into focus the available and potential models to support the decision-making process. To do so, we use the decision-framework to go over the existing models, and to identify opportunities for extensions. The decision-framework is also used in Chapter 5 to structure general recommendations to practitioners (see Section 5.6.1).

4.5 Models and research opportunities

Quantitative models on return handling are practically non-existent. This section puts forward the state-of-the-art on quantitative support for material handling expounding opportunities for return handling models. An early overview of the use of OR tools in material handling can be found in Matson and White (1982).

The list of the main research areas in warehousing with respect to return handling can be drawn from the previous section (see also Van den Berg and Zijm, 1999). For information systems for return handling, see Kokkinaki et al., 2004. Models for the remainder of the topics are now discussed. For a more detailed discussion, see De Brito and De Koster (2004).

4.5.1 Long-term decisions

Facility layout and design

A successful research area is facility layout. A well-known approach is Muther's (1973) Systematic Layout Planning concept, for which many improvement algorithms are known (see Tompkins et al., 1996; Bozer et al, 1994; and Goetschalckx, 1992). The major objective in the underlying models is to minimize the total cost of daily transport between the different areas in the facility. For some facility types special layout models have been developed with the reduction of travel time as primary objective (Bartholdi and Gue, 2000; and Roodbergen, 2001).

An important shortcoming in the models is that many other relevant restrictions and objectives are not taken into account, such as congestion reduction. The models and solution methods can be applied straightforwardly to facilities with return flows and handling areas. The existence of dedicated areas to returns do not have to change the models fundamentally. However, it is important to incorporate returns operations from the start in layout decisions, since the solutions may change dramatically when compared to a situation without returns (think of crossing flows, or travel distances). It would be interesting to study the impact that taking into account returns has on layout. This is a topic that has not received attention from researchers so far.

Outsourcing

Literature on process outsourcing is mostly of a qualitative or quantitative empirical nature. Although much literature deals with outsourcing of warehousing and transport to logistics service providers (see for example Rabinovich et al., 1999; Van Laarhoven et al., 2000), academics have not thoroughly addressed the outsourcing decision of return handling so far. Among the exceptions are the works by Krumwiede and Sheu (2002) and Meade and Sarkis (2002). In the first, a model is presented to aid third-party logistics providers to decide whether, or not, to enter the reverse logistics market. Meade and Sarkis (2002) address the selection of third-party logistics providers. The authors claim that the factors to take into account when selecting a third-party reverse logistics provider, differ from traditional factors for supplier choice.

Table 4.2: Research opportunities for long-term decisions

	Research opportunity	**Supporting literature**
Facility layout and design	To extend the models for Systematic Layout Planning (SLP)	SLP models: Tompkins et al., 1996; Bozer et al., 1994; Goetschalckx, 1992; Bartholdi and Gue, 2000; Roodbergen, 2001
Outsourcing	To intensify research in this area	Krumwiede and Sheu, 2002; Meade and Sarkis, 2002

Table 4.2 summarizes the research opportunities for long-term decisions and the literature that can be of support.

4.5.2 Medium-term decisions

Integrating operations: return policy

Distant sellers and other retailers usually accept merchandize back up to a number of weeks after delivery or purchase. CTC puts the threshold at about two weeks and does not charge the client for returns. In practice, we find various charging schemes including partial refundable costs. Schemes to charge returns and some of the associated dilemmas have been studied in the literature, like how to control opportunistic returns (see Hess et al., 1996). Researchers have established relations between return policies and a number of elements, among which: salvage value (Davis et al., 1995 and 1998, Emmons et al., 1998), mismatching probabilities (Davis et al., 1995; Hess et al., 1996), speed of consumption (Davis et al., 1998), product's value to the consumer (Davis et al., 1995; Hess et al., 1996), and product's quality (Moorthy and Srinivasan, 1995; Wood, 2001).

However, factors like the maximum contractual return period have not always been explicitly involved in the discussion. In environments where the customer is entitled by law to return merchandize free of charge (see Office of Fair Trading, 2003), the freedom the retailer has is on fixing the contractual return period together with the shipping and returning charges, and price, as follows:

- t, maximum contractual return period,
- p, price of the product,
- c_{sc}, shipping charges, and
- c_{rc}, returning charges.

The *utility function of the retailer*, here named U_r, is a function of additional factors, like:

- c_h, handling/warehousing costs,
- c_{rh}, return handling costs,
- x, quantity shipped, and
- y, quantity returned,

For the retailer, the decision variables are t, c_{sc}, c_{rc} and p, while c_h, c_{rh} are input variables, and x and y are output variables.

The *utility functions of customers* i= 1,..., m, here identified as u_i will depend of factors, such as:

- p, price of the product,
- t, maximum contractual return period,
- q, quality of the product,
- c_{sc}, shipping charges,
- c_{rc}, returning charges.

Naturally, customers will mostly prefer low prices, a long return period, high quality products, and low shipping charges. Based on these factors, each customer i decides on

- x_i, the quantity ordered by client i, and
- y_i, the quantity returned by client i.

All the actors involved intend to maximize their utility function. The retailer is the leader as he/she sets *a priori* some of the parameters, such as t, p, c_{sc} and c_{rc}. In turn, customers will react to the values of these parameters and maximize their utilities.

The problem can be written in the following general form:

$$\max_{p,t,c_{sc},c_{rc}} \quad U_r(p, t, c_{sc}, c_{rc}; y, x, c_h, c_{rh})$$

s.t.

$$y = sum_{i=1}^{m} argmax\ u_i(y_i; p, t, x_i, q, c_{sc}, c_{rc})$$
$$x = sum_{i=1}^{m} argmax\ u_i(x_i; p, t, y_i, q, c_{sc}, c_{rc})$$
$$x_i \leq y_i$$

Summing up, for a given strategy that the retailer may choose, customers will have a 'best' strategy to follow. The retailer has to anticipate these reactions while setting the decision variables.

The aforementioned model gives a holistic approach to return policies by giving plenty of room to incorporate multiple critical factors. The format of the problem resembles a Mathematical Programming problem with Equilibrium Constraints (MPEC), see Luo et al., 1996.

The MPEC is closely linked to the Stackelberg game-theoretical models (see e.g. Debo et al., 2004 on coordination of closed-loop supply chains). Solving the MPEC, demands first proper estimation of the utility functions and inherent relations between individual factors. The following literature on return policies can assist on this. The model by Hess et al. (1996) comprises price, the value that the product has to the consumer, and the shipping costs. The authors infer from the results that the seller has an incentive to set a non-refundable charge to avoid opportunistic behavior and that higher prices will have higher non-refundable charges. Moorthy and Srinivasan (1995) investigate the role of return policies in signaling quality (e.g. customers may associate *a priori* high quality products with tolerant product policies). The authors consider the following variables: price, matching probability (between customer's wishes and product), depending on quality and various costs both for the retailer and for the costumer. Somewhat opposed to Hess et al. (1996)'s point of view, Moorthy and Srinivasan (1995) suggest that high quality sellers (in principle associated with high prices) should consider taking up buyer's transaction costs. This puts into evidence the need for more research in this area. Davis et al. (1998) have specifically computed the optimal level of 'hassle' for return policies. They included factors such as the trial value of the product. They concluded that a retailer tends to offer a low-hassle return policy when the product cannot be consumed during the trial period, when there are opportunities of cross-selling, and the returned merchandize has high salvage value. Though in these references, the maximum contractual return period has not been included as a decision variable, the references are still helpful to draw relations between other variables.

Furthermore experiences similarly to the ones described by Wood (2001) can be conducted to tune the parameters' relations. Wood (2001) carried out experiences with undergraduate students for two types of return policies: lenient vs. restricted. The author examined the deliberation time for the decisions of 1) order, and 2) keep-or-return. The author further examines the consumer's evaluation of quality and the likelihood of continued search while waiting for the product. The study shows that continued search is more probable in the case of restricted policies rather than lenient policies. One can judge this to be contradictory. Yet, the author explains it by defending that product ownership is more a perception than the factual possession.

Concluding, the point is that setting a return policy is a complex matter because of the many hidden elements that can influence profitability. Quantitative support on the topic is more than welcome.

Integrated operations: reusable packaging

In order to determine economic benefits, the needed number of reusable packages and the distribution over the network has to be determined. Kroon and Vrijens (1995) and Duhaime et al. (2000) use respectively a location-allocation and a minimum-cost-flow model to minimize the empty reusable packaging. To determine the environmental impact of reusable crates, Life Cycle Analysis (LCA) can be used (see Pappis et al., 2004 and Bloemhof-Ruwaard et al., 2004). For every process (production, handling, transport) or material usage the impact on the environment (for example global warming or acidification) can be established by calculating the emissions of different components. It is still necessary to choose one of the existing methods to calculate these emissions. *A priori* there is no "best method" as its appropriateness depends on the production cycle, the transport technologies, the country, and so on.

Inventory Management

If return rates are high, such as in distant selling businesses, it becomes necessary to manage return stocks explicitly. One can also look at this from a completely different perspective: remote sellers are overselling to customers that return merchandize (and possibly underselling to customers that do not return merchandize).

One can think about making two categories of customers: the ones that (systematically) return merchandize vs. the ones that do not. Or better, to discriminate between less and more profitable customers taking into account purchased and returned merchandize.

The above is an obvious simplification of reality since many other categories can be distinguished. For instance, catalog companies carry large amounts of historical customer data that can be employed to draw the profile of each customer class.

Existing inventory models with priority customers can be stretched to this new application (see Kleijn and Dekker, 1999). Research has showed that '... in some cases it is optimal to ... reserve inventory for possible orders from higher-margin customers' (Cattani and Souza, 2003). In other words, it may be optimal to reserve inventory for customers that do not systematically return merchandize. This nurtures confidence in the opportunities that this sort of models can offer to retailers like catalog companies. Return-handling costs can be explicitly utilized to draw the line between the two classes. In this way, return-handling costs are plugged in explicitly, bringing more realism to inventory management with product returns.

There are many other issues on inventory management with product returns for instance in remanufacturing settings. Recent reviews can be found in Dekker et al. (2004).

Internal (return) transportation

Operations Research models (stochastic models, mixed-integer linear programming models or simulation) can be applied successfully in the evaluation of material handling systems, in particular estimating the number and type of vehicles needed. By comparing multiple scenarios, with multiple types of material handling systems, an evaluation of the best system can be made. The underlying models try to determine the number of vehicles of a certain type in a certain facility. Examples are the evaluation of single-load versus multiple load vehicles (Van der Meer, 2000), or lifting versus non-lifting vehicles (Vis, 2002). Other, related, design areas are vehicle transport track design, choice of pick-up and delivery points, design of deadlock-free tracks, track claim design, or design of battery loading areas. The paper by Goetz and Egbelu (1990) is an example. Material handling systems used for both forward and return flows may have to meet different requirements. Depending on the return volume, separate systems may be needed, that are better fit for return handling.

Information systems

On this we refer to Kokkinaki et al. (2004).

Table 4.3: Research opportunities for medium-term decisions.

	Research opportunity	Supporting literature
Integrated operations: return policy	To model this as the Mathematical Programming problem with Equilibrium constraints (MPEC)	- MPEC: Luo et. al, 1996 - models on relations between key variables: Hess et al., 1996; Moorthy and Srinivasan, 1995; Hess et al., 1996; Moorthy and Srinivasan, 1995; Davis et al., 1998; - empirical evidence on relation between key variables: Wood, 2001
Integrated operations: reusable packaging	Life Cycle Analysis (LCA) and Eco-eco Models	- Operations Research models: Kroon and Vrijens, 1995; Duhaime et al. (2000) - LCA models: Pappis et al., 2004; Bloemhof-Ruwaard et al., 2004
Inventory Management	To model two classes of customers: less and more profitable taking into account purchased and *returned* merchandize.	- Inventory Management with priority customers: Kleijn and Dekker, 1999; Cattani and Souza, 2003
Internal (return) transportation	To employ returns explicitly in existing models	- evaluation of material handling systems: Van der Meer, 2000; Vis, 2002; Goetz and Egbelu, 1990
Information systems	see Kokkinaki et al., 2004	

Table 4.3 summarizes the research opportunities and the literature that can be supportive for medium-term decisions.

4.5.3 Short-term decisions

Inventory, storage and order picking models

This topic includes particular problems within warehouses, such as order batching, order picking, routing pickers in a warehouse, warehouse zoning (dividing a picking area in zones to achieve certain objectives), product storage allocation, forward versus reserve storage area decisions.

Many papers deal with warehouse planning and control. There are several overview papers in this area; recent ones are by Van den Berg (1999), Rouwenhorst et al. (2000) and Wäscher (2002). The following topics have been addressed in Operations Research literature: product to storage allocation, Heskett (1963); order batching, wave picking, De Koster et al. (1999); routing order pickers in a warehouse, Roodbergen (2001); warehouse zoning, worker balancing, De Koster (1994); Bartholdi and Eisenstein (1996); and Bartholdi et al. (1999); forward - reserve problem, Hackman and Platzman (1990); pallet or container loading, Coffman et al. (2000).

All these topics are strongly interdependent in their impact on warehouse performance (e.g. order through time). There is some literature on combinations of these above-mentioned problems (see Gademann et al., 2001; and Roodbergen, 2001). Recently, storage and routing received some more attention (see, for example, Dekker et al. 2002).

Currently, no models exist that explicitly include return flows. Here is a list of relevant issues that should have priority:

- Whether or not to set-up separate storage areas for returns, or to consolidate them with existing stock. Return volume seems to be a decisive factor, as it is concluded in Chapter 5: above a threshold, returns are going to be dealt with in a separate area. Quantitative models can bring insight on what is missing: for instance to identify where the threshold is. The trade-off is in the size of the storage area and order pick travel time, but also in the cost of a warehouse of increased size. Storing returns on separate locations may save time in storage, but potentially requires more space, which in turn increases pick times.

- How long to buffer product returns before consolidating them on stock? Important factors that play a role in such decision are the quantity, variety and timing of the returned items. The larger the stored batch size is, the more efficient the storage process becomes, while on the other hand the buffer space may become overcrowded and the stock is not available in time.

- Storing returns versus order picking: how to sequence and route both return storage with order picking? In many occasions, return job scheduling issues play a role, since picks can only be carried out when the (returned) products are at their location (this is the case at CTC, see section 4.3). On the other hand picks are much more urgent, because of due times for shipment. This problem has received no attention from researchers so far.

Vehicle planning and scheduling

A large part of the literature on material handling equipment covers planning and control issues of unit-load automated storage and retrieval systems, i.e. AS/RS (see Bozer and White, 1984; Bozer and White, 1984, 1990; and Hausman et al., 1976).

Another large group of papers is on planning and control of automated guided vehicle (AGV) systems. These internal transport systems are suited to work in highly dynamic, where the horizon over which information is available of loads that need transportation is usually short. On a slightly longer horizon, information may be known in advance, but is uncertain. Load arrivals are stochastic and also transportation times are stochastic, due to congestion and intersection control policies.

The following activities have to be carried out by a controller of the system: dispatching of vehicles to pick up certain loads, selecting the route, scheduling the vehicle, and dispatching vehicles to parking positions. When returns are involved, the planning and scheduling of such material handling equipment will change. Returns can be modelled as another type of (storage or transport) job that has to be carried out. However, particular-sequencing restrictions will apply. For example storage jobs resulting from returns must be carried out prior to retrieval jobs. Or, for unit load handling machines, it must be attempted to combine jobs in a double play to increase machine utilization. Vis (2002) has developed a new control concept to schedule storage and retrieval for a unite load AS/RS working in multiple aisles. Unit loads are for instance pallets. However, this does not apply necessarily to the situation of returns as products are mostly returned item by item (or at least in small quantities). Products in small quantities are normally stored or retrieved by a worker travelling with proper equipment. As Vis (2002) describes, in this case retrieval and storage requests are not combined.

Table 4.4: Research opportunities for short-term decisions

	Research opportunity	Supporting literature
Inventory, storage and order picking models	- to investigate whether, or not to separate storage areas	Chapter 5
	- to investigate how long buffer product returns	(not explicit)
	- storing returns vs. order picking	(not explicit)
Vehicle planning and scheduling	To extend Automated Storage/ Retrieval Systems (AS/RS) models	Bozer and White, 1984; Bozer and White, 1984, 1990; Hausman et al., 1976; Iris, 2002

Table 4.4 summarizes the research opportunities and the literature that can be supportive for short-term decisions.

In conclusion, there is a shortage of quantitative models to support return handling decisions. At the same time, there are many opportunities to extend existing forward models or to initiate new research paradigms. Presumably, these quantitative models will not be straightforward and more has to be learned on return processes before they can be developed and implemented successfully.

4.6 Summary and conclusions

Handling return flows involves unique processes such as collection, inspection, selecting, sorting, and recovery (see also Chapter 2). This demands additional decisions on a larger number of issues.

This chapter served the following purposes:

- to put together a decision-framework for return handling, and
- to identify potential models to support the decision-making process.

The decision-making framework for return handling was organized from long- to short-term decisions, as follows.

- Long-term decisions

  - facility layout & design
  - outsourcing

- Medium-term decisions

  - integrating operations (return policy and reusable packaging)
  - inventory management
  - internal (return) transport
  - information systems

- Short-term decisions

  - inventory, storage and order picking control
  - vehicle planning and scheduling

Note that the decisions cannot be taken in isolation, because the many interdependencies.

Explicit models, to support the return handling decision-making process in the warehouse, have been largely ignored up to now. For a number of research areas, we highlighted in Section 4.5 how forward models can be extended, or how new models can be launched, to include return handling. We identified several research gaps that can be turned into a research agenda, as described next.

- Which impact do return flows have respectively on:

  - the warehouse layout;
  - material handling systems (e.g., whether dedicated return handling systems do pay off);
  - storage and picking procedures (ex. route combination of returns' storage and pick ups).

Furthermore we suggested the use of the MPEC formulation to e.g. help retailers deciding upon the return policy.

A new direction to inventory modelling was also put forward as by categorizing customers in two classes, i.e. less and more profitable depending on whether, or not, the customer (systematically) returns merchandize.

The environment that surrounds forward and return operations today should also have a place in academic research. To mention only two: packaging legislation in the European Union and e-commerce. It is a fact that packaging waste regulation has kindled research interest on material recovery. The impact of packaging legislation, both standardization and reuse, on present warehousing operations has however not been thoroughly investigated. Regarding e-commerce, it is well known that fairly tolerant return policies have impact on return flows (see Piron and Young, 2000). Yet, the impact on warehouse operations still lacks investigation.

Most likely some of the ideas for future research laid down here are not straightforwardly carried out. We believe that learning more about the practice of return handling can subtract some of the modelling difficulties. Not only quantitative models are needed, but in order to implement it successfully, more qualitative, or empirical approaches are necessary. For example, research towards best practices may help decision makers to come up with solutions for sorting, buffering, and storage. By conducting simultaneous desk and field research, quantitative models will plausibly aid on real return handling decision-making.

Concluding, the handling of return flows is not as the usual handling of forward flows coming into the warehouse. This was illustrated with an example in Section 4.3 and further discussed in Section 4.4. It involves other processes than forward logistics, thus it involves additional decisions that call for explicit decision-making support tools.

Furthermore, the interactions between forward flows and return flows should also be taken into account in future research. Chapter 5 takes a first step in this direction, by analyzing the specific decisions of combining vs. separating forward and reverse flows during transport, receipt, and storage.

Chapter 5

Return Handling: an exploratory study

We shall never cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time

T. S. Eliot

5.1 Introduction

According to the Material Handling Industry of America (MHIA, 2002), material handling is the movement, storage, control and protection of material, goods and products throughout the process of manufacturing, warehousing, consumption and disposal. The focus is on the methods, mechanical equipment, systems and related controls used to achieve these functions, usually internal, within the company (see, for example, Tompkins et al., 1996). According to research of ELA (1999), 7.7% of the expenses of 500 interviewed European companies consists of logistics costs, of which 2% is in warehousing and 3.1% is in transport (1.2% administration and 1.4% inventory costs).

Return handling is even more costly. In some businesses return rates can be over 20% (for example in the catalogue industry and online sales), and returns can be especially costly when not handled properly (see Meyer, 1999 and Morphy, 2001). As reported by O'Neill and Chu (2001), Forrester Research concludes that in 1999 the value of returned goods purchased online was 600 million US dollars, and the cost of processing them was $468 million. On top of this, this year, these numbers are likely to augment steeply.

Return flows affect all the actors in the supply chain. Figure 5.1 illustrates those flows, where the flows with origin at the consumer are represented in more detail. Used products may enter the reverse chain when collected to be repaired, refurbished, remanufactured or recycled (see Chapter 2 for more on recovery options). Next to used products, packaging and waste are sometimes moved upstream between the chain actors. In addition, take-back agreements between parties result in reverse flows of non-used products. The focus of this chapter will be on retail logistics. In this case the reverse flows are *mainly* due to commercial agreements or obligations towards suppliers or customers, i.e, *B2B* and *B2C commercial returns* (see the framework in Chapter 2).

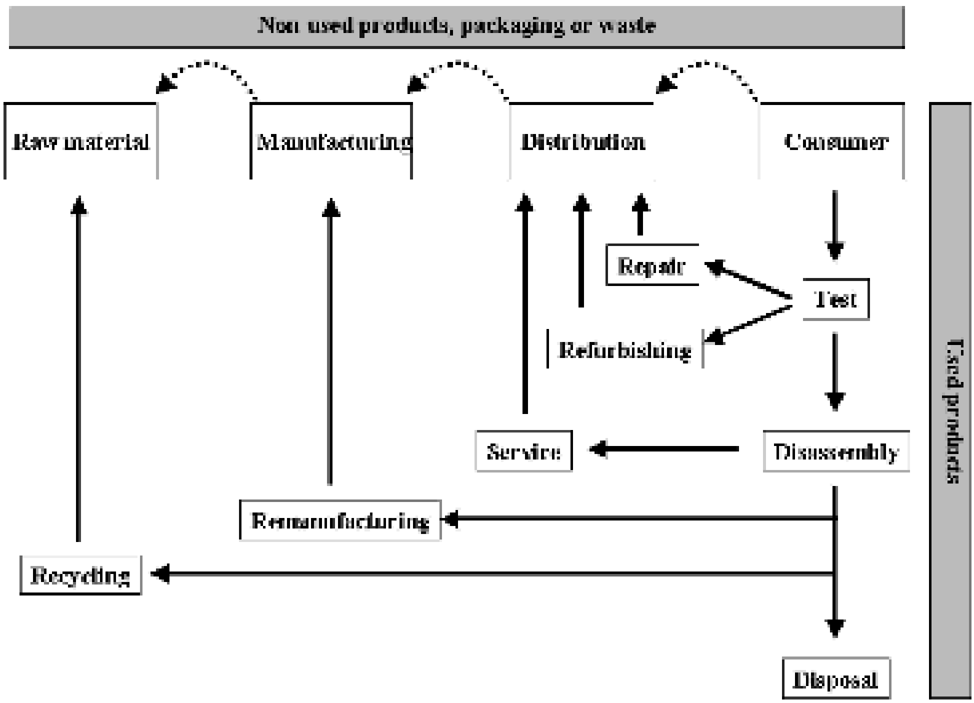


Figure 5.1: Reverse flows in the supply chain.

The systematic study of return flows has gained increasing attention, either with respect to manufacturing or retail logistics (see RevLog, 2003). In spite of all the literature dedicated to return flows (see Chapter 1), the details of retail return operations and financial aspects of storage, handling and transportation have been overlooked. Some exceptions are the studies by Beullens et al. (1998), Dethloff (2001) and Beullens et al. (2004). These contributions are in the area of vehicle routing when both forward and reverse flows are taken into account. Yet, in the retail environment, the studies are practically absent. As put by Tibben-Lembke and Rogers (2002): "Although much has been written about many specific aspects of reverse logistics, or specific activities, the collection and disposition of reverse logistic product, in the retail context have been largely ignored." Tibben-Lembke and Rogers (2002) provide an overview of overall differences between forward and reverse logistics for retailers. The authors remark that the reverse process is less transparent and accordingly reverse logistics costs are less visible than in forward logistics.

In this chapter we consider the handling of return flows and its relation with forward logistics. The factors contributing to the decision whether or not to combine inbound and outbound flows during the handling process of product returns are investigated. That is done by comparing nine retailer warehouses. This leads to the identification of key factors contributing to the different practices. The analysis brings further insights about the complicating issues, possible simplifying solutions and practical implications. Finally, propositions are put forward feeding future studies on return handling efficiency. The analysis and results were reported in De Koster, De Brito and Van Vendel (2002).

The remainder of the chapter is structured in the following way. Section 5.2 reports relevant operational issues regarding the handling of returns. Subsequently, Section 5.3 presents the cases and the methodology. After that, Section 5.4 analysis the nine case studies and compares them. The discussion and implications are put forward in 5.5, and Section 5.6 is dedicated to overall conclusions, recommendations for practice and research opportunities.

5.2 Handling returns

Not only the product itself but also the product carrier (pallet, roll cage, etc.) and packaging materials may go back and enter again the supply chain constituting thus reverse flows. Therefore, handling returns may involve dealing with a variety of products, as well as a variety of packaging materials. Furthermore, products may return before use due to commercial agreements or after use at the end of the life cycle. The former, also known as B2C commercial returns and reimbursement returns (see the framework in Chapter 2), are not always saleable at the original price, but in many situations these are new products that can be put again in stock (see De Brito and Dekker, 2003). End-of-life returns, mainly a consequence of environmental legislation steadily increasing in the European Union, may later be reused, remanufactured, recycled, or properly disposed. In this chapter, end-of-life returns are not considered since they are currently negligible for the retailers in question. For further information on end-of-life return handling issues, see De Koster et al. (2000).

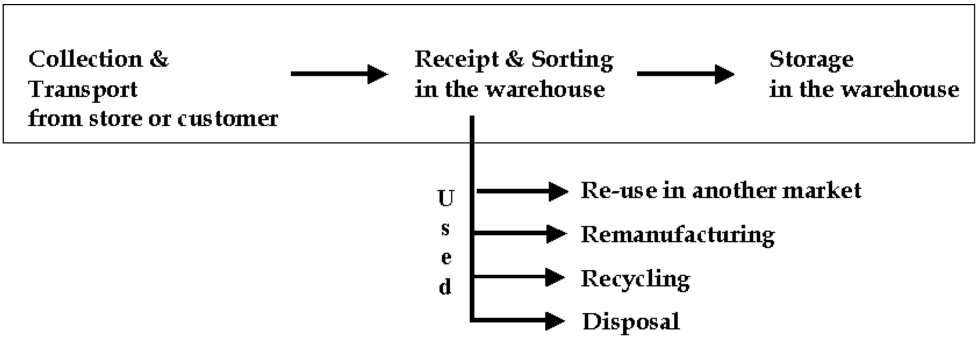


Figure 5.2: The process of handling returns.

In order to handle returns in practice, several decisions about the logistics process of the returned products have to be taken. The *focus* here is on the decision whether or not to combine forward and reverse flows during the return handling process. In addition, and when appropriate, we comment on related warehousing decisions (see Chapter 4).

Figure 5.2 exhibits the three stages of this process, as considered in this chapter:

- Collection & transport to the warehouse
- Receipt & sorting in the warehouse
- Storage in the warehouse

In the first stage companies have to decide if they are going to simultaneously pick up returns and distribute new goods. The trade-off here is between the exploitation of existing resources (trucks, route planning) and the increase of complexity (e.g. new and returned products sharing truck capacity). Later, returned products have to be received and sorted at the warehouse. In this second stage, consisting of receipt and sorting, companies have to decide whether or not these operations are to be done in the same area/facility where procured products are handled. Finally, in the third stage products in good condition are put back in inventory to be sold again (a common practice in several businesses).

The decision on combining vs. splitting reverse and forward flows, is looked at from two perspectives: *i)* the physical storage and *ii)* the registration of information in the management system. In general terms, firms have to decide if they will use the same facilities and network structures to handle both the forward and the return flow of products. This may imply additional transport, space, or even buildings and specialized labor requirements. Moreover, all these decisions are subordinated to the overall objectives of the company such as minimizing costs, providing a high service level and keeping high controllability of operations. The different stages of handling returns are the central aspects of the case study analysis. The next section considers the case study methodology.

5.3 The case studies: brief description and design

The cases comprise the handling of returns in warehouses of three lines of businesses: food stores, non-food store chains and mail order companies. All of these are mature industries that deal with returns on a daily basis. In total nine retailer warehouses were considered, three per industry branch allowing inter- and intra-industry comparison.

Food retailing is a business with large volumes and small profits. The margin in the Netherlands is about 1% to 2% per item (see De Koster and Neuteboom, 2001). The three food retailers studied, identified as FR1, FR2, FR3, have full line warehouses. This means that the full line of products is stored in the warehouse, and is supplied via the warehouse to the supermarkets.

The non-food store chains are here called SC1, SC2 and SC3. They are all large non-food store chains in the Netherlands. SC2 and SC3 are the largest department stores. SC1 is a large speciality retailer in sports apparel and accessories.

Finally, the mail order companies labelled as MO1, MO2 and MO3 are the largest mail order companies in the Netherlands. Customers usually order from catalogues, which are freely distributed. Nevertheless, the Internet is also increasing its role as a market channel. As case candidates the main players in the Netherlands were elected.

In the case of food-retailers however, also all national players have full-line regional warehouses with assortment and sizes comparable to regional players (see De Koster and Neuteboom, 2001). Thus, for this study of warehouse operations, it is indifferent to choose national or regional players in the food sector.

In the first stage of the methodology design, more companies were contacted by phone in order to evaluate the feasibility of the research. Data availability and willingness to cooperate during the planned research period were decisive factors on whether, or not, to include a concrete case in this study. In total nine retailer warehouses became suitable for research. In addition to detailed interviews at each distribution center with logistic and other specialist managers, field surveys were carried out on site to gain an appreciation of the issues involved. After that, phone calls followed to clarify aspects when necessary. Subsequently, interviewees had the opportunity to check the information collected. The field research took place in 1999/2000. Information about the handling process (transport, receipt and storage regarding each warehouse) was gathered.

In addition and to facilitate the understanding of the conditions in which decisions are taken, the following additional data was collected: type of product and materials being returned (*what-type*, see Chapter 2), return policy, and return volume. Moreover, an estimative of the space and manpower assigned to return handling, as well as the associated costs are given. This data will help as a criteria to evaluate the performance of the retailers, with respect to return handling (see 5.5). Below we list all the elements.

Contextual factors

- Type of returned product or material (goods, carriers, materials)
- Return policy (time and other constraints)
- Return volume (per return flow, and compared with total outgoing flow)

The process

(focus: separation vs. combination of reverse and forward flows)

- Transport (combined vs. separated; also: self-executed or not)
- Receipt (combined vs. separated; also: automated vs. manual handling)

- Storage (combined vs. separated)

Manpower, space and associated costs

- Manpower during receipt and storage (amount of labor dedicated to return handling)
- Space for receipt and storage (the area devoted to return handling)
- Personnel and space investment

The costs of stocking and handling returns were estimated on the basis of the space used for return handling and storage processes. The estimation was carried out as follows. In the case there were areas dedicated to returns, these areas were simply measured. The same was done when return storage was combined with outbound storage. Next, the yearly facility costs for returns were obtained by depreciating the total investment costs of the facility in 30 years and taking a part of this amount proportional to the space for returns. In addition, personnel costs were considered, with an average of approximately 27,300 annual euros per employee (this is an estimated value based on the salaries in the Netherlands, 2002). These are not the total costs of handling returns, since transportation costs and inventory holding costs are not included. However, building/renting the warehouse and manpower costs represent the large slice of total costs (presumably above 50% and 25% respectively, see De Koster, 1996). In addition, substantial investments in information systems for returns usually have to be made (Olsen, 2000; Linton and Jonhston, 2000), which have a much shorter depreciation period than 30 years. Finally, it is very difficult to include costs of internal transportation personnel (for instance forklift truck drivers), since they are not solely dedicated to return handling. In the next section and for clarity purposes, information on other particularities, retailer specific, or directly related to the handling of product returns is added.

5.4 The case studies: analysis and comparison

5.4.1 Contextual factors

Food retailers

Among the three investigated food retailers, FR3 is active in the whole country, while FR1 and FR2 operate at a regional scale. A variety of *consumer* *goods*, from dry groceries, dairy products, beverage and meat, to vegetables, fruit, and frozen products have to be stored in the warehouse.

FR1 has one central distribution center (DC). The national market share is about 2%, and the 30 supermarkets are served from the DC. The supermarkets are totally owned and exploited by the FR1 organization. The majority of the 8,000- 9,000 stock keeping units (SKUs) are mainly shipped to the 30 supermarkets via the DC. Fresh dairy products, bread and cheese are directly shipped from the suppliers. The distribution center of FR1 deals with the following *what-type* of returns: *i*) consumer goods (supermarket stock), *ii*) distribution items (various carriers such as roll cages, crates, pallets), *iii)* other (waste) materials (such as paper and plastic).

The food retailer FR2 is also a regional chain with a single DC. The national market share is 1.4% and the 30 supermarkets are served from the DC, including the bread and the meat that are manufactured in in-house integrated factories. In total, this supermarket organization deals with about 11,000 SKUs. FR2 deals with return types identical to FR1 i.e. products, different carriers and other (waste) materials. The warehouse has two buildings, one for cold store, return handling and waste, and the other for the remaining activities including bread and a meat factory. The food retailer FR2 deals with the same type of returns as FR1 (see previous paragraph).

FR3 is actually a wholesaler with about 500 franchised supermarkets, for which the operations of storage and distribution are similar to those of FR1 and FR2. The national market share is 10.6% with an assortment of 12,000 products including tobacco and cosmetics. FR3 has several warehouses. For this study, the newest warehouse is considered, from which 134 supermarkets are served. FR3 receives back few products and little waste material because the supermarkets are responsible for disposing the packaging materials and waste. If the supermarkets wish the DC to handle it, they have to pay for it. Therefore, the returns are mainly product carriers. The warehouse has a two-floor structure, with the top floor dedicated to freeze and cold storage.

Table 5.1. shows quantitative data concerning the return flows (expressed in roll cages) at the three food retailers. It is clear that the majority of returns at the food retailers consist of empty carriers, e.g. empty roll cages and crates (more than 60% of the returns in all cases). Actually, almost all returns at FR3 are empty carriers because independent entrepreneurs have to pay if they want the DC to handle their returns. Materials (like paper and plastic) and waste handling is significant only at FR1 and FR2, both having a policy to centrally collect and handle returns and waste. Furthermore, at all food retailers, FR1, FR2 and FR3, return products have to be authorized to obtain money restitution (see Chapter 4 on integrating operations, medium-

Table 5.1: Outgoing and return flows (in roll cages, per week) at the food retailers.

Description	FR1		FR2		FR3	
Outgoing flow	17,000		14,950		28,000	
Returned						
distribution items	6,500	38%	5,600	37%	8,400	30%
other materials	4,000	24%	3,000	20%	255	0.9%
consumer products	100	1%	100	1%	20	0.1%
Total returns	10,600	63%	8,700	58%	8,675	31%

term decisions).

Non-food store chains

SC1 is part of a European retail organization with five different store chains in the Benelux in the shoe and sports sector. There are three shoe store chains, with 87, 40 and 65 stores respectively. The two sports chains have 30 and 16 stores respectively. All the stores are served from the central warehouse studied in this chapter. The assortment is about 4,000 articles. However, when size and color are included, there are about 20,000 SKUs of *consumer goods*, divided in the categories men's, women's, children's and sports shoes and clothing, and accessories.

SC2 is a chain of seven large department stores in The Netherlands in the luxury market segment. The assortment consists of *consumer goods* such as shoes, clothing, white and brown goods, books, CDs etc. (about 300,000 SKUs, changing constantly). All stores are delivered 1 to 3 times a day from the central warehouse. On average, there are 30,000 SKUs in storage, half of which consist of fashionable clothing, which have a short selling life.

SC3 is a chain of 66 department stores in The Netherlands, with *consumer goods* such as clothing, shoes, white and brown goods, books, CDs etc. The total assortment consists of about 200,000 SKUs (not all on stock). The stores are replenished at least once a day from one of the four warehouses. All warehouses carry a different part of the assortment. In this chapter the central warehouse is studied. The assortment consists of fashionable clothing, books and media products and is responsible for 50% of total revenues.

The three distribution operations are therefore broadly comparable. They all serve own stores with a fairly similar assortment and a large number of SKUs on average on stock, although the total assortment of SC2 and SC3 is much larger than that of SC1. The other difference between SC1 and the

Table 5.2: Outgoing and return flows (in roll cages, per year) at SC1, SC2 and SC3.

Description	SC1		SC2		SC3	
Outgoing flow	4,500,000		18,000,000		55,000,000	
Total returns	630,000	14%	1,700,000	9.4%	4,000,000	7.3%

other two retailers is that SC1 does not have hanging garments. For the other two retailers this requires special storage and handling systems such as overhead conveyors (see Chapter 4, on warehousing internal transportation, medium-term decisions). The main return decision is taken centrally by the DC, giving the DC more control over the returns (see Chapter 4 on integrating operations, medium-term decisions). For instance, the DC may decide that packaging material is returned on Thursdays, product returns on another day and so on. SC1 tries actively to find the best sales outlet for the products and reallocates products to different stores. These are special *stock adjustments*, which sometimes in practice are referred as to condensation returns. All the DC's have considerable amounts of product returns, varying between 7.3% to 14% of outgoing flows (Table 5.2).

Mail order companies

Customers can order by mail, phone, fax, or internet and can return the merchandize without any obligations up to four weeks after receipt.

MO1 is a US company that trades in exclusive *consumer goods* for collectors, such as miniature cars, dolls, porcelain and jewels. The European Distribution Center is investigated, from which all customers in Europe are delivered, usually by national post organizations (PO). Products are shipped from the DC to hubs of these PO's in Europe. The assortment is about 10,000 SKUs, the return time limit is 30 days. About 7,000 products are shipped per day. This is approximately 7,000 customer orders. Besides the products themselves, product certificates have to be included, as well as leaflets.

MO2 is a home shopping company, with a wide assortment of *consumer goods*. The company has two DCs. The DC studied here carries hanging garments, small household appliances and small technical products, about 10,000 SKUs in total. Products are shipped via parcel carriers, in total 10 million units per year and 25,000 orders per day (on average, in 1995). The return time frontier is 1 week.

MO3 is a German mail order company. The Dutch DC ships to customers in The Netherlands and Belgium. The assortment of this DC consists mainly of small household appliances and clothing. Registered customers receive a catalogue twice a year. The maximum allowed time in which customers may return products is 2 weeks.

Product return flows are about 10%, 30% and 25% of the outgoing flow respectively for MO1, MO2 and MO3. Apparently, all mail order companies accept all returns and customers are usually credited (see Chapter 4 on integrating operations, medium-term decisions).

Table 5.3 summarizes the aforementioned information regarding the return type and policy of the nine retailers.

5.4.2 The process

Food retailers

FR1 uses small swap bodies with cooling capacity for transport between the DC and the stores several times per day. Transport is self-executed. After dropping off a full swap body at the store, the truck picks up the previous swap body, which is now loaded with returns, and transports it to the DC. All returns are *received for inspection in a separate zone* of the shipping area. After inspection, products are sorted and separated.

A third party will subsequently discard products in poor state, paper, bread, vegetables and other material waste. Product carriers are sorted manually and dispatched to separate storage areas (there are separate areas for the distribution items, like empty roll cages, empty crates, and empty pallets). Products as-good-as-new are manually put back in the inventory together with the procured products.

All packaging material and waste generated in the supermarkets is centrally collected at the DC, for scale advantage (see Stock, 2001).

Trailers are used to transport to and from the supermarkets in the case of FR2. Although there are 4 deliveries per day, supermarkets can only return twice a week. This has to do with the fact that returns are only picked up at the last supermarket in each route with 2 or 3 supermarkets.

Returned products are *received in a separate zone* of the second building, while returned carriers are received at both buildings. Carriers will then be inspected in separate zones of each of the buildings. The integrated bakery and butchery handle respectively bread and meat waste. Other waste materials are handled by third parties. Products in an as-good-as-new state go back to inventory. The collection of packaging material and waste is centralized at the DC.

FR3 self-executes the transport by means of trailers, many with three

Table 5.3: Return type and policy at nine retailers.

Return type and policy		
FR1	**FR2**	**FR3**
Consumer products, different carriers, and other (waste) materials	Consumer products, different carriers, and other (waste) materials	Few consumer products and little waste material. Mainly distribution items (empty carriers)
Central collection of packaging materials and waste at DC	Central collection of packaging materials and waste at DC	Supermarkets are responsible to dispose packaging materials and waste. They have to pay if they want DC to collect their waste
Product returns have to be first authorized so a money restitution can follow (see Chapter 4 on integrating operations, medium-term decisions)		
SC1	**SC2**	**SC3**
Consumer goods (sports shoes, clothing and accessories), distribution items, packaging and other materials (such as paper and decorative materials)	Consumer goods (shoes, clothing, white and brown goods, books, etc.), packaging and distribution items (hangers, plastic bins and clothing stands)	Consumer goods (clothing, shoes, white and brown goods, books, etc.), packaging and distribution items (hangers, plastic bins and packaging material)
Special stock adjustments returns are initiated at the sales department and are credited to the stores. All other returns e.g. originated by consumer's complaints, are initiated by the stores, which remain owner of the products (B2C commercial returns)	Products can be returned when the purchasing department grants permission. Except for off-season returns, of which the stores keep the ownership, stores are credited for returns	The purchase department decides what should be returned. The DC decides the return instant. Returns are credited to the stores. Except for fashionable clothing all returns are sold out at reduced prices
MO1	**MO2**	**MO3**
Collector items (miniature cars, dolls, porcelain and jewels, etc.)	Clothing, small household appliances	Clothing, small household appliances
Contractual time to return: 4 weeks	Contractual time to return: 1 week	Contractual time to return: 2 weeks
All products can be returned at no cost within the contractual time to return (see Chapter 4 on integrating operations, medium-term decisions)		

temperature compartments. Usually there are three deliveries per day per supermarket, giving opportunities to pick up the empty carriers. The returns are received in both floors of the warehouse, while the empty carriers are received through special dock-doors at the top floor. There is a special shuttle truck that moves returns between the two storeys, to make sure that the returns are handled at the proper dock. Crates are sorted and palletized through an automated system. All transport is daily and self-executed. However, when excess capacity is needed, transport is outsourced.

Returns collection is included in the route, although this is done differently at all three retailers. The internal handling differs as well. All retailers have separate loading docks for empty (beer and soft drink) crates. All have separate areas where empty product carriers are stored. Waste materials at FR1 and FR2 are received and handled (sorted) in separate areas, as well. FR2 also disposes meat and bread waste. FR1 has outsourced this. Returns of good products, close to the keeping date, form a minority in all organizations and are added to ordinary stock locations. These are usually sold at selected outlets at a lower price. At FR3, all waste material is weighed per store, since the stores have to pay for the disposal. This is not done at FR1 and FR2. All returns are handled manually, except empty product carriers at FR3, which are sorted and palletized automatically. As exhibited in Table 5.1, the volume of such returns is the largest at FR3. Table 5.4 summarizes the return process for the food and other retailers.

Non-food store chains

Returns are picked up by the delivery truck and included in the route. SC3 self-executes while SC1 and SC2 outsource the transport. Nevertheless, both SC1 and SC2 keep control of the transport planning. Receipt and inspection of returns is rather similar for the three store chains. However, while SC1 and SC3 have a separate storage area for returns, SC2 only has a separate storage place for out of season products (see Table 5.4).

Mail order companies

After unpacking, inspection, packing and re-labelling, the 'as-good-as-new' products are eventually added to regular stock. MO1 has a temporary location for returns, from where orders are first served. However, when capacity is reached in this location, product returns are stored together with initial stock. MO3 also has a hybrid storing strategy. It distinguishes on the one hand bulk locations for initial stock and on the other hand multi-SKU locations for

Table 5.4: The return process at the nine retailers.

Transport, receipt, sorting and storage		
FR1	**FR2**	**FR3**
Transport is self-executed, combined with several deliveries per day, per store	Transport is self-executed, combined with daily deliveries. However, returns are possible only twice a week per store	Transport is self-executed, combined with three daily deliveries
*S*eparated area for checking and separate storage per carrier type; products as-good-as-new go back to inventory of new products	Similar to FR1). However, bread and meat waste are handled at the integrated factories	Returns are received at both floors in separated zones, while empty carriers are received only at top floor. Sorting and palletizing empty crates is automated
SC1	**SC2**	**SC3**
Transport is outsourced, but transport planning is self executed	Transport is outsourced, but transport planning is self executed	Transport is self-executed
Several deliveries per store per week, several stores per truck route. All deliveries are in roll cages. Empty roll cages and returns are picked up at the store	About 1 delivery per sales department per store per day, usually only 1 store per truck route. Returns are picked up at the store	About 1 delivery per store per day, usually only 1 store per truck route Returns are picked up at the store by occasion of deliveries
Returns are received, checked and sorted at a separated part of the dispatching area		
Paper is discarded. Products as-good-as-new are manually stored in separated areas respectively for stock adjustments returns, B2C returns (e.g. complains) and other materials	Off-season returns are stored on special pallet locations. Other good products are stored on free locations (bin storage area) or added to the regular stock	There is a separate storage area (basement) where products are re-priced and stored in bulk before they are sold out at the “budget market” special outlet. Expensive fashion clothing is added to the regular stock.
MO1	**MO2**	**MO3**
Transport is outsourced. Orders are shipped to hubs of national P.O.s in Europe. Products are returned via national P.O.s. Transport of forward and return flows is not combined	Transport is outsourced, but transport planning is self executed. All shipments are automatically sorted by postal code area. Returns are integrated in the truck route and are picked up at the customer	Transport is outsourced to P.O. Only sorting per country is necessary. Transport of forward and return flows is not combined
Returns are checked, reconditioned, repacked, labelled and added to the regular stock.		
There is a separate return receipt and handling area		
All products are stored in pallet racks. Product returns are at first (and until capacity is reached) stored in a separated location, from where orders are picked first	There are three main storage areas: bulk (pallets), pick stock and hanging clothing	All regular products that are received in small quantities are stored on multi-SKU bins. This also holds for all returns. There are three main storage areas: boxed clothing, hanging clothing and a bin storage area for other products. Bulk stock is stored elsewhere

later replenishment (small quantities) and for returns (Table 5.4). In order to handle the large number of returns, each of the three mail order companies uses dedicated software.

5.4.3 Manpower, space and associated costs

The (internal) warehousing costs have been estimated. From the subsequent analysis it appears that the warehousing costs for returns (storage and handling only) form an appreciable amount of the total warehousing costs. In fact, the total costs of handling returns are much higher when transportation, and handling in stores are included.

Food retailers

Table 5.5 exhibits quantitative data on the manpower and dedicated space to handle returns in the warehouse as a percentage of total area and manpower employed. In matters of space, FR3 needs almost the triple of area for the returns than FR1, and one third of the space used by FR2 (Table 5.5). One must recall that on the one hand FR3 deals with little waste and FR1 has outsourced disposal, while FR2 integrates the treatment of bread and meat waste. The absolute estimated yearly costs to handle returns are 304, 320 and 394 thousand euros respectively for FR1, FR2 and FR3. In percentages, these correspond to 6.5%, 12% and 5.8% of the total warehousing costs. Recall that FR1 has to handle somewhat fewer crates and bins than FR3, but much more waste. FR2 handles less returns than FR1, no matter what type (see Table 5.1), but the relative costs are much higher. Costs per returned roll cage vary between 45 and 90 euro cents, with FR1 at the low end and with FR3 closest to 90 euro cents.

Table 5.5: Manpower (in FTE) and space (m^2) at the retailers with stores.

Description	**FR1**		**FR2**		**FR3**	
Manpower in the DC	149		70		198	
Manpower for returns	10	6.7%	7	10.0%	12	6.0%
Total DC area	15,000		35,000		43,000	
Return area	770	5.1%	6,000	17.1%	2,108	4.9%
	SC1		**SC2**		**SC3**	
Manpower in the DC	50		240 ±50 temporary		170	
Manpower for returns	5	10.0%	±8	±2.8%	10	5.9%
Total DC area	15,000		45,000		33,000	
Return area	1,850	12.3%	±4,500	±10%	3,000	9.1%

Non-food store chains

SC1 uses 12.3% of the total warehouse area and 10% of the total employees to handle returns. The numbers for SC2 are 2.8% and 10%, and for SC3 are about 6.0% and 9.1% for respectively area and manpower for product and material returns. (Table 5.5) The estimated yearly costs to handle returns are in absolute values 192, 324 and 369 thousand euros respectively for SC1, SC2 and SC3. These values correspond to 10.6%, 3.6% and 6.5% of the total costs in the respective warehouses. This corresponds to much less than 45 euro cents per return unit, with SC3 and SC1 having respectively the lowest and the highest costs.

Mail order companies

The impression given by the visits to these companies is that they use between 5% to just above 10% of the warehouse space to handle returns, and around 10% to 15% of the working force. However, thorough estimation was not possible for all mail order companies due to the way some handle returns. For this reason, return handling's cost comparison is out of the question. Yet, it is feasible to provide a rough estimation of the costs. One should keep in mind the dimensions of mail order companies businesses and that they have large number of product returns (Meyer, 1999). Given the percentages provided above, and based on the costs per return unit of the non-food store chains, one can estimate the warehousing handling cost per return unit as being approximately 45 euro cents. This embraces the work dedicated to returns as receipt, inspecting/sorting and bringing them to storage location. For simplicity one may assume that each individual operation corresponds to one third of the cost. Goods also have to be transported to the customer, and back, in the case of returns. In the Netherlands, several mail order companies charge the customer with about 5 euros for transportation costs. Considering that customers order 2 or 3 items at a time, the transportation cost per product is estimated as being 1,50 euros.
Figure 5.3 depicts the processes involved from purchasing to delivering the goods to the customer, as well as the processes involved in the case of returns. Note that the operation inspection/sorting is much simpler for newly purchased products than for returned products. In the latter instance, every individual return has to be checked and re-conditioned if necessary (for instance ironing returned clothes). With Figure 5.3 in mind, Table 5.6 displays estimated costs for mail order companies, when a return occurs (constructed as described before).

In Table 5.6 one observes that the costs double (from 1.95 to 3.90 euros)

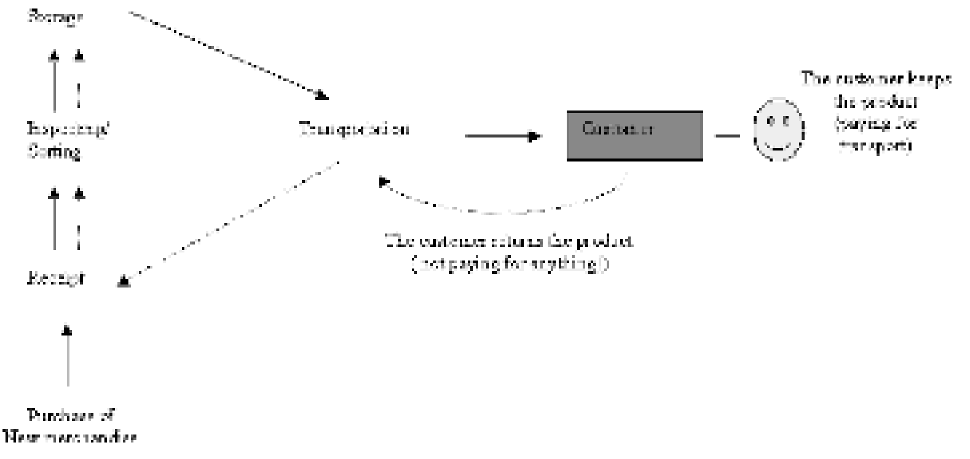


Figure 5.3: The process of handling returns, with and without returns.

Table 5.6: Simple estimation of the costs for mail order companies, with and without returns in euros (see Figure 5.3).

	with return	without return
Forward Process		
Receipt	0.15	0.15
Inspection/Sorting	0.15	0.15
Storage	0.15	0.15
Transport	1.50	1.50
Return Process		
Transport	1.50	
Receipt	0.15	
Inspection/Sorting	0.15	
Storage	0.15	
Transportation paid by the customer		−1.50
Total costs	3.90	0.45

when a return occurs, but due to the financial construction (the customer only pays for transportation costs when he/she keeps merchandize), the "net cost" increases by more than a factor 7 (from 0.45 to 3.90). These numbers are not surprising as in many industries, moving products back from the customer to the producer costs between 5 to 9 times more than moving the same product forward (Stock and Lambert, 2001).

More costs are involved on top of those discussed above, as all the three mail order companies had a separate module in the Warehouse Management System dedicated to return handling. These systems demand substantial investment costs since it is hardly found as a standard functionality. This software helps to monitor returns as for instance the number of times an item has been returned.

5.5 Discussion and implications

In the previous section, we depicted the operational aspects of handling returns associated with nine retailer warehouses in the Netherlands. Next we put forward three general and three specific propositions, based both on literature and on our empirical analysis, feeding future studies on return handling efficiency.

P1: Converting product returns into a *sold product* more than triples the costs of immediately selling a product in one-trip.

It is not new that a lot of money is involved in returns. The Reverse Logistics Council have estimated that handicap return management costs every year billions of dollars to U.S. firms (Rogers and Tibben-Lembke, 1999).

In the previous section, the estimated handling costs for mail order companies doubled when products are returned. This follows naturally from the processes involved. All the forward processes have to be performed once again, but now for returns (transport, receipt, inspection/sorting, and storage). Yet, the increase in costs is likely to be underestimated since every returned product undergoes a thorough check followed by an indispensable reconditioning procedure. In this respect, return handling is operationally more demanding than forward handling. Actually, return handling in the DC alone has been estimated as being twice as expensive as forward handling (see Zuidema and De Koster, 2002b). The point is that returns contribute substantially to operational costs, emphasizing the need for return handling efficiency.

P2: Reducing uncertainty (not only on quality, quantity, and time, but also on product diversity) is critical for large-scale return handling.

Reverse Logistics has been associated with high uncertainties on time, quantity and quality (see Dekker et al., 2004).

The empirical research allows us to state that not only when, how much and the state of products, but that also the product diversity is a central source of uncertainty (see also conjecture P5). Moreover, one can expect that different combination scenarios of those four factors are more or less problematic for return handling. For instance more of the same, i.e. large volume of similar type of products is likely to be handled more efficiently than a group of products with very different characteristics.

Indeed, we could notice that all retailers had mechanisms to reduce the aforementioned uncertainty while steering the return scenario as much as possible. Every retailer with stores centralized the return authorization. Although with limitations, this gives the possibility to determine the instant (time) for certain types and amounts of returns (quantity, quality and diversity) being collected. For example, a retailer may determine that only one stream of waste is being returned, or that complaint returns are collected alone on Thursday, and so on.

Mail order companies have somewhat less chance of reducing uncertainty, especially the ones that use P.O. services. Yet, MO2 integrates the delivery route with return pick-ups at customers. In this case, the customer phones the retailer requiring a pick up, to which the retailer proposes the pick up date. Although customers are entitled by law with the right of returning products, the mail order companies formally restrict the return period from one to four weeks after the customer has received it. Still, there is evidence that customers do not always respect the time of the return constraint (see Chapter 6 and Schmidt et al., 1999).

Though mail order companies have limited control over returns, all invested in information systems to register return data. Mail order companies showed concern in limiting the number of times a returned item goes back to the market and in recognizing customers that repeatedly return merchandize. From the interviews it was not possible however to assess which action is taken in the case of customers that frequently return products. Nonetheless, each retailer was clearly involved in reducing uncertainty on quality, quantity, time, and product diversity of returned products.

P3: Return handling has special warehousing requirements that are fundamentally different from those of forward flows, being of importance for efficient handling.

Both academics and practitioners have pointed out that Reverse Logistics is likely to have different basic requirements than forward logistics either in respect to infrastructure (Gentry, 1999) or knowledge (Meyer, 1999).

This study gives empirical evidence to this type of assessments, in the context of product flow handling in the warehouse. Table 5.7 was constructed with the data of Table 5.1, Table 5.2 and Table 5.5. By observing Table 5.7 (numbers were rounded to not create illusory accuracy), one can notice that FR3 uses 33% more Full Time Equivalents (FTE) to deliver 65% more products than FR1, per week (FR3 uses 186 FTE to deliver 28,000 roll cages per week, while FR1 uses 139 to deliver 17,000). In contrast with this good relative forward performance, FR3 uses more people than FR1 and FR2 to handle less volume of returns. This happens in spite of automatic crate handling in FR3 and manual handling at the other two food retailers. The direct impact on the cost per returned roll cage is the following: FR1 with a cost slightly above 45 euro cents and FR3 with a cost close to 90 euro cents per roll cage. One may suspect from these numbers that FR3 is not really being efficient. However, it is likely that FR3 is in a learning phase, since the correspondent investigated DC had started operations recently (see Section 5.4).

Table 5.7: Material flow per manpower (in FTE): forward vs. return flow.

Description	**FR1**	**FR2**	**FR3**	**SC1**	**SC2**	**SC3**
			FORWARD flow			
Flow (roll cages/week)	17,000	14,950	28,000	90,000	360,000	1,100,000
Manpower (FTE)	139	63	186	50	(±)265	170
(1) Flow per FTE	122	237	150	1,800	1,358	6,471
			RETURN flow			
Flow (roll cages/week)	10,600	8,700	8,675	12,600	34,000	80,000
Manpower (FTE)	10	7	12	5	(±)8	10
(2) Flow per FTE	1,060	1,243	723	2,520	3,400	8,000
			RETURN relative to FORWARD (flow per FTE)			
(2-1)/1	7.69	4.24	3.82	0.40	1.50	0.24

Another aspect is that for almost all retailers with stores an FTE handles several times the flow, when it is reverse than when it is forward (see Table 5.7). One should keep in mind that in the case of the food retailer, the bulk of returns are crates, bins, followed by wrap materials and waste. The DC of each of the food retailers handles less than 1% of products (see Table 5.1). In the case of the store chains, the return types were not discriminated (see Table 5.2). Since the goods are mainly clothing, it is not unreasonable to think that the shops already performed the initial check. Besides this, some

Table 5.8: Material flow per area (in m^2): forward vs. reverse flow.

Description	**FR1**	**FR2**	**FR3**	**SC1**	**SC2**	**SC3**
			FORWARD FLOW			
Flow (roll cages/week)	17,000	14,950	28,000	86,538	346,154	1,057,692
Area (m^2)	15,000	35,000	43,000	15,000	45,000	33,000
(1) Flow per m^2	1.13	0.43	0.65	5.77	7.69	32.05
			RETURN FLOW			
Flow (roll cages/week)	10,600	8,700	8,675	12,115	32,692	76,923
Area (m^2)	770	6,000	2,108	1,850	4,500	3,000
(2) Flow per m^2	13.38	1.45	4.12	6.55	7.26	25.64
			RETURN relative to FORWARD (flow per m^2)			
(2-1)/1	10.80	2.39	5.32	0.14	-0.06	-0.20

of these returns result from stock adjustments, basically not needing thorough inspection. However, when space is considered, for some retailers products require more average space for return handling than the space required for outbound products (see Table 5.8, which was built with data from Table 5.1, Table 5.2 and Table 5.5). This occurs with retailers SC2 and SC3 that indeed have hybrid storage strategies (see the discussion on the process in the previous section).

Apart from these mixed facts the point is that a retailer may have a very good relative performance in forward flow, but the opposite relative performance with the reverse flow. As mentioned before, a FTE in FR3 handles more forward flow than a FTE in FR1, but the opposite happens with the reverse flow (similarly when comparing SC1 and SC2). All the above fits in the context of our conjecture: return handling has different warehousing requirements than those of forward flows. Indeed, return handling encompasses operations as inspection, which is not part of forward handling. Yet, this implies that there is room for research to identify potential specific needs that matter in efficient warehousing handling. As put by Tibben-Lembke and Rogers (2002), "... and much future research is needed to discover how to best structure reverse logistics operations."

Table 5.9 sums up the decisions of combining (C) vs. separating (S) the forward from the reverse flows during the three stages of return handling: transport, receipt, and storage. All the retailers with stores (food and non-food store chains) combine the transport of product returns with outbound flows. All the warehouses have a separate area to receive returns. On storage,

Table 5.9: Decision on whether to combine (C) vs. to separate (S) the forward and the reverse flows.

	Food companies			**Store chains**			**Mail order companies**		
	FR1	FR2	FR3	SC1	SC2	SC3	MO1	MO2	MO3
Transport	C	C	C	C	C	C	S	C	S
Receipt	S	S	S	S	S	S	S	S	S
Storage	C	C	C	S	C/S	S/C	C/S	C	C/S

the majority of the retailers combine the flows, one separates and three retailers have a mixed or hybrid arrangement. Below we discuss three conjectures with these facts in mind.

P4: For retailers that supply (a sufficient number of) stores it is most efficient to collect the returned material to the DC with the same truck that delivers the products.

The rationale behind this is very simple. The truck returns to the warehouse anyway and it also saves precious space for the stores, which are often placed in urban areas with little expansion possibility and very high land prices. In addition, in the case of waste or obsolete products, a number of stores should be included in the return route to have economies of scale (Stock, 1992). Yet, one should notice that when more than one store is included per route, the loading of return material complicates the unloading of purchased products at the stores that follow in the route. This is the case for FR2 and SC1. Nevertheless, FR2 was able to simplify the operation by allowing each store to return material only when the store is the last in the route, which happens maximally twice a week. This emphasizes the importance of self-executing the truck route planning. Actually most of the retailers considered in this study kept control of the route planning. FR1, FR2, FR3 and SC3 self-execute the transport operations. The store chains SC1 and SC2 outsource the transport but they keep the route planning in-house. MO2 uses a delivery service but also keeps the route planning in-house.

P5: For retailers that handle a high volume of returns, it is more efficient to unload and sort returns in a separate area of the DC.

All the warehouses separate the inbound and outbound flows during the receipt phase and all the retailers deal daily with large volumes of product and material returns. Product returns demand operations additional to those of purchased products, such as inspection. If the volume of returns is not substantial it could still be reasonable to combine the forward and reverse flows, but in the converse situation it is not likely. A complicating factor for return handling is the diversity of products. Yet, handling of large homogeneous flows may be automated. For instance at FR3 all empty crates are automatically unloaded from roll cages, sorted per type and stacked on pallets. In practice the design of the warehouse layout has to take into account the return handling. Comparing the numbers for return costs as part of total warehousing costs enforces this. They vary from 3.6% at SC2 to 12% at FR2. The fact that FR2 uses two separate buildings to receive product and material returns demanding transportation between the buildings is likely to contribute to this relatively higher relative cost.

Separating vs. combining storage is related with the market for returns, as follows:

P6 a: If the market for returns is different from the original market then product returns are stored in a different area from those of purchased products.

P6 b: If the market for returns is the same then storage of product returns is likely to be combined with purchased products. Exceptions will be found in the case of high-intended control over returned products.

For food retailers all returned products in good condition are stored together with new products and they are sold in the same market. The same holds for mail order company MO2. Department store SC2 combines storage apart from off-season products, which are sold in another market. SC3 mainly sells returns in "budget" outlets so they separate storage. This retailer only combines the storage for expensive articles, which are sold in the original market. SC1 is an exception in the sense that it separates storage but returned products go back to the same market. This is related to the fact that SC1 is very concerned about keeping track of returns. This comes along with the active role of SC1 in finding the best store to reallocate product returns. MO1 stores returns at first in a separate location from which orders are picked first. This goes with MO1's aim of giving priority to returned products for shipment to customers. Such an approach provides a quick means to learn more about the market, the product, and even the process. For instance, repeated returns may indicate that some aspect is being overlooked during return check or that customer expectations are not being met at all. When capacity is reached in the temporary location, product returns are put together with purchased products. MO3 uses a hybrid solution: small amounts of received products, including returns, are stored in a single bin (max 10 SKUs) on one location. For MO3 the control over returns is an issue of great importance. Mail order companies have an additional difficulty because they have a substantial volume of returns and elevated product diversity (number of SKU's) coming back in small quantities (per customer). Before we started this study we suspected that the combination of volume and product diversity would have an impact on the storage decision. From the analysis though the complicating factor seems to be the decision of controlling returns. Yet, both volume and product diversity can be a point of further research since they might not be a complicating factor by itself but be so when combined with other factors. Furthermore, to have a relevant degree of return monitoring and control, a separate module for returns in the warehouse management system is desirable as it is already the case for mail order companies.

5.6 Conclusions

This exploratory study facilitates the development of theory for return handling and supports both recommendations for practice and academic research. Return handling contributes considerably to operational costs. When products are meant to be put again in inventory, they have to pass a close inspection and inevitable reconditioning procedures, which are manpower-intensive and therefore expensive. Not only quantity, quality and timing are relevant sources of uncertainty in the reverse stream but also product diversity, as this study showed. Reducing these four fronts of uncertainty streamlines return handling operations, increasing efficiency. However, to master forward handling does not seem enough for efficient return handling. There is actually empirical evidence for the existence of different basic requirements in return handling vs. forward handling, also in the warehouse scene. Among the studied companies, retailers having a good relative performance in handling forward flows were not always able to perform as well with respect to reverse flows.

Regarding the focus on factors contributing to combine vs. to separate the reverse and forward flows, three conjectures were put forward. In those we established relations between the following issues (see also Figure 5.5):

1. serving stores & the transport phase decision;
2. return volume & the receipt at the warehouse;
3. the market for returns & the storage decision.

In more detail, we conjuncture that:

Table 5.10: To combine (C) vs. to separate (S) the forward and the reverse flows: critical factors and implications.

	To combine vs. to separate the forward and the reverse flows		
	Collection and transport	Receipt and sorting	Storage
Remark	All retailers with stores combine transport	All retailers separate receipt	The majority of retailers combine storage
Influencing factor	To serve (a sufficient number of stores)	A substantial volume of returns	The market for returns
Complicating factor	More than one store per route	The combination of volume and variety of the return flow	Intended controllability over returns
Simplifying action	To allow stores to return material only when they are the last in the route	To automate the handling of homogeneous returns	Small amounts of purchased and returned products are stored at the same location
Practical implication	To keep route schedule in-house	To anticipate packaging (waste) legislation	Information systems for product returns
		To design the warehouse (also) with return handling in mind	
Associated conjecture	P4	P5	P6a, P6b

- For retailers that supply a sufficient number of stores it is most efficient to collect the returned products, carriers and waste to the DC with the same truck that delivers the products (P4).
- For retailers that handle a high volume of returns, it is more efficient to unload and sort returns in a separate area of the DC (P5).
- If the market for returns is different from the original market then product returns are stored in a different area from those of purchased products (P6a).
- If the market for returns is the same then storage of product returns is likely to be combined with purchased products. Exceptions will be found in the case of high-intended control over returned products (P6b).

Table 5.10 refers to these findings during all the three stages of return handling. One can notice that the retailers do not diverge much in some of the particular decisions. This finding has been one of the inputs for the aforementioned conjectures and it constitutes a valuable guideline for future research. Besides that, some associated recommendations for practice and research opportunities derived from the detailed information about all the cases follow below.

5.6.1 Recommendations for practice

Here we make first recommendations for practice regarding the long- and medium-term warehousing decisions. Figure 5.4 is structured according to the decision-framework of Chapter 4 and it summarizes the general recommendations. After that, we pay attention to the specific focus of this chapter, i.e. the decisions on combining vs. separating forward and reverse flows during transport, receipt and storage.

While designing the warehouse layout, practitioners should take into account return handling explicitly, i.e. returns receipt location and future storage locations.

For retailers with stores wishing to reduce return uncertainty there are two key-factors: to centralize return authorization and to keep routing in-house even when outsourcing transport. These actions give the retailers the opportunity to restrain return uncertainty by determining the exact moment of each pick up (taking into account the stores' needs). Alternatively, they can set it as a constraint to the third party, when outsourcing transport.

Furthermore, if forward handling is the only concern, the warehouse may end up with undesirable high costs for return handling due to disregarded internal transport. Automating the return handling for homogenous returns may simplify operations. However, this calls for substantial investment and it relates primarily to returned product carriers. This is a sensitive matter, especially with the enforcement of the directives on packaging and packaging waste of the European Union. Therefore, retailers have to think thoroughly on the consequences of packaging legislation before investing heavily on return handling automation. For instance, if manufacturers comply to the packaging standards launched by the European Committee for Standardization and packaging gets lighter, is the automatic handling equipment able to deal with this?

The last recommendation is to employ a dedicated module within the warehouse management system for return handling monitoring. This suggestion is related to the indication of fundamental differences in handling the two types of flows and to deficiencies in standard software regarding return handling.

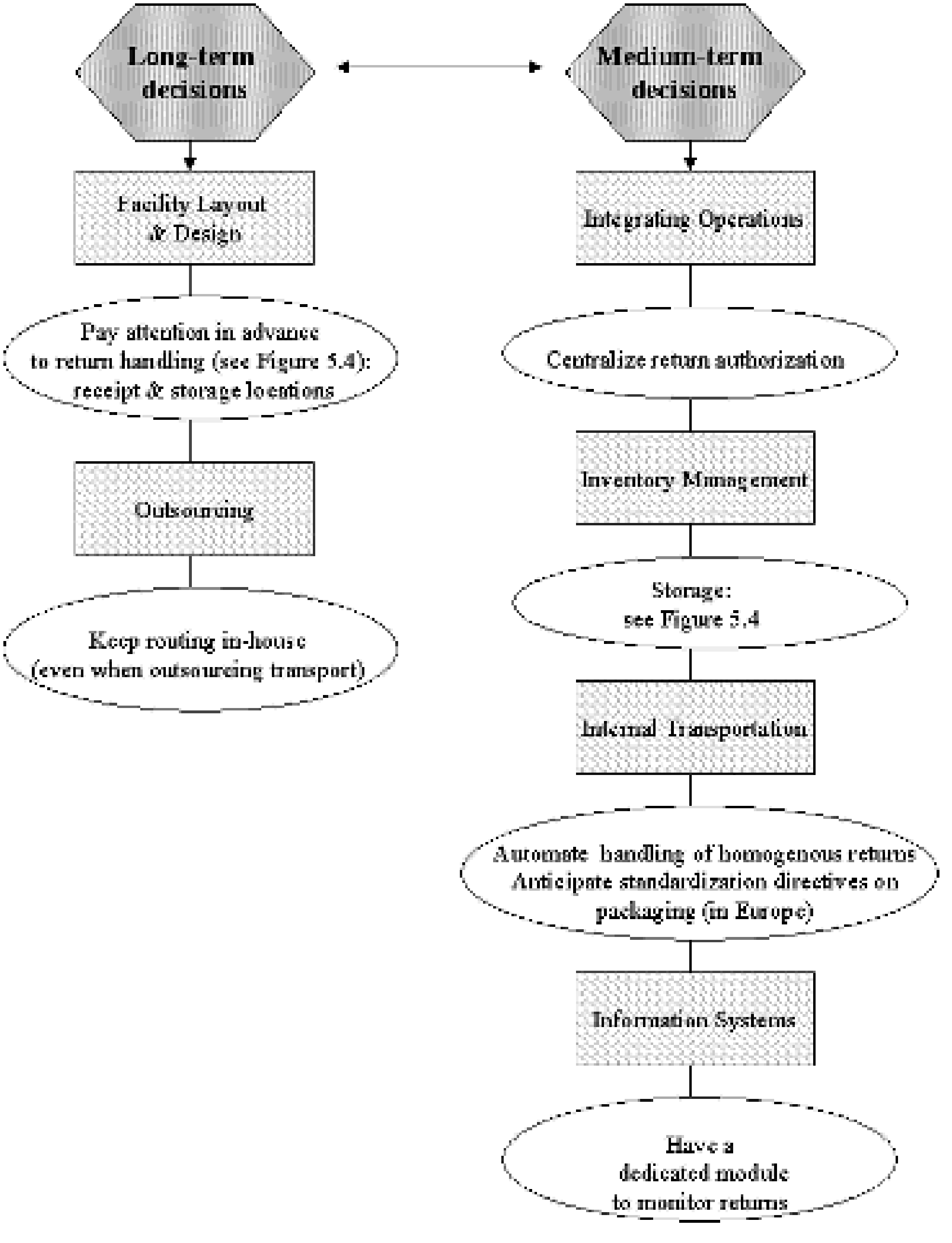


Figure 5.4: Decision-scheme on general long- and medium-term warehousing decisions.

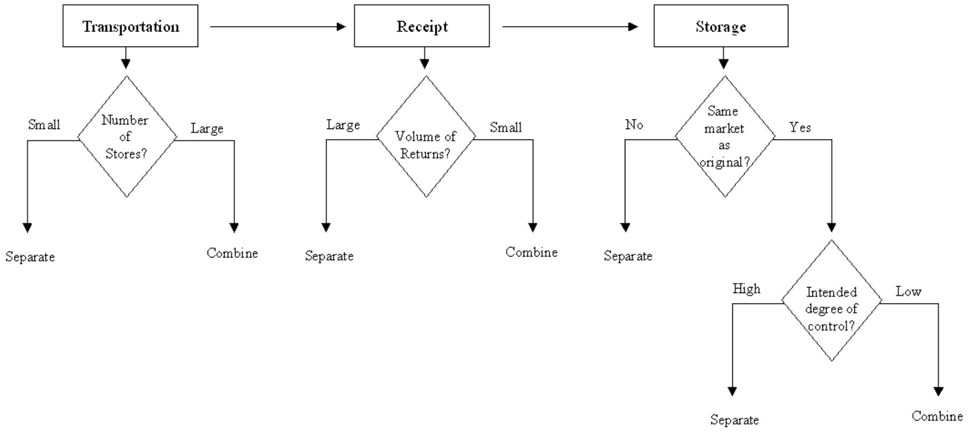


Figure 5.5: Decision-making scheme on combining vs. separating forward and reverse flows during transport, receipt and storage.

Regarding the focus on factors contributing to combine vs. to separate, explicit advise is given in Figure 5.5.

5.6.2 Research opportunities

The conjectures presented in this chapter facilitate future studies on return handling efficiency. For this reason, the perceived relations between factors contributing to decisions during the handling process have to be further investigated. Besides this, the absence of disagreement for some decisions should be a guideline for case selection and for the investigation of additional factors. One could notice that all the retailers with stores combine the transport of outbound and inbound flows. In future research one may seek a priori contrasting cases, or investigate the role of geographic store's dispersion. Furthermore, all the retailers unload and sort returns at a separate area of the DC. A conjecture stating that the high volume of returns is responsible for this, was brought forward. Again, counter cases and new factors can be sought. In this way, theory on warehouse handling efficiency can be built.

One aspect not taken into consideration here is the overall strategy of the firm, which may justify different return strategies and handling processes. This presumably helps us to understand why some retailers do not object so much to costs when the goal is to keep track or to control returns. Indeed, research towards mechanisms to cut back uncertainty in its four dimensions (quantity, quality, time and product diversity) would be of practical value. Though, there are studies on the impact of return policies on a number of elements like opportunistic behavior and speed of consumption (see Hess et al., 1996 and Davis et al., 1998), the impact on operations has not yet been thoroughly investigated.

Another aspect lacking investigation is on the dispatching tactics when both returned items and new merchandize are in stock. A typical situation in a company is having the marketing department believing that new merchandize should be shipped first, while the logistical department may think otherwise (see Zuidema and De Koster, 2002a). In general terms, there is a need for research on issues of monitoring and control return handling, bringing efficiency to operations (see also Chapter 4 on quantitative support for return handling). In addition, the technical literature, as mentioned in the introduction, may benefit from a close look at warehouse running costs. While modelling warehouse operations and associated costs, researchers would be more apt to explicitly de-couple forward from reverse costs if robust estimates were found.

Chapter 6

Inventory Management: a critical analysis of assumptions

Man is an animal suspended
in webs of significance
he himself has spun

Clifford Geertz,
paraphrasing Max Weber

6.1 Introduction

As mentioned in the previous chapter, Inventory Management and Control is one of the key decision-making areas while managing product returns. Fleischmann et al. (2002), van der Laan et al. (1999) and Inderfurth and van der Laan (2001) are recent examples of scientific literature on inventory control with product returns. From a modelling perspective, one of the consequences of reverse flows is the loss of monotonicity of inventory levels between replenishments of new products. That is, the inventory level does not only decrease because of demand but it may also increase in the case of returns. Since this makes the analysis much more difficult than traditional inventory control, authors use simplifying assumptions regarding the return process. These assumptions typically are 1) the demand flow is a (compound) homogeneous Poisson process; 2) the return flow is a (compound) homogeneous Poisson process, and 3) the return process is independent of the demand process (see Fleischmann et al., 1997; Dekker and van der Laan, 1999). However, there is nearly no (scientific) literature providing empirical analysis of data on reverse flows. Thus, in this chapter we explore the validity of these common assumptions by means of real data. First of all, we present a methodology to check the assumptions empirically. We describe actual practice in companies with respect to information storage on returns and to inventory control. Moreover, we apply the methodology to real data and we discuss practical implications of our findings, for instance with respect to information management on inventory systems with returns. We employ data from three companies here referred to as CERN, MOC and RF. Both CERN, the European Organization for Nuclear Research (see Cern, 2000) and RF, a refinery in the Netherlands, deal with internal material returns. MOC, a mail-order company, handles customer product returns. The results of this study have appeared in De Brito and Dekker (2003b).

The remainder of the chapter is organized as follows. The next section is dedicated to a review of the main assumptions in the literature when it comes to inventory models with return flows. Then, in Section 6.3 the methodology is put forward and the statistical analysis and tests are described. In Section 6.4 the data of the three companies is described. The data analysis can be found in Section 6.5. The last section sums up the conclusions, practical and theoretical implications and research needs.

6.2 Inventory models with returns: a literature review

Literature on inventory control models with return flows can be divided into two streams: 1) typical repair models; 2) other models with *imperfect correlation* between demand and returns. In the former models there is a perfect correlation between machine failure and the demand for a substitute, where the number of machines or parts in the system is constant. This chapter concentrates on product returns that fit in the second group. For recent surveys on repairable inventory theory we refer to Cho and Parlar (1991) and to Guide and Srivastava (1997b).

This review considers two types of models: deterministic models and stochastic models.

6.2.1 Deterministic models

Schrady (1967) considers a deterministic inventory model in which a certain percentage of sold products comes back, after a known period of time, to be repaired. Repaired items are put in inventory to be eventually re-used. Since the demand and the return processes are assumed to be continuous deterministic flows, the dependency relationship between the demand and return process is not explicitly modelled. Later, Richter (1996) and Teunter (2001) extended this model with the option of product disposal. With respect to the demand and return processes, Schrady's assumptions remain roughly the same in both extensions. Richter's model however considers a discontinuous return flow as returned products are collected at variable moments in time. Also in a deterministic context, Minner and Kleber (2001) discuss the optimal control for a production and remanufacturing system with continuous and non-stationary rates for both the demand and return processes.

6.2.2 Stochastic models

The stochastic models can be divided into two groups: periodic review models and continuous review models.

Periodic review models

This category of models typically focuses on proving the structure of the optimal policy rather than finding optimal parameter values. For instance, Simpson (1978) provides the optimal policy structure for an inventory model with product returns in which product demands and returns can be stochastically dependent within the same period only. Demand and returns are known through a joint probability function, which can differ from period to period. Inderfurth (1997) extends the previous model with non-zero (re)manufacturing and procurement lead times. All other assumptions equal the ones of Simpson. Inderfurth proves that there is a simple optimal control policy structure as long as the leadtimes for manufacturing and remanufacturing differ at most one period. Buchanan and Abad (1998) consider a system with partial returns. Each period, a fixed fraction of products is lost while a stochastic fraction is returned. The authors establish an optimal policy for the case that the time until return is exponentially distributed. Toktay et al. (2000) study ordering policies for a business case of single-use Kodak's cameras. The model is as follows. After using the camera, customers take it to a shop/ laboratory to develop the film. The laboratories return the used cameras to Kodak (but sometimes they go to the so-called jobbers). Kodak dismantles the used cameras and reuses the flash circuit board of every camera in the manufacturing of new ones. A closed queueing network model is applied to decide on periodic ordering decisions. Custom demand is treated as a Homogeneous Poisson Process (HPP) from which a known percentage is returned. The time the cameras are with respectively the customer and the lab are modelled by a queueing system with two infinite servers with general processing times. These two servers together model the time until the camera returns to Kodak. Another important feature of this paper is the identification of the information's value according to different scenarios. Kiesmüller and Van der Laan (2001) develop a periodic review inventory model where product returns depend on the demand process. Both the demand and the return streams follow a Poisson distribution. All returns depend on previous demands through a constant time until return, and two probabilities: the return probability (when demand occurs, it is assumed to be known whether, or not, an item returns) and the probability that a returned item is in a sufficiently good condition to be remanufactured. The authors compare this model with the situation of independent demands and returns. The outcome supports that it is worth using information about the dependency structure between demands and returns. Mahadevan et al. (2002) model a hybrid manufacturing and remanufacturing system with independent demand and return Poisson processes. The authors employ a push policy to combine the decision of when and how much to (re)manufacture. Teunter and Vlachos (2002) inquire the necessity of a disposal option for a similar model. The independent demand and return processes are modelled according to a Poisson or a Normal distribution. The conclusion is that only under certain circumstances the disposal option brings economic benefits.

A special case of periodic review models is the newsboy model, where only a single period is considered. Two newsboy models with returns have been respectively proposed by Vlachos and Dekker (2000) and Mostard and Teunter (2002). In the first, a constant fraction of the the sold items is returned and can be re-sold only once. In the second, each item that is sold has a constant probability of being returned and once returned it has a constant probability of being recovered. Returned items can be re-sold more than once. Both articles investigate the optimal order quantity for the single period. These models are inspired by the order size decision that mail-order-companies and e-tailers face every season.

Table 6.1: The assumptions of the literature on inventory models with returns.

	Demand process	Return process	Processes' relations
	Deterministic models		
Schrady (1967) Teunter (2001)	Continuous (constant) rate	Continuous (constant) rate	Independent
Richter (1996)	Idem	(Periodic) constant rate	Independent
Minner and Kleber (2001)	Continuous (dynamic) rate	Continuous (dynamic) rate	Independent
	Stochastic periodic review		
Simpson (1978) Inderfurth (1997)	General non-stationary	General non-stationary	Dependency allowed in same period only
Buchanan and Abad (1998)	Random variable	A stochastic fraction of demand comes back after an exponentially distributed time	
Toktay et al. (2000)	HPP	Partial returns and general distribution	Dependency comprised through a queueing system
Kiesmüller and van der Laan (2001)	HPP	HPP	Returns depend on demand by a constant return probability and time until return
Mahadevan et al. (2002)	HPP	HPP	Independent
Teunter and Vlachos (2002)	Poisson or Normal	Poisson or Normal	Independent
Vlachos and Dekker (2000)	Stochastic	A fraction of the demand	Independent
Mostard and Teunter (2002)	Idem	Partial returns	Each item is re-sold with constant probability
	Stochastic continuous review		
Heyman (1977)	Compound renewal process (explicit expressions for Poisson distribution)	Compound renewal process	Independent
Muckstadt and Isaac (1981)	HPP	HPP	Independent
Van der Laan et al. (1999)	HPP	HPP	Independent
Fleischmann et al. (2002)	(Compound) Poisson Process	HPP	Independent
Yuan and Cheung (1998)	HPP	A constant fraction of demand comes back after an exponentially distributed time	
Bayindir et al. (2003)	HPP	HPP	Independent

Continuous review models

Heyman (1977) analyzes different disposal policies for a single-item inventory system with returns. He uses a model where demands and returns are independent compound renewal processes and all leadtimes are zero. An explicit expression for the optimal disposal policy is given when the processes are Poisson. Also Muckstadt and Isaac (1981) investigate the control of a single-item inventory system with independent demands and returns following a Poisson Process. The authors derive some approximations. More recently, Van der Laan et al. (1999) deal with policies in the context of two inventory facilities, one of new products and the other of remanufactured items. The model is based on unit demand and unit returns with independent Poisson processes. Fleischmann et al. (2002) derive an optimal policy and optimal control parameters for a basic inventory model with returns where demand and return are independent Poisson processes. Yuan and Cheung (1998) discuss an (s,S) inventory system with returns and analyze the impact of partial returns on rental systems. Demands are assumed to follow a homogeneous Poisson process and there are no lost customers. Customers keep the acquired item during an exponentially distributed time. When this period ends, the item is either returned or disposed, with a given probability already known upon demand. They also assume that the return period is already known at the time of demand. Bayindir et al. (2003) employ a queueing model to investigate a hybrid (re)manufacturing system when the return ratio is a decision variable. Demand and return processes are independent and follow Poisson distribution. The time in market follows a general distribution. The authors conclude that the remanufacturing facility is more or less used depending on whether the production capacity is finite or not.

Although the above does not constitute an exhaustive review of the literature on inventory models with returns, it serves to identify the common assumptions of these models. Table 6.1 summarizes the main assumptions of the demand and return processes, and of the dependency structure between these two processes. More information on inventory models with returns can be found in Van der Laan et al. (2003).

The bulk of the literature, especially when uncertainty is modelled, assumes the following: 1) the demand is a homogeneous (compound) Poisson process; 2) the return process is also a homogeneous (compound) Poisson process, and 3) the two processes are independent. These choices have to do with the tractability of the Poisson distribution. This is also the main reason behind the independence assumption. In fact, less restrictive assumptions complicate the analysis significantly. Besides, as the review of the literature shows, in order to pursue an exact analysis or to give explicit expressions for optimal policies one has to make these common assumptions. The independence assumption has also been motivated by the scarcity of individual data on product returns (see Fleischmann et al., 1997). This motivates empirical analysis of real data.

6.3 Methodology

The statistical analysis encompasses the demand process, the return process, and the relation between these two processes. Before developing a testing framework for the demand and return processes, first the notation is introduced. Let $P(t)$ be a counting process that at time $t \geq 0$ equals

$$P(t) = \sum_{k=1}^{N(t)} Q(k) \tag{6.1}$$

where $N(t) \in Z$ is the number of customer arrivals in the time interval $(0, t)$, and $Q(k)$ is the amount of items ordered (or returned) by client k. $P(t)$ is a Homogeneous Compound Poisson Process (HCPP) if (see Tijms, 1994):

- $N(t)$, $t \geq 0$ is a Poisson Process;
- $Q(k)$ is identically and independently distributed;
- $N(t)$ and $Q(k)$ are independent processes;

Let the subscript D refer to a demand process and the subscript R to a return process and let T be the random variable indicating the time to return. It is clear that if the return probability $p = 1$ and T is negative exponentially distributed, then $P_D(t)$ being an HCPP implies that $P_R(t)$ is an HCPP which is independent of $P_D(t)$. However, in the case $p < 1$, $P_R(t)$ is *not* a homogeneous compound Poisson process given $P_D(t)$. To understand the latter consider a demand y time units ago. The probability that this demand will trigger a return is equal to

$$\frac{p \cdot e^{-\lambda \cdot y}}{p \cdot e^{-\lambda \cdot y} + (1 - p)} \tag{6.2}$$

where λ is the scale parameter of the exponential distribution of the random variable T, which represents the time to return. Since Equation 6.2 depends on y, we are not in the presence of an HCPP.

6.3.1 Testing HCPP

One may still opt for approximating $P_R(t)$ with an HCPP if there are demands occurring regularly. To evaluate whether a process $P(t)$ behaves as an HCPP consists of checking the three sufficient and necessary conditions mentioned before. In order to first check whether it is acceptable that $N(t)$ is a Poisson Process, one can then check if

A) $N(t)$ follows the Poisson distribution, and if
B) $N(t)$ has independent increments.

The last item implies that the occurrence of events after any time t is independent of the previous occurrences. For the first part, A), a chi-squared goodness-of-fit test can be used (see Bain and Engelhardt, 1967). To employ this test the potential outcome space has to be split into intervals. For a good test performance, the number of intervals should be as many as possible as long as the expected number of observations is at least about 5 per interval. The second part, i.e. B), can be handled through a Ljung-Box Q test which directly checks if the autocorrelations between increments are significant or not. This test can be found in standard statistical packages, and can be carried out without sophisticated knowledge of time series theory (see Box et al., 1994). The investigation over $Q(k)$ can be carried out by applying a Wald-Wolfowitz runs test for randomness (see Walpole et al., 1998) and again a Ljung-Box Q test. For the former test one finds in the literature tables of critical values from sample size 6 onwards. Finally, the test of independence based on Pearson's coefficient can be used to trace whether $N(t)$ and $Q(k)$ are independent or not (Bain and Engelhardt, 1967). This test gives the best results when the sample is larger than 10 data observations. Next subsection describes the technical details of the aforementioned statistical tests, which are summarized in Figure 6.1. The choice of those tests was made targeting the following objectives: simplicity, parsimony, usefulness and test performance (against small sample sizes).

6.3.2 Testing exponentiality of the time to return

Besides the assumptions in the literature regarding demand and return each being a HCPP, these two processes are commonly assumed to be independent. In the proposed methodology there is no direct investigation about whether the demand and return processes can be dealt with as independent processes, because the data to be analyzed is likely to have only a small amount of returns. Instead, it is investigated whether it is reasonable to model the *time until return* with an exponential distribution. The advantage of this is

1. To test if $N(t)$ is a Poisson Process		
A) $N(t)$ follows a Poisson distribution	→	**Chi-squared test**
B) $N(t)$ has independent increments	→	**Ljung-Box Q test**

↓

2. To test if $Q(k)$ is		
A) independent	→	**Ljung-Box Q test**
B) identically distributed	→	**Wald-Wolfowitz test**

↓

3. To test if $N(t)$ and $Q(k)$ are independent		
	→	**test of independence**

Figure 6.1: Statistical analysis scheme to test if a process is an HCPP.

that one may pool over multiple products, when the return lag is likely to be the outcome of a logistical process rather than being a product specific process. Inherently, one can expect that the process affects the outcome of the tests. The exponential assumption also appears in the literature (see Section 6.2). So, indirectly it is tested how dependent returns are of previous demand occurrences. The outcome has important consequences for inventory management, which are discussed later in this chapter.

The *time until return* is the period from the moment a product is acquired until it is returned. A goodness-of-fit statistical test, k^2, constructed by Gan and Koehler (1990), is used for this investigation. According to the authors, this test fairly detects the non-exponentiality in the presence of data from a Weibull, a LogNormal, or Normal truncated, among two dozens of other distributions.

6.3.3 Statistical tests: more details

Here, more technical details on how to carry out the aforementioned statistic tests are given (see Figure 6.3.2).

Chi-squared goodness-of-fit test

Test hypothesis:

1A) $N(t)$, $t \leq 0$ follows a Poisson distribution;

The procedure is as follows (see Bain and Engelhardt, 1994). First, one has to divide the whole potential outcome space into c intervals $A_1, A_2..., A_c$; Let o_j be the number of observations within interval j and p_j the probability of an observation falling in A_j and $e_j = n * p_j$ the expected number in the j^{th} interval with n being the sample size. For an error Type I equal to α (i.e. with the probability of rejecting the hypothesis given that it is valid being equal to α) we reject the hypothesis if the value of test statistic is larger than the $(1-\alpha)$ quantile of a Chi-squared distribution with $c-2$ degrees of freedom, i.e. if

$$\sum_{j=1}^{c} \frac{(o_j - e_j)^2}{e_j} \geq \chi_{1-\alpha}(c-2) \tag{6.3}$$

To have an accurate test e_j should be larger or equal than 5, or so, for each interval A_j. To have as many cells as possible is desired because it increases the degrees of freedom. For the test on the demand process we observed the number of arrivals per month, and for the return process the number of returns per year. After that, the chi-squared test was employed.

Ljung-Box Q-test

Test hypotheses:

1B) $N(t)$ has independent increments;

2A) $Q(k)$ is independently distributed;

The test is based on a chi-squared test statistic (Box et al., 1994), which is an approximated distribution of the autocorrelations. The MINITAB statistical package was employed to carry out this test.

Wald-Wolfowitz test

Test hypothesis:

2B) $Q(k)$ is identically distributed.

To apply this test (see Walpole et al., 1998), one has to divide the sample into two mutually exclusive categories, e.g. above and below the median. The test statistic is the number of runs, i.e. groups of one or more observations of the same category. The test detects deviation in randomness and it may suggest non-randomness due to trends or periodicity. To test the hypothesis, one may rather divide the sample into two and then test if the distributions are identical. However, these tests are only suitable for large enough samples (Kanji, 1999).

Test of independence

Test hypothesis:
3) $N(t)$ and $Q(k)$ are independent.

The test is based on Pearson's correlation coefficient (see Bain and Engelhardt, 1994). The time between arrival of clients and the amount ordered (or returned) constitute the samples. In this way, it can be tested whether the demand process is independent of the ordered quantities (and similarly to the return process). For very small sample sizes, less than 10 observations, a non-parametric rank test is preferable, e.g. the Spearman's rank correlation test.

k^2 goodness-of-fit test

Test hypothesis:
Time until return has an exponential distribution

The test is based on the $P - P$ probability plot (see Gan and Koehler, 1990). This plot is built drawing $Z_i = F(X_i/\hat{\lambda})$ versus p_i, where

- F is the cumulative distribution function,
- X_i is the i^{th} lower ordered observation, $i = 1, ..., n$ with n being the sample dimension (i.e. the sample X is put in ascending order, X_1 being the lowest observed number and X_n the highest),
- $\hat{\lambda}$ is the estimated scale parameter,
- p_i is an appropriate plotting position.

The degree of fit is decided based upon the linearity featured in the graph. The statistic proposed is based on measures of linearity:

$$k^2 = \frac{\sum_{i=1}^{n}((Z_i - \bar{Z})(p_i - \bar{p}))^2}{\sum_{i=1}^{n}(Z_i - \bar{Z})^2(p_i - \bar{p})^2} \tag{6.4}$$

Approximations for the lower p^{th} percentile are obtained through the formula below:

$$1 - {k_p}^2 = \frac{1}{\lambda_p + n \cdot \beta_p} \tag{6.5}$$

A table with the coefficients λ_p and β_p can be found in Gan and Koehler (1990).

6.4 The data

Case 1 - CERN

CERN is a very large research center with more than 7 000 scientists. These scientists have several warehouses at their disposal with more than 15 000 stock keeping units. Scientists have two ways of acquiring the products they need for their experiments: by going to the self-service stores or, by ordering via the web from the main warehouse. The first is meant for low-value regularly used items, i.e. the *'consumer' type of goods*, and the latter for all other items (*industrial goods*. In both situations, scientists provide the budget code of the project they are working on. This code is therefore registered and the project is charged for the delivery (CERN, 1999). For already 10 years, CERN registers inventory transactions through the LIMS package which has been used on top of Baan's TRITON system. Dr. B. Schorr and Dr. M. Krever developed the LIMS package (CERN, 1997). The database encompasses the following general information for each transaction occurrence:

- product identification by means of a code and a name;
- product quantity and its monetary value;
- store identification (main vs. self-service store);
- transaction types, e.g. replenishment from supplier, delivery to client, and returned by client;

In the case of products issued to scientists, the date of order placement, date of planned and actual delivery, budget number and client code are in principle registered.

In the case of a return, the date of transaction, the budget number and client code can also be registered. Originally, an attribute was created in CERN's database to register the reason for returning the product, but in practice it is not used. The main return reason is actually *reimbursement* (see Chapter 2). In addition, the database had reason's codes for wrong deliveries, technical faults, delivered too late or even never ordered by the client.

If the transaction is a replenishment, the supplier code and name is recorded in the database. CERN's data is not only extraordinary by its dimension and life span, but also due to the individual registration of transaction occurrences, including the identification of returns, client codes and budget numbers. In most other commercial packages, transaction data are stored only for a short time and are aggregated to e.g. monthly or yearly demand figures. When a product is returned at the CERN, it is possible to trace back its date of purchase.

The procedure we used to trace back returns is as follows. If the client number is registered, the return is associated with the most recent purchase by this client whose amount is larger than the quantity returned. If not, but the budget number is known, the inspection is now done through the issues purchased under this budget number. The rationale behind this is that sometimes the client who receives the product is not the one who returns it. Still, it is most likely that it is a client within the same project, i.e. with the same budget number.

In several cases of return occurrences it is not possible to make a link with any previous delivery, because the client and budget identification are missing. In other cases, there is no registration of previous deliveries to these clients. Possible explanations are that the products are being returned under another project, or that they were purchased before the implementation of the database.

Case 2 - Mail-order Company MOC

The second set of data comes from a mail-order company active in the Dutch market, here referred to as MOC. The main product line is fashion, but household appliances and furniture are also found in MOC's catalogues (*consumer goods*). Customers can order by mail, phone, fax or internet. Merchandize can be returned at no cost up to a limited amount of time after delivery, yet the company sometimes also accepts later returns. The returns correspond to the *reimbursement returns* type of the framework in Chapter 2.

MOC sends out two catalogues per year: spring/ summer and autumn/ winter. Before the season starts, the catalogue is sent to a subset of recurrent customers, which can pose their orders even though the products are not delivered before more than one month has passed. These orders help the expert's committee to point out an estimation of how many of each single item will be sold over the whole season. This estimated value is periodically updated together with the return percentage, as more information becomes available on both sold and returned items.

MOC is very defensive towards making data on product demand and returns open to the public. The data made available by MOC for this research is as follows: estimated values for the average return percentage per *time unit* both for fashion and hardware products and for the years 2000 and 2001. Detailed information on the *time unit* and the return percentages remains confidential throughout the chapter. Based on the provided information, 4 samples of *time until return* are going to be constructed and used for the statistical testing: fashion-2000; fashion-2001; hardware-2000; hardware-2001 (more information can be found in Section 6.5). Then, for each of them is tested whether, or not, it is reasonable that the underlining distribution consists of a negative exponential. Due to the character of the data, the demand and return processes are not investigated in isolation.

Case 3 - Refinery RF

The third case concerns a refinery in the Netherlands. The warehouse keeps thousands of materials in stock. The warehouse owns the majority of these materials while "customers" own the rest. In the latter situation, though materials are kept in stock in the warehouse of the refinery, there are no monetary exchanges directly associated with a particular demand or material return. Nevertheless, the transactions are registered in the database. We consider the *spare parts* inventory, which mainly consist of slow movers with consumption in a maximum of four months per year. Product returns consist of spares that maintenance personnel did not need for a given maintenance job or rotable spare parts previously repaired to an as-good-as-new condition. Thus, the returns reason correspond to the *service returns* category of the framework of Chapter 2.

The company uses the SAP R/3 material management module for their inventory control. In this system information on demand is stored on a monthly basis. Accordingly, the immediate returns are netted. Only returns that occur in future months are visible (unless they have been netted with new demands). The return lag is determined by identifying for each return the latest month with a positive (netted) demand. Unlike the CERN case, we did not have client or budget codes for tracing. So, the tracing cannot be done with the certainty of the CERN's case. Yet, since in this case we are dealing with slow-movers, the extracted data is credibly very close to the real process. The inventory control policy of SAP employs basically the net demand and ignores returns. The database consists of data from the last 4 years. We have analyzed data from some 800 materials.

6.5 Data analysis

The scarcity of data and, in many cases, its confidentiality explain the lack of publications on empirical analysis of return flows. Yet, this chapter tests real data on demand and product returns. As mentioned previously, three sets of data are considered: data on demand and in-company returns of the warehouse of CERN in Switzerland and of two companies in the Netherlands, a mail-order company and a refinery. Other products than the ones discussed here were investigated. However, it was not always possible to trace back all the return occurrences (see Section 6.4), and sometimes there were insufficient observations to pursue satisfactory testing. In spite of these difficulties, the process of data analysis and the findings have both academic and practical implications, as discussed later.

Case 1 - CERN data analysis

For each product, the results of the analysis state whether, or not, it is reasonable to accept that:

Hypothesis 1: The demand process is an HCPP.
Hypothesis 2: The return process is an HCPP.
Hypothesis 3: The time elapsing between return and demand occurrences follows an exponential distribution.

Table 6.2: Statistical analysis of two products of CERN's database.

Demand process			Return process			Time until return		
No. obs.	Period	Decision	No. obs.	Period	Decision	No. obs.	Period	Decision
Stabilizer gas								
283	88-98	Rej.	12	88-97	Not rej.	12	88-97	Not rej.
36	96-98	Rej.						
26	97-98	Not rej.						
Large agenda								
1043	88-99	Rej.	14	89-98	Not rej.	17	89-99	Not rej.
1009	88-98	Rej.						
362	96-98	Rej.						
253	97-98	Rej.						

The decision to reject, or not, in each of the tests is based on a Type I error, $\alpha = 0.05$, i.e. the probability of rejecting the hypothesis given that it is valid, equals 0.05. The results of the analysis of two products can be found in Table 6.2. One of the products is a *stabilizer gas*, and the other is catalogued as a *large agenda*. Both of these products have return rates around 5% of the issued quantities and a large number of issues. One of the reasons these

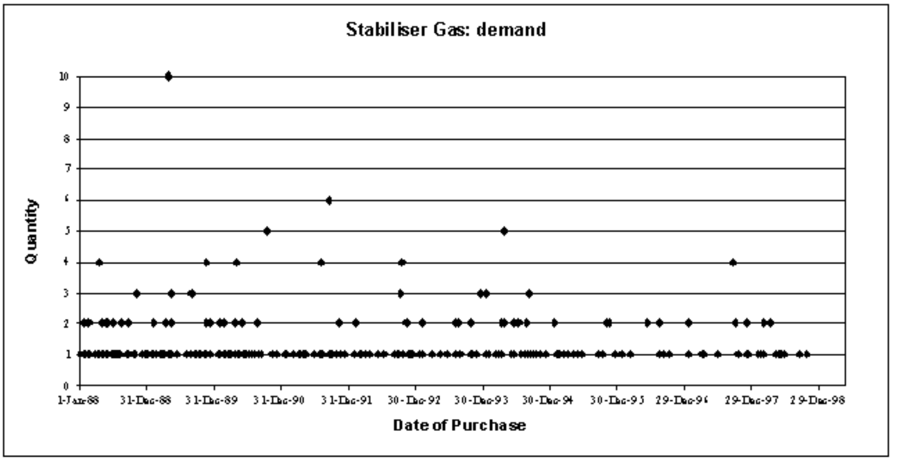


Figure 6.2: Stabilizer gas: date of purchase vs. purchased quantity.

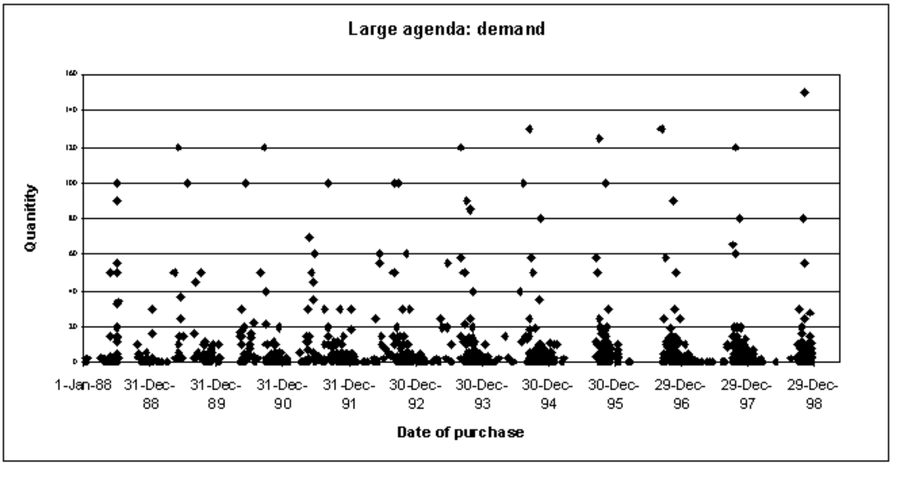


Figure 6.3: Large agenda: date of purchase vs. purchased quantity.

products were chosen for analysis is the possibility of tracking a sufficient number of observations to pursue the required tests. In the case of unit purchases and by assuming no lost or backlogged demand, one may opt for carrying out the tests only for the demand and for the time until return. If the first two hypotheses are not rejected, and making an analogy with queueing systems, one can consider the demand-return process as an $M/M/\infty$, i.e. both the time between demand occurrences and the time until return follow an exponential distribution. For such a queueing system the output flow will eventually behave as a Poisson Process (Ross, 1996), dispensing in this way the need for testing it.

In the case of the stabilizer, it is rejected that the demand process follows a homogeneous Poisson Process for the periods 88-98 and 96-98, but not when only data from 97 and 98 is taken into account. Thus, demand does not remain stable for a period of 10 or even 3 years, but the opposite is acceptable for a couple of years (see Figure 6.2). Regarding the return process, a HCPP is not rejected. It is also statistically not rejected that the time until return is exponentially distributed. begincenter

The *large agenda* is a seasonal product, as observed in Figure 6.3. Therefore, for all the periods considered, the assumption of a HCPP demand is rejected. Actually the demand occurrences do not even behave as a Poisson Process. However, it is accepted that the time in market is exponentially distributed and that the return process is a HCPP. One can explain this by the fact that there are always enough products in the market. Making an analogy with queueing systems this means that the server is always busy, so the output flow does not depend so much on the demand process, but on the service time.

Figure 6.4 is a dotplot of the ordered quantities of the product agenda. One can notice that there are on the one hand many orders of low quantities and on the other hand a few orders of large quantities. This puts forward a division in two groups, namely small and large orders. Other graphical representations, among which the histogram of Figure 6.5 helped us to make the division at the order quantity 20: large orders are the ones of quantities larger or equal than 20 (100 out of 1043). We proceed testing whether, or not, the smaller orders follow an HCPP. The hypothesis is rejected. The seasonality is likely to be the reason for this outcome. Regarding the large order, a tailor-made procedure to integrate these orders in a possible ordering policy is advisable.

Due to insufficient data of individual products, three groups of products (aggregated data) are investigated next. The existence of many, but infrequent individual orders, justifies that the demand follows a Poisson Process (Tijms, 1994). Therefore, the statistical analysis deals with the time until return alone. Group 1 consists of several gases, Group 2 of products with traceable returns, and Group 3 includes Group 2, as well as the returns of the product '*large agenda*' (Table 6.3).

Table 6.3: Outcome of the investigation whether, or not, *time until return* is negative exponentially distributed.

	Group 1	Group 2		Group 3	
		A	*B*	*B*	*C*
No. obs.	18	40	37	53	35
Decision	Not Rej.	Rej.	Not Rej.	Rej.	Not Rej.

Note: *A*= total number of observations; *B*= A minus some very large observations; *C*= B minus the products which returned within 1 week.

It is accepted that the sample of 18 return inter-occurrence times in the first group of products follows an exponential distribution. For the total of 40 return inter-occurrence times of the second group, the exponentiality is, however, rejected.

To investigate whether the data could reasonably follow another distribution, four probability-plots of the exponential and other distributions were traced (Figure 6.6). The plot for the exponential points out that the three large observations are disturbing a good adjustment of this distribution. Indeed, it is not rejected that the data is exponentially distributed if the three large return times are removed. These return times fall between 6 months and one year after purchase, while all the other returns occur within less than 3 months after acquisition. The 3 "odd" return observations may be the result of the termination of projects and a separated treatment is recommendable. Yet, to decide how to deal with these situations in practice, it would be helpful to really have registered the return reason, as it was conceived by CERN's database, but regrettably not used.

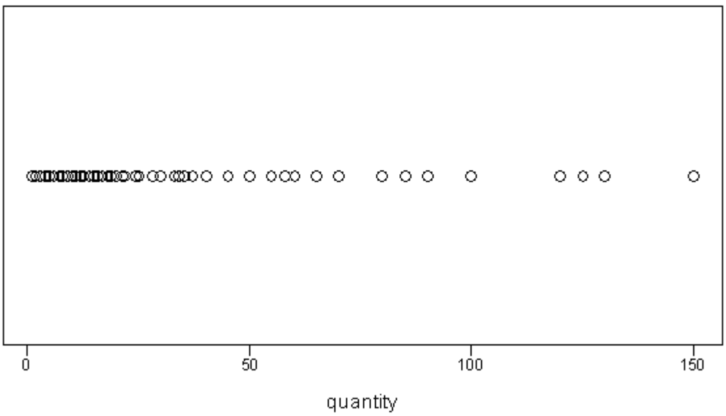


Figure 6.4: Large agenda: dot-plot of the purchased quantity.

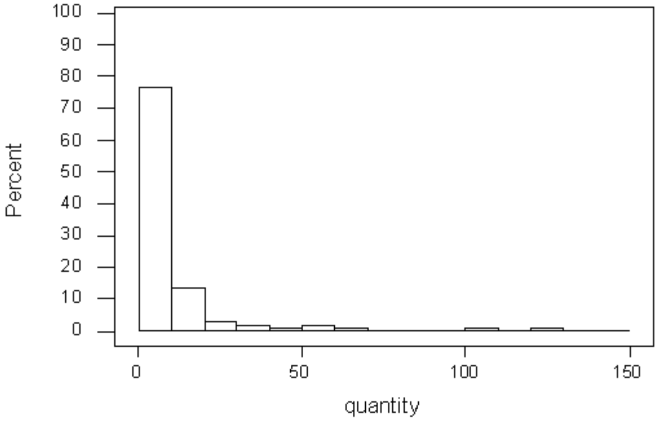


Figure 6.5: Large agenda: histogram of the purchased quantity.

For Group 3 of products, the very large observations were put aside in analogy to the analysis of Group 2. Still, it is not statistically acceptable that these products come back after an exponentially distributed lag. There is one aspect that has not been considered until now. From an inventory perspective, when products come back almost immediately, it is like the demand did not occur in the first place. Therefore, one can distinguish between short-lag returns and longer lag returns. The longer lag returns are the ones likely to have more impact on inventory control, since they may suggest annulment of order replenishments by the warehouse. The short-lag returns can be simply subtracted from the demand process.

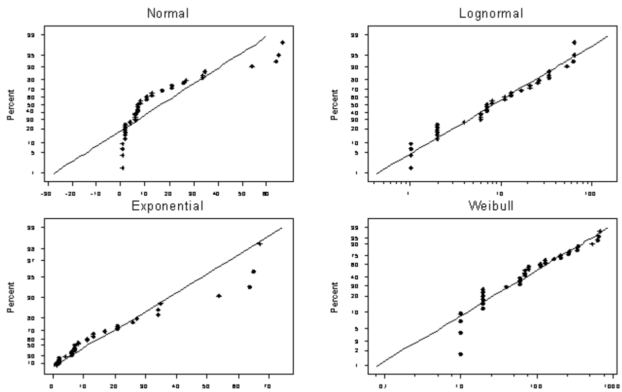


Figure 6.6: Group 2 of products: four probability plots.

The issues discussed in this paragraph give emphasis to the importance of recording return reasons. Moreover, one would then be able to identify the returns which feed demand, and those which not (e.g. wrong delivery, no longer needed). This information could later be used in the forecast of returns and it could help to design improved inventory policies. Following the above arguments, it was investigated for Group 3 whether, or not, longer lag returns follow an exponential distribution. Short-lag returns were those of one week or less return time. In that case, the hypothesis was not rejected.

Case 2 - MOC data analysis

The demand in distance-selling environments (and especially on fashion) is known to fluctuate considerably through time, dispensing the test to evaluate whether, or not, the demand behaves as an HCPP. MOC provided the estimated values for the average return percentage per period both for fashion and hardware for the years 2000 and 2001. For example, the estimated returns for fashion products in the year 2000 are spread over the first five periods after sales as follows: 5%, 70%, 22%, 2% and 1%. The absolute values are confidential.

Because MOC protects detailed information on product demands and returns, the testing samples are constructed based on the information provided by MOC, i.e. the estimated return rates per time unit. Four samples were put together, namely: fashion- 2000; fashion- 2001; hardware- 2000; hardware-2001. The size of the sample is 100, which is not an unreasonable number of returns in this setting. In other words, 100 return-lag occurrences were put together according to the estimated return rates per period. It was tested whether the time elapsed between return and demand occurrences followed an exponential distribution.

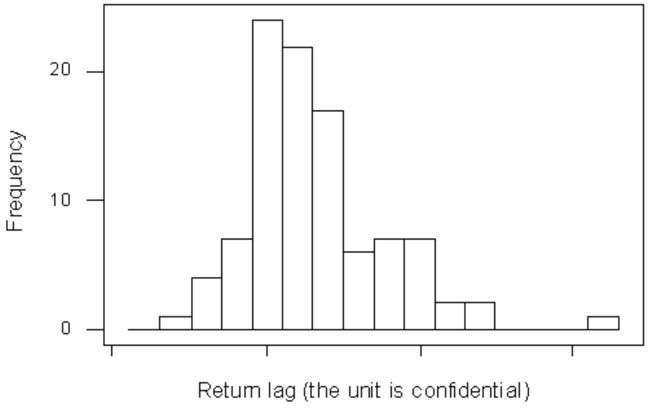


Figure 6.7: MOC Fashion 2000: histogram of the return lag.

For all the four cases tested (fashion-2000; fashion-2001; hardware-2000; hardware-2001) the hypothesis has been rejected. Figure 6.7 is a histogram of the return lag for Fashion in the year 2000. A tentative explanation for non-exponentiality is the presence of the short-lags. However, when the long-lags are tested the hypothesis is still rejected. This is because of the thick tail spread in time as manifested in Figure 6.7, even without the short-lags.

Case 3 - RF data analysis

In the case of the refinery, it was not tested if demand follows an HCPP because of the lack of demand occurrences per product and because the data is aggregated in monthly-netted demand. We scanned about 800 materials and found 137 return occurrences. From those, about 8% could not be traced back, which we therefore left out of consideration. We tested whether the time elapsing between return and demand occurrences follows an exponential distribution, when the lags are pooled over all the products. The assumption is rejected for $\alpha \geq 0.005$, so it is rejected for the usual values of α. We also have tested the hypothesis for non-owned products only (corresponding to 80% of the traced returns). The rationale behind this test has to do with the non-existence of monetary exchanges by occasion of returns of materials that are in any case owned by the customer. The customer is not going to be refunded when he or she returns any products or materials. Thus, there is no monetary incentive to return as soon as possible. Therefore, we suspected that this would lead to a spread of a thick tail, conflicting with the exponential distribution. Figure 6.8 illustrates the existence of a tail. However, the tail effect still remains when only non-owned materials are considered.

From the data we noticed that for some products the stock level was above the desired maximum level (as specified by RF) for a substantial amount of time. The fact that returns are not taken into account in the inventory control contributes to this overstock.

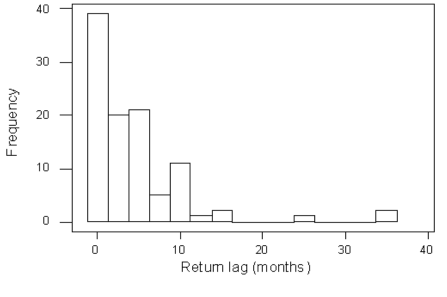


Figure 6.8: RF: histogram of the return lag.

6.6 Summary and conclusions

In this chapter we presented a methodology for the statistical testing of the common assumptions in the literature on inventory modelling with product returns. We proposed statistical tests (see Figure 6.1) to test the following hypotheses:

- The demand process is a Homogeneous Compound Poisson Process.
- The return process is a Homogeneous Compound Poisson Process.
- The time elapsing between return and demand occurrences follows a negative exponential distribution.

With the developed methodology it is possible to carry out the desired testing even with small sample sizes (below 20). Obviously, for extremely small sample sizes no statistical test will be able to guarantee much rigor.

We applied the developed methodology to the following three sets of real data.

Case 1: data from an in-company warehouse with internal returns in Switzerland (CERN),

Case 2: data from a mail-order company with commercial returns in the Netherlands (referred to as MOC), and

Case 3: data from an in-company refinery warehouse in the Netherlands (referred to as RF).

We found that for some products the common assumptions on the theoretical models fit reasonably well. However, we also found products for which they do not. Regarding the (non-)validity of the common assumptions, we empirically observed the following.

A) Demand did not always behave as an HCPP due to seasonality and/or non-stationarity (e.g. agenda and stabilizer gas- CERN).

B) In spite of non-stationary demand, there are products for which we did not reject that the return process behaves as an HCPP (e.g. large agenda- CERN). One can explain this by the fact that there are always enough products in the market. Making an analogy with queueing systems this means that the server is always busy, so the output flow depends on the service process rather than the demand process.

C) In some cases we did not reject that the time to return behaves according to a negative exponentially distribution (e.g. stabilizer gas and Group 1- CERN). So, for these cases the assumption that the time to return is negative exponentially distributed appears to hold.

D) There are products for which the time to return did not seem to behave as an exponential distribution. This is likely caused by a thick tail (e.g. see RF analysis) or due to many short-lag returns (e.g. Fashion 2000- MOC).

We employed data on products of in-company warehouses (CERN and RF) with internal returns and a mail-order company with commercial returns. However, we believe that the findings and its implications are transferable to a much larger group of demand-return processes. In the case of equipment leasing, we conjecture that although the tail of the time to return distribution may behave as an exponential, the same is unlikely to hold for the short-lag returns. In maintenance settings, we believe that the validity of assumptions depends on whether the maintenance is corrective or preventive. In the first case the assumptions are likely to be valid.

6.6.1 Theoretical insights

There are 2 situations to consider.

1. When modelling, we assume independence between demands and returns.

   - If demand follows a Poisson distribution we have, using standard results for a $M/G/\infty$ queuing system, that the return process is also Poisson. If, when modelling, independence between demands and returns is assumed this means that it is appropriate to assume Poisson process for *both* the demand and return streams.
   - If demand is not a Poisson process, but the product is a fast-mover and the time to return is a negative exponential distribution, then we can use standard results from a $G/M/\infty$ queuing system. Using the high-traffic argument ('servers' are always busy), we have that the return process is Poisson. This implies that the Poisson distribution is a good approximation for the return process, as long

as the product is a fast-mover and the time to return is negative exponentially distributed.

2. When modelling, we explicitly take into account dependence between demands and returns.

   In this case, and when the time to return is negative exponentially distributed, one can exploit the memoryless property. If you know at the moment of sale if a product will return or not, the total number of products in the market that will return is sufficient to forecast the number of returns. Note, however, that in practice this only occurs in very specific situations. For example, if you not only sell to costumers, but also offer service contracts to some of them, you know which products will return. Another example for which you know in advance which products return is when some products are sold while others are leased. A drawback of this situation, however, is that the lease time is not likely to be negative exponentially distributed.

   If you do *not* know in advance if a sold product will return or not, you cannot make use of the memoryless property (see the introduction of Section 6.3).

6.6.2 Managerial implications

Returns can be said to be a "necessary evil" as they complicate inventory control. Generally, it is important to know how much will come back and when. This knowledge can be used to avoid superfluous replenishment orders and the outdating of products. Therefore, it is important that companies monitor returns, investigate return reasons, and estimate (the distribution of) the return lag. Companies may then try to influence the return lag, for instance to shorten it.

In the context of inventory management and control, we put forward the following suggestions:

- First separate short-lag returns from long-lag returns. Then, proceed to netting of the short-lag returns, i.e. $(D^{'} = D - R)$, so it is as returns have never occurred. Especially for long-lag returns: monitor the return distribution, the return rates and register return reasons. The latter helps to find return patterns that may be useful to find ways of shortening the lag and/or to fine-tune the inventory control policy (e.g. cancellation of replenishments when many products are expected to return).

- When investing in product return information (e.g. tracking and tracing) and its storage, the following should be taken into account.

  If you know in advance which products are going to return, then, according to the theoretical insights above, one should investigate whether, or not, the return lag is likely to behave as a negative exponential distribution. If it is, one only has to keep track of the total number of products in the market that will return to forecast returns.

  If you do not know in advance which products are going to return, or if the time to return is not negative exponential, you may wish to collect advanced information on returns.

  In a stationary environment investments on tracking and tracing may pay off. However, in a non-stationary environment or if information is not reliable, an advanced use of information may have lower performance than a more parsimonious use. Chapter 7 investigates this issue in depth.

  It is important to note, however, that in practice there are other considerations regarding the investment in information systems then inventory management alone. We mention customer relationship, product responsibility and control, and visibility.

From the process of acquiring data and from the data available for this research we conclude that detailed data on product and material returns is extremely scarce. When data on returns is found, it is most likely to be aggregated with demand, limiting statistical analysis. Besides this, we anticipate that many companies are losing opportunities to improve their inventory management due to lack of data on returns (see also Chapter 7).

6.6.3 Research needs

This chapter presented the first empirical analysis regarding the validity of common assumptions in the literature on inventory management with product returns. The data analysis only covered some specific situations and more analysis is needed to generalize the results.

We have used several real examples to verify whether the time to return behaves as a negative exponential. For some instances the hypothesis was accepted, for others rejected. In some situations the impact of using the wrong assumptions may be small, for others they may be large. Research is needed to assess this impact. Also, for the cases for which the impact is large, models need to break with the traditional assumptions in the literature on inventory modelling with returns.

Inventories for seasonal products with returns are very difficult to manage. Especially at the end of the season it is important to consider the product returns, as the product's value drops rapidly at the end of the season. This should be considered in research on inventory modelling with product returns. Anyway, researchers can be more explicit about the situations in which their assumptions hold or not.

Chapter 7

Inventory Management with product returns: the value of information

In any decision situation,
the amount of relevant information available
is inversely proportional to the importance of the decision.

(Cooke's Law), Paul Dickson

7.1 Introduction

Products and packaging return into the supply chain for a diversity of reasons (see Chapter 2). For instance, beverage containers are returned by the consumer to the retailer against reimbursement, single-use photo cameras are turned in for the film to be developed, and now millions of products purchased through mail-order-companies, e-tailers and other distant sellers, are being returned every day.

There is a lot of money involved with the handling of product returns (Rogers and Tibben-Lembke, 1999). One of the difficulties in handling returns efficiently is that return flows are often characterized by a considerable uncertainty essentially regarding time and quantity. If one could exactly know how much is going to be returned and when, one would certainly benefit from incorporating this perfect information a priori in the management of production, inventory, and distribution. In many cases this is far from feasible (see

Trebilcock, 2002). Nevertheless, one may attempt to forecast the timing and the amount of product returns. To do so, one has to hypothesize about the return flow properties based on historic demand and return data.

There are not many papers that investigate the impact of information on inventory management with product returns. The ones that do so assume known return probabilities or consider specific cases where the most-informed method leads to the best forecast. However, in environments where data is scarce or unreliable, or in environments that are volatile, information may be misleading. This study reports on the impact that such (mis)information has on inventory management. This chapter identifies situations in which the most informed method does not necessarily lead to the best performance. Furthermore, the impact on inventory related costs of having inaccurate estimates of the time-to-return distribution is investigated for a wide range of parameters. In addition, the implications for the practice of inventory management with returns will be discussed. This work has been reported in De Brito and Van der Laan (2003).

The remainder of the chapter is structured as follows. First, Section 7.2 illustrates that estimates of the return rate can be massively erroneous in practice. Next Section 7.3 reviews the literature on the topic. Subsequently Section 7.4 elaborates on procedures to estimate the net demand. By means of an exact analysis, Section 7.5 identifies situations in which more information does not necessarily lead to better performance. Section 7.6 then presents a simulation study to quantify the impact of misinformation with respect to inventory related costs. In Section 7.7, the managerial implications are discussed and Section 7.8 concludes by giving recommendations for future research.

7.2 (Mis)information in practice

This chapter reports on the impact of (mis)information in an inventory system with product returns. Misinformation means here that the properties we assume for the *future* return flow do not correspond to the actual properties of the *future* return flow. Further attention is paid next on how misinformation can occur in a given system.

Figure 7.1 illustrates how the "information" arrives to the decision-maker. A tool transforms data into "information" (e.g. system parameters), with which the decision-maker controls the system. On the one hand, data may be insufficient, abundant, ambiguous or conflicting (see Zimmerman, 1999) causing misinformation as input. On the other hand, the tool may be imperfect creating some sort of distortion. The impact of misinformation on inventory systems has for long been studied. Bodt and Van Wassenhove (1983) explained how firms could see the advantages of using Material Requirements Planning (MRP) being drastically reduced due to misinformation. Gardner (1999) showed how important is to choose an adequate forecasting tool while investing in customer service levels. Some misinformation mechanisms are well-known in inventory management, like the bullwhip effect, as introduced by Lee et al. (1997). Misinformation is a general phenomenon, not specific for systems with product returns. Yet, academics and practitioners agree that managing systems with product returns is very demanding with respect to neat information, which is sparsely available (see Gooley, 1998; Guide, 2000b; De Brito et al.,2003; Kokkinaki et al., 2004).

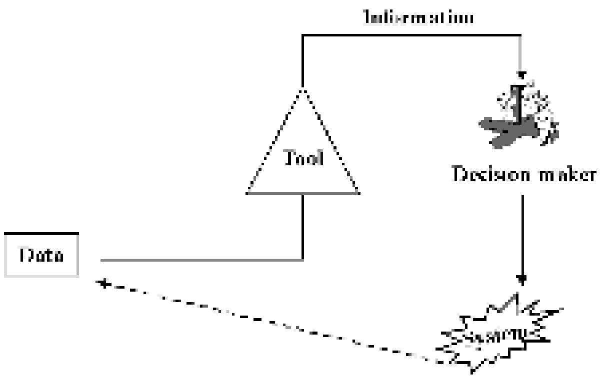


Figure 7.1: Relation between data and decision-making.

In this chapter, the source or reason of misinformation is not a matter of concern. The objective of this study is to evaluate the impact of misinformation on the system, given that misinformation occurs. Next a real-life example illustrates that misinformation on product returns does happen in practice. The company's name is here disguised as MOC.

MOC is a large Western European mail-order-company (see also Chapter 5). Well before the start of the season, the company has to decide on what to offer for sale in the upcoming catalogue. A great part of the total stock to cover all the season has to be ordered many weeks in advance because production lead times are long. This is many times the case in Europe or the U.S. where manufacturing comes from Asia (see Mostard and Teunter, 2002). The order decisions take into account the expected future demand and returns for each line of products. Since there is however no data available on the sales of the coming season, the forecast is not much more than a rough estimate. In particular, a mail-order-company in the Netherlands uses estimates that on average are more than 20% off the real return rate and sometimes even more than 80%. The above illustrates that large mis-estimation of the return rate does occur in practice. This chapter analyzes its impact on inventory management.

7.3 Literature review

The literature dealing with product returns has been growing fast in the last years. This literature falls in the general umbrella of closed-loop supply chain management. For contextual contents, see Rogers and Tibben-Lembke (1999); Guide and Van Wassenhove (2003); Dekker et al. (2004). Inventory Management has received chief attention from the beginning until now, which has brought about a richness of studies (see e.g. the following recent ones: Van der Laan et al., 1999; Inderfurth et al., 2001; Fleischmann et al., 2002). In spite of these and many other contributions, there are few articles that simultaneously consider the forecasting of product returns, inventory management and information issues. Below follows a review on specific literature contributing to close the aforementioned gap.

Goh & Varaprasad (1986) developed a methodology to compute life-cycle parameters of returned containers by employing data on demand and returns. The authors claim that a careful estimation of these parameters aids to effective inventory management. They apply their method to data on soft drinks as Coca-Cola and Fanta from the Malaysia and Singapore markets. The approach requires a time series of aggregated demand and another one of aggregated return data. They used a 50-point time series of monthly data. The precision of the method depends on how accurate the estimation of the return distribution is. This estimation has the Box-Jenkins time series techniques as basis. The authors call the attention of the reader to the fact that a data set with less than 50 points is too short to employ the methodology. Large time series should also be avoided. Therefore, they recommend a time series of 50 points, or a 4-year period of data coming from a stable market environment. Our research contributes to contrasting situations: with imperfect or misleading data.

Kelle & Silver (1989) proposed four forecasting procedures of net demand during lead time in the case of reusable containers. Every procedure has a different level of information requirement. The least-informed method uses the expectation and the variance of the net demand together with the probability of return. The most-informed one calls for individual tracking and tracing of containers. The authors evaluate the forecasting methods taking the most-informed method as a benchmark. The analysis, however, applies only to the case of perfect information on the return parameters. This chapter employs the methods proposed by Kelle and Silver (1989) but it elaborates on the potential impact of (mis)information.

Toktay et al. (2000) consider the real case of new circuit boards for Kodak's single use remanufactured camera. The goal is to have an ordering policy that minimizes the procurement, inventory holding and lost sales costs. A six-node closed queueing network is employed to represent Kodak's supply chain. Accordingly, the returns of cameras depend on past sales by a return probability and an exponential time lag distribution. Some of the procedures of Kelle and Silver are used to predict the unobservable inventory at the customer-use network node. The authors compare several forecasting methodologies with different levels of information. This chapter provides an exact and more general analysis of the impact of (mis)information. Furthermore, the four methods of Kelle and Silver are compared numerically for a wide range of parameter values with respect to misinformation. Therefore, besides an intra-method comparison, here an inter-method analysis is also presented.

Marx-Gómez et al. (2002) consider a case of photocopiers that may return to the producer after being used. The authors put forward a method to forecast the number and time of returned photocopiers. Firstly, data is generated according to two scenarios: successful vs. not so successful return incentives. These scenarios, together with expert knowledge, constitute the basis for developing a set of forecasting rules. The expert evaluates factors, such as demand and life cycle parameters. An extended approach of the model is suggested by allowing a follow-up period to self-learn the rules. This neuro-fuzzy process calls for data on demands and returns. Besides this, one should notice that the method of Marx-Gómez et al. depends on a priori knowledge on product returns, which have been acquired by the producer.

Overall one can conclude that the proposed procedures are very demanding with respect to reliable data. This chapter takes the more realistic perspective of misinformation and analyzes its impact.

7.4 Forecasting methods

The main notation used in this chapter is as in Table 7.1.

Consider a single product, single echelon, periodic review inventory sys-

Table 7.1: Notation.

t,	the current time period; $t = 0, 1, 2, \ldots$
L,	order leadtime
$D_L(t)$,	r.v. representing the demand during the interval $[t+1, t+2, \ldots, t+L]$
$R_L(t)$,	r.v. representing the returns during the interval $[t+1, t+2, \ldots, t+L]$
$ND_L(t)$,	the net demand during the leadtime (equal to $D_L(t) - R_L(t)$).
p_j,	the probability of an item returning after exactly $j = 1, \ldots, n$ periods, n being the largest j for which the return probability is larger than zero.
p,	the probability of an item ever being returned, i.e. $\sum_{j=1}^{n} p_j$.
u_i,	demanded amount during period i and $i \leq t$.
y_i,	the total amount returned in each previous period $i \leq t$.
S,	base-stock level.
k,	safety factor

tem. Each individual demand returns with probability p according to some return distribution. We assume that this process does not change in time (stationary case). Returns are immediately serviceable. The order lead time is a fixed constant L. Demands that cannot be satisfied immediately are fully backordered. Following the methodology of Kelle and Silver (1989), for each time period t a base-stock policy is applied. If the net lead time demand, $ND_L(t) = D_L(t) - R_L(t)$, follows a normal distribution the optimal base stock level is given as

$$S = \mathrm{E}[ND_L(t)] + k \cdot \sqrt{\mathrm{Var}[ND_L(t)]} \tag{7.1}$$

with $E[ND_L(t)]$ and $\mathrm{Var}[ND_L(t)]$ being the expectation and variance of the net demand during lead time. The safety factor k is determined according to some desired performance level (see e.g. Silver et al., 1998).

In order to estimate $\mathrm{E}(ND_L(t))$ and $\mathrm{Var}[ND_L(t)]$, the four methods first put forward by Kelle and Silver (1989) are used. Apart from the expectation and variance of the demand during lead time ($\mathrm{E}[D_L(t)]$ and $\mathrm{Var}[D_L(t)]$ respectively), each method requires a different level of information for estimating the lead time returns. Below, in increasing order of information needs, the four methods, denoted A–D, are listed (see Appendix 1 for details).

Method A - Average behavior

This method requires the following information:

- p, the overall return probability, i.e., the probability that a product is being returned eventually.

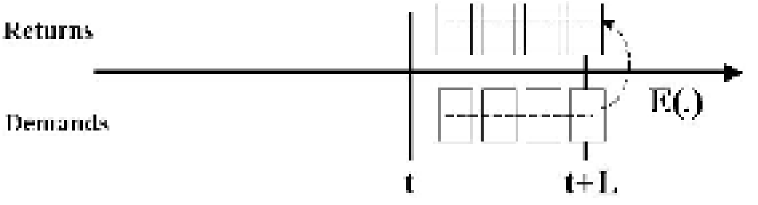


Figure 7.2: Method A (it uses the overall return probability to compute the expected returns coming from demand during the lead time.

This method is an approximation in the sense that all the returns during the lead time are assumed to be perfectly correlated with the demand during that same lead time and independent of previous demands (see Figure 7.2). Returns during the lead time are estimated through the overall return probability (it is like if a product is to return, it returns instantaneously). Then, demand and returns during the lead time are simply netted (see also Chapter 6). No historical information is used with respect to demands and returns, so in a static environment the resulting base stock level is constant in time.

Method B - Return distribution

Suppose that we are at the end of period t. This method requires information on previous demand per period and the knowledge of the return distribution as follows:

- u_i, demanded amount during period $i \leq t$.
- p_j, the probability of an item being returned exactly after j periods, $j = 1, ..., n$, with n being the largest j for which the return probability is non-zero.

This method makes use of the return probabilities to determine the number and moment of the returns during the order lead time (see Figure 7.3).

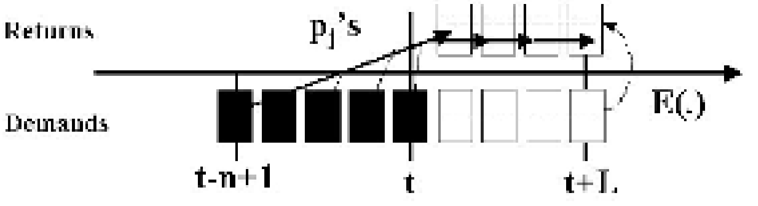


Figure 7.3: Method B (it uses past demand and return probabilities $p_j's$ to compute returns coming from past demand and it employees expected values for returns coming from demand during the lead time).

Method C - Return distribution & return information per period

Suppose that we are at the end of period t. In addition to the requirements of method B, this method makes use of observed data on aggregated returns:

- u_i, demanded amount during period $i, i \leq t$.
- p_j, the probability of an item being returned exactly after j periods, $j = 1, ..., n$, with n being the largest j for which the return probability is non-zero.
- y_i, the total amount of returned products in each period $i, i \leq t$.

This method updates the number of items that have returned, which are observed, and takes this into account to compute future returns (see Figure 7.4). Thus, Method C aims at improving Method B by taking into account the

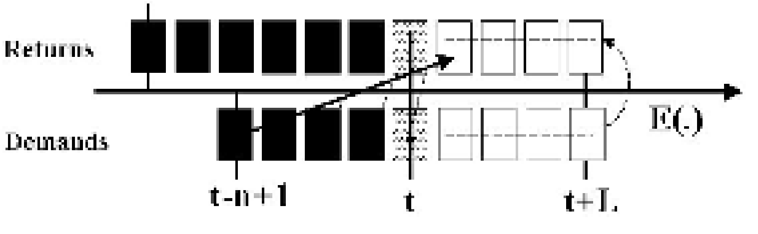


Figure 7.4: Method C (it uses information on past demand and past returns to compute the returns coming from past demand; it uses information on current demand to compute returns coming from period t; and it uses expected value to compute returns coming from demand during the lead time).

correlations between the observed aggregated returns in recent periods and the future lead time returns. An analytical method, however, is not available, so Kelle and Silver (1989) developed an approximation (see Appendix 1) that is accurate as long as the purchased amount is relatively large and the return probabilities are positive for several periods (in practice $n \geq 4$).

Method D - Return distribution & tracked individual returns

Let t be the last observed period. Besides the requirements of method B this method requires to track back in what period each individual return has been sold:

- u_i, demanded amount during period $i, i \leq t$.
- p_j, the probability of an item being returned exactly after j periods, $j = 1, ..., n$, with n being the largest j for which the return probability is non-zero.
- Z_i^t, the observed total number of product returns from each past purchase $u_i, i < t$.

To employ this method, one has to be able to trace back the returns, i.e. to know from which order period each specific return is coming from (see Figure 7.5).

Given perfect information this method makes optimal use of all relevant information.

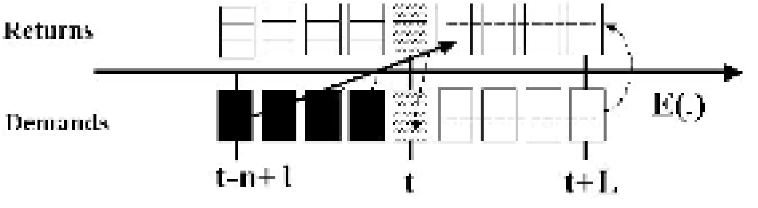


Figure 7.5: Method D (it uses information on past demand and observed returns from each past demand to compute the returns coming from past demand; it uses information on current demand to compute returns coming from period t; and it uses expected value to compute returns coming from demand during the lead time).

Summarizing, all four methods for estimating the net demand during the order lead time, make use of the expectation and variance of demand. Additionally, each method has different requirements with respect to product return information. Method A is the least demanding: only an estimate of the return rate is needed. Apart from the return rate, Method B requires the return time distribution. On top of that, Method C also needs a record of the aggregated returns per period. Finally, to employ Method D one needs to invest in a system that allows to scan individual returns and track them back to the period in which they were originally sold.

Given perfect information one expects that the method that uses more information outperforms the methods that use less. The remainder of the chapter investigates how the various methods perform in presence of misinformation. First, Section 7.5, identifies situations in which Method B may outperform the most informed method, Method D. Then Section 7.6 compares Methods A–D with respect to inventory related costs and confirm the findings of Section 7.5 by means of a simulation study.

7.5 Forecasting performance

This section analyzes the relative performance of Methods B and D given misinformation. Methods A and C contain approximations which makes them less interesting for an exact analysis. Besides that, Method A is a rather naive forecasting method, which is not expected to perform very well in general (this will be confirmed in Section 7.6) and the performance of Method C tends to be very close to that of Method D (Kelle & Silver, 1989).

Since, given perfect estimation, Method D is expected to lead to the best forecast of the expected lead time net demand, we use Method D *given perfect information* as a benchmark for our study. Given *imperfect* estimation, both Methods B and D will do worse than the benchmark, but it is important to know whether there are situations in which Method B outperforms Method D. Therefore, with respect to the expected lead time net demand we would like to compare

$$\left|\widehat{\mathrm{E}}_B[ND_L(t)] - \mathrm{E}_D[ND_L(t)]\right| \textit{ and } \left|\widehat{\mathrm{E}}_D[ND_L(t)] - \mathrm{E}_D[ND_L(t)]\right|$$

Here '$\widehat{\ }$' denotes a forecast, based on forecasts $\{\widehat{p}_i\}$ of $\{p_i\}$. However, the above expression depends on observations Z_i of past product returns coming from demand u_i. Accordingly, we take the conditional expectation with respect to the return process given the history of the demand process, $\mathcal{E}_{R|D}$:

$$F_{\{E\}} = \mathcal{E}_{R|D} \left\{ \left| \widehat{\mathrm{E}}_B[ND_L(t)] - \mathrm{E}_D[ND_L(t)] \right| - \left| \widehat{\mathrm{E}}_D[ND_L(t)] - \mathrm{E}_D[ND_L(t)] \right| \right\} \tag{7.2}$$

Note that if $F_{\{E\}} < 0$ then, on average, Method B outperforms Method D with respect to the expected net leadtime demand and *vice versa* if $F_{\{E\}} > 0$. Similarly, the performance measure with respect to the variance of the lead time net demand is

$$F_{\{V\}} = \mathcal{E}_{R|D} \left\{ \left| \widehat{V}(< t)_B - V(< t)_D \right| - \left| \widehat{V}(< t)_D - V(< t)_D \right| \right\} \tag{7.3}$$

To make the analysis more readable we define $\pi_i = \sum_{j=1}^{t-i} p_j$ and we write '$\sum$' for '$\sum_{i=t-n+1}^{t-1}$'. In section 7.5.1 we analyze the expectation of the net demand during leadtime and in section 7.5.2 its variance.

7.5.1 Analysis regarding the expectation of lead time net demand

Define

$$E_{\{BD\}} = \widehat{\mathrm{E}}_B[ND_L(t)] - \mathrm{E}_D[ND_L(t)],$$
$$E_{\{DD\}} = \widehat{\mathrm{E}}_D[ND_L(t)] - \mathrm{E}_D[ND_L(t)]$$

Obviously, $E_{\{BD\}} = 0$ implies that, given misinformation, Method B performs at least as good as Method D and $E_{\{DD\}} = 0$ implies that, given misinformation, Method D performs as good as the benchmark and therefore performs at least Method B will not have a better performance. Conditioning on the signs of $E_{\{BD\}}$ and $E_{\{DD\}}$ we have 4 remaining cases, EXP1–EXP4, to analyze:

Case EXP1: $E_{\{BD\}} > 0$ and $E_{\{DD\}} > 0$

Case EXP2: $E_{\{BD\}} < 0$ and $E_{\{DD\}} < 0$

Case EXP3: $E_{\{BD\}} < 0$ and $E_{\{DD\}} > 0$

Case EXP4: $E_{\{BD\}} > 0$ and $E_{\{DD\}} < 0$

From the analysis of EXP1–EXP4 in Appendix 2 we conclude that, on average, Method B results in a better forecast of the expected lead time net demand in the case we consistently under- or overestimate the return probabilities $pj's$.

From cases EXP1–EXP4 it is also clear that the difference between the methods increases as the R_i get bigger. In other words, for higher return rates the differences between the methods are also larger (with respect to the forecasts of the expected lead time net demand).

7.5.2 Analysis regarding the variance of lead time net demand

Using expressions (7.13) and (7.23) in Appendix 1 we define

$$\begin{aligned}
V_{\{BD\}} &= \widehat{\mathrm{Var}}_B[ND_L(t)] - \mathrm{Var}_D[ND_L(t)] \\
&= \sum \left[u_i \widehat{R}_i(1-\widehat{R}_i) - (u_i - Z_i)Q_i(1-Q_i)\right] \\
V_{\{DD\}} &= \widehat{\mathrm{Var}}_D[ND_L(t)] - \mathrm{Var}_D[ND_L(t)] \\
&= \sum (u_i - Z_i)\left[\widehat{Q}_i(1-\widehat{Q}_i) - Q_i(1-Q_i)\right]
\end{aligned}$$

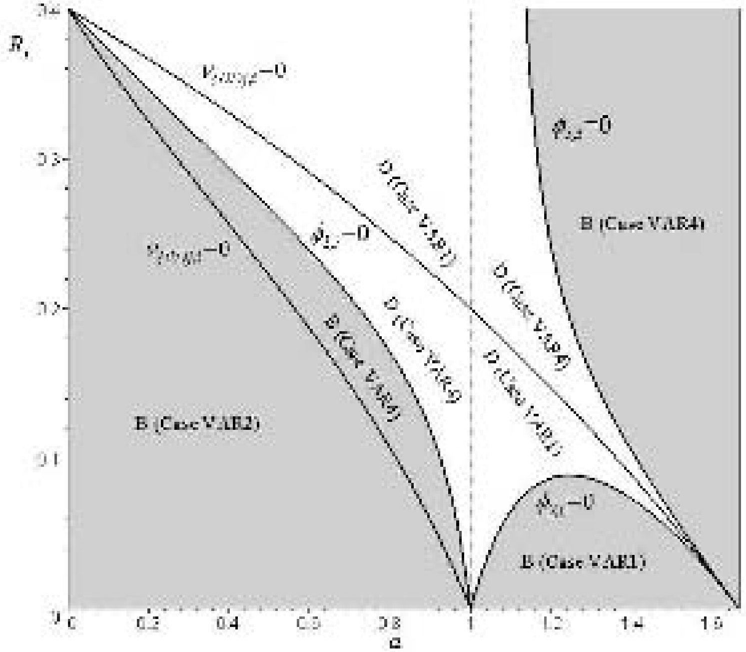
We attempted an analysis of the performance measure with respect to the variance, as defined in (7.3), similarly to the analysis pursued for the expected value. However, we did not obtain straightforward inequalities (see De Brito and van der Laan, 2003). It is very likely that with respect to the variance there are situations for which Method B outperforms D, but also situations for which D outperforms B. We enhance the analysis by looking again at the special case that we misestimate the overall return probability, i.e. $\widehat{p} = a \cdot p$ for some $a : 0 \le a \le 1/p$, while the shape of the return distribution remains intact. We can write $\widehat{R}_i = aR_i$ and $\widehat{Q}_i = aR_i/(1-a\pi_i)$. Still it is difficult to analyze $F_{\{V\}}$ directly because of the summations. So, instead we analyze the individual *coefficients* of u_i in $V_{\{BD\}}$, $V_{\{DD\}}$,and $F_{\{V\}}$. Denote these by $\nu_{\{BD\},i}$, $\nu_{\{DD\},i}$, and ϕ_i. If we define $Z_i = \beta_i u_i$, $0 \le \beta \le 1$ we can write

$$\begin{aligned}
\nu_{\{BD\},i} &= R_i\left[a(1-aR_i) - \left(1 - \tfrac{R_i}{1-\pi_i}\right)\left(\tfrac{1-\beta_i}{1-\pi_i}\right)\right] \\
\nu_{\{DD\},i} &= (1-\beta_i)R_i\left[\tfrac{a(1-aR_i/(1-a\pi_i))}{1-a\pi_i} - \tfrac{1-R_i/(1-\pi_i)}{1-\pi_i}\right]
\end{aligned}$$

$$\phi_i = \begin{cases}
\phi_{1,i} = & aR_i\left[(1-aR_i) - \left(1 - \tfrac{aR_i}{1-a\pi_i}\right)\left(\tfrac{1-\pi_i}{1-a\pi_i}\right)\right] \quad \text{(VAR1)} \\
\phi_{2,i} = & -\phi_{1,i} \quad \text{(VAR2)} \\
\phi_{3,i} = & R_i\left[2\left(1 - \tfrac{R_i}{1-\pi_i}\right) - a\left(1 - \tfrac{aR_i}{1-a\pi_i}\right)\left(\tfrac{1-\pi_i}{1-a\pi_i}\right) - a(1-aR_i)\right] \quad \text{(VAR3)} \\
\phi_{4,i} = & -\phi_{3,i} \quad \text{(VAR4)}
\end{cases}$$

Figure 7.6 gives an example of how the preference regions are constructed through $\nu_{\{BD\},i}$, $\nu_{\{DD\},i}$, and ϕ_i in terms of a and R_i. Note that the boundary between the preference regions of Method B and D only depends on ϕ_i (the coefficient of $F_{\{V\}}$) and not on the coefficients of $V_{\{BD\}}$ and $V_{\{DD\}}$. Since ϕ_i does not depend on Z_i the analysis is independent of a particular realization of observed returns.

Figure 7.6: Preference regions for $F_{\{V\}}$ in terms of a and R_i; $\pi_i = \beta_i = 0.6$, $p = 0.7$.

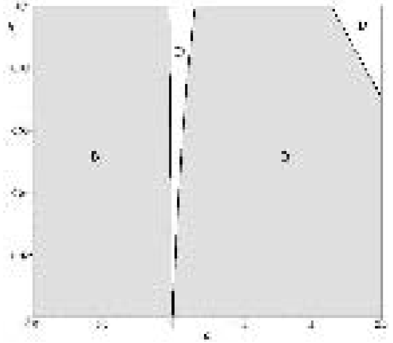


Not all the combinations of R_i and a in Figure 7.6 are feasible, since $R_i \leq p - \pi_i$ and $a \leq 1/p$. Figures 7.7a-f depict the preference regions for the feasible area only and for various values of p and π_i. From these figures it appears that Method B performs better as R_i gets smaller, π_i gets larger or p gets smaller, particularly if $a < 1$. Note that the R_i tend to be small if the base of the time-to-return distribution, n, is large compared to the lead time L. At this time we would like to stress that the analysis of this section does not depend on time t, since equations (7.12)–(7.3) do not depend on t, nor did we make any assumptions on realizations of the demand process $\{u_i\}$ and observed returns $\{Z_i\}$.

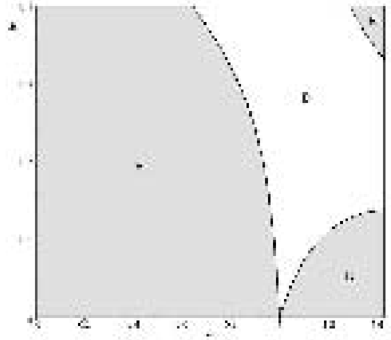
In summary, we conclude that it is not at all obvious that Method D, which is the most informed method, performs better than Method B. In fact, we have identified situations in which Method B performs better, on aver-

Figure 7.7: Preference regions in terms of a and R_i for various values of π_i and p.

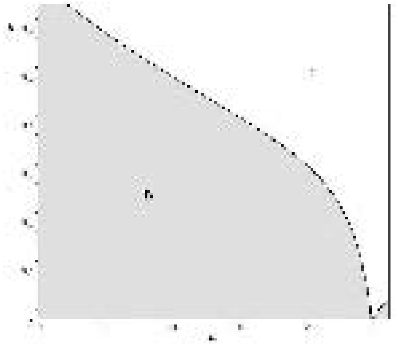
(a) $\pi_i = 0.3; p = 0.40$



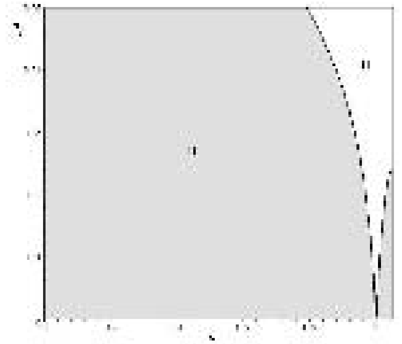
(b) $\pi_i = 0.3; p = 0.70$



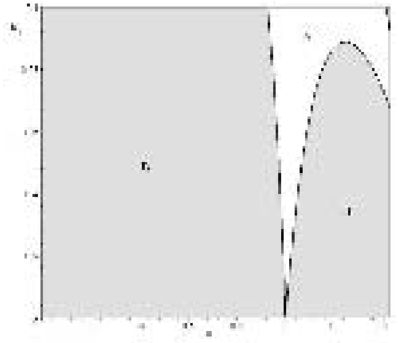
(c) $\pi_i = 0.3; p = 0.95$



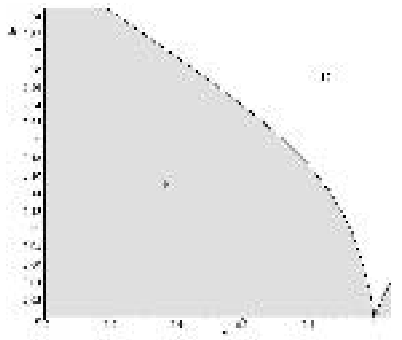
(d) $\pi_i = 0.9; p = 0.95$



(e) $\pi_i = 0.6; p = 0.70$



(f) $\pi_i = 0.6; p = 0.95$



age, with respect to the expectation and variance of lead time net demand. In particular, when all return probabilities are underestimated or all return probabilities are overestimated Method B has opportunities to outperform Method D. In the next section we will quantify the impact of misinformation with respect to costs.

7.6 Cost performance

7.6.1 Experimental design

In order to quantify the impact of misinformation on inventory related cost performance we conducted a simulation study. We consider holding and backorder costs as described later. The experiments are based on the inventory system that was introduced in Section 7.4 and are conducted in the following manner. Each period t we draw the cumulative demand $D(t)$ from a normal distribution with mean μ_D, variance σ_D^2, and coefficient of variation $cv_D = \frac{\sigma_D}{\mu_D}$ (values are rounded to integers; negative numbers are treated as zero). For each individual item of this cumulative demand we determine the time to return based on the pre-specified return probabilities, $\{p_j\}$. Each period, estimates of the expectation and variance of the net demand during lead time are computed according to one of methods A–D. These estimates are subsequently used to compute the base stock level, S. At the end of each period, overstocks are charged with a holding cost \$ h per item, per period, whereas stockouts are penalized with \$ b per occurrence. At the end of each simulation experiment we calculate the total average cost per period as the total average holding plus backorder costs per period. Note that all methods use *estimates*, $\{\widehat{p}_j\}$, of the real return probabilities, $\{p_j\}$, since the latter are not known. The same holds for the overall return probability, p, which is estimated as $\widehat{p}$.

Each simulation experiment consists of at least ten simulation runs of 5.000 periods, preceded by a warm-up run of the same length. The simulation stops as soon as the relative error in the total average costs is less than 1%. In order to make a better comparison among simulation experiments we make use of common random numbers. Please note that in this study all parameters are assumed to be constant over time.

Based on the estimates $\mathrm{E}[ND_L(t)]$ and $\mathrm{Var}[ND_L(t)]$ of the mean and variance of net lead time demand the base stock level S is computed as in (7.1). Assuming that the net demand during lead time is normally distributed, the cost optimal value of the safety factor, k, satisfies $G(k) = 1 - \frac{h}{b}$, where $G(.)$ is the standard normal distribution (see Silver et al., 1998).

The time-to-return distribution $\{p_j\}$ consists of two components: The overall return probability p and the *conditional* time-to-return probabilities $\{\overline{p}_j\}$ given that the item returns. The (unconditional) time-to-return probabilities then are defined as $p_j = p \cdot \overline{p}_j$, $j \in [0, 1, \ldots, n]$. In the simulation experiments we use two conditional time-to-return distributions. The first one is a geometric distribution with conditional expected return time $T = 1/q$, i.e. $\overline{p}_j = q(1-q)^{j-1}$, $j = 1, 2, \ldots, \infty$. The second is a discrete uniform distribution with conditional expected return time $T = (n+1)/2$, i.e. $\overline{p}_j = 1/n$, $j = 1, 2, \ldots, n$. Please note that in this study all parameters are constant in time.

7.6.2 Numerical study

In the case of perfect information, i.e. $\hat{p} = p$ and $\hat{p}_j = p_j$, method D will outperform all other methods since it is using all of the available information in a correct way. In order to investigate the effect of misinformation, we consider two types of errors in the parameter estimates. The first is a misspecification of the overall return probability, p, while the expected return time is preserved. The second is a misspecification of the conditional expected time-to-return, T. This affects the shape of the time-to-return distribution, but the estimated overall return probability is preserved. For example, suppose that the real time to return distribution is given by $\{p_1, p_2, p_3\} = \{0.2, 0.1, 0.2\}$. Then an estimate of $\{\widehat{p}_1, \widehat{p}_2, \widehat{p}_3\} = \{0.1, 0.05, 0.1\}$ would have the same conditional expected time-to-return (2.0), but a 50% lower estimated return probability. An estimate of $\{\widehat{p}_1, \widehat{p}_2, \widehat{p}_3\} = \{0.3, 0.1, 0.1\}$ would have the same overall return probability (0.5), but a lower conditional expected time-to-return.

For numerical comparisons we define the relative difference of some method m with respect to method D as follows:

$$\text{relative difference} = \frac{\text{costs method } m - \text{costs method D}}{\text{costs method D}} \times 100\%$$

Perfect information

Comparing the four methods in the case of perfect information (Tables 7.2–7.3) we observe here that method D is indeed superior to the other methods, although the differences with respect to methods B and C are not significant for $p \leq 0.8$ (less than 1 percent). The performance of Method A is extremely poor. It uses the assumption that all lead time returns are correlated with the lead time demands. This causes a systematic underestimation of the variance in the lead time net demand, especially for high return rates and large lead

Table 7.2: Comparison of Methods A–D in the case of perfect information; Geometric time-to-return distribution; $\mu_D = 30$. *) results below 1% are not significant.

	Methods			
	A	**B**	**C**	**D**
	relative difference*			costs
Base case: $p = 0.5, T = 1.67, cv_D = 0.2$ $L = 4, h = 1, , b = 50$	24.9%	0.2%	0.0%	26.07
$\mathbf{p = 0.8}$	111.8%	0.9%	0.4%	22.85
$\mathbf{p = 0.9}$	129.3%	3.1%	0.6%	21.24
$\mathbf{T = 2.50}$	35.7%	0.3%	0.1%	27.98
$\mathbf{T = 5.00}$	56.7%	0.4%	0.0%	30.70
$\mathbf{cv_D = 0.4}$	36.3%	0.0%	0.0%	44.80
$\mathbf{cv_D = 0.8}$	24.8%	0.0%	0.0%	83.00
$\mathbf{L = 8}$	10.6%	0.2%	0.1%	32.94
$\mathbf{L = 16}$	4.1%	0.1%	0.0%	43.37
$\mathbf{b = 10}$	11.0%	0.1%	0.2%	19.18
$\mathbf{b = 100}$	36.7%	0.1%	-0.2%	28.69

times. Because of this poor performance we will not consider Method A in the remainder of the numerical study.

Misinformation on the overall return probability

We define the relative error in the estimated return probability as follows

$$\text{relative error} = \frac{\hat{p} - p}{p} \times 100\%$$

Tables 7.4–7.5 show that Method B structurally outperforms the more information intensive methods C and D in the case of misinformation of plus or minus 10% or more. Under an error of -20%, the relative difference can be as large as -5%. Under an error of $+20\%$, the relative difference can be as large as -20% for a return probability of 0.5 and as large as -60% for a return probability of 0.8. The performance of Method C is fairly close to the benchmark, although it usually performs worse.

The relative cost differences become bigger as the return rate goes up. This is not surprising as with increasing returns also the impact of (mis)information increases. Note that the cost improvement of Method B with respect to the benchmark can be as large as 60% under 20% overestimation and a return probability of 0.8.

Table 7.3: Comparison of Methods A–D in the case of perfect information; Uniform time-to-return distribution; $\mu_D = 30$. *) results below 1% are not significant.

	Methods			
	A	**B**	**C**	**D**
	relative difference*			costs
Base case: $p = 0.5, T = 2.50, cv_D = 0.2$ $L = 4, h = 1, b = 50$	44.9%	0.3%	0.2%	28.59
$\mathbf{p = 0.8}$	171.4%	2.4%	1.1%	26.23
$\mathbf{p = 0.9}$	181.4%	4.3%	1.8%	24.83
$\mathbf{n = 4.50}$	59.6%	0.7%	0.3%	31.14
$\mathbf{n = 8.50}$	65.0%	0.3%	0.1%	32.68
$\mathbf{cv_D = 0.4}$	65.0%	0.2%	0.1%	50.22
$\mathbf{cv_D = 0.8}$	48.3%	0.2%	0.1%	93.61
$\mathbf{L = 8}$	18.2%	0.3%	0.2%	34.93
$\mathbf{L = 16}$	8.6%	0.2%	0.0%	44.80
$\mathbf{b = 10}$	24.1%	0.6%	0.2%	21.07
$\mathbf{b = 100}$	68.2%	0.6%	0.2%	31.33

An increase of the lead time makes the relative differences smaller. A longer lead time results in a larger portion of the lead time returns that come from expected issues during the lead time itself. Methods B, C, and D treat this category of returns in exactly the same way, so the relative differences become smaller.

Using a similar argument we expect that an increase in the expected time-to-return, T, results in larger relative differences. As the expected time-to-return increases the portion of lead time returns that come from expected issues during the lead time decreases. The relative differences therefore increase, as Tables 7.4–7.5 also show.

An increase in demand variation also has a negative impact on the relative differences. This probably is because more demand uncertainty also leads to more return uncertainty. More information on the return distribution than has less impact on cost performance. The difference between the methods thus becomes smaller as the uncertainty in returns increases.

The analysis of Section 5.5 showed that in the case of misinformation of the return probability Method B performs better than Method D with respect to the expected lead time net demand, while the difference between the methods increases as the return rate increases. With respect to the variance the analysis was less straightforward. Sometimes Method B outperforms Method

Table 7.4: Comparison of Methods B–D in the case of misestimation of the return probability; Geometric time-to-return distribution; $\mu_D = 30$. *) results below 1% are not significant.

			Methods		
			B	**C**	**D**
	$\hat{p}$	error	rel. difference*		costs
Base case:	0.40	-20%	-1.9%	0.3%	35.15
$p = 0.5, T = 1.67,$	0.45	-10%	-0.9%	0.2%	29.07
$cv_D = 0.2, L = 4,$	0.55	+10%	-5.2%	0.7%	35.54
$h = 1,\ b = 50,\ k = 2.054$	0.60	+20%	-17.9%	2.4%	84.33
	0.64	-20%	-5.3%	1.2%	42.45
$\mathbf{p = 0.8}$	0.72	-10%	-3.9%	1.3%	31.18
	0.88	+10%	-43.1%	8.5%	92.26
	0.96	+20%	-67.1%	6.6%	692.04
	0.40	-20%	-3.1%	0.5%	37.10
$\mathbf{T = 2.50}$	0.45	-10%	-1.5%	0.3%	31.06
	0.55	+10%	-7.7%	1.2%	37.13
	0.60	+20%	-26.7%	4.4%	86.12
	0.40	-20%	-0.6%	0.0%	90.71
$\mathbf{cv_D = 0.8}$	0.45	-10%	-0.2%	0.0%	85.39
	0.55	+10%	-0.8%	0.0%	87.21
	0.60	+20%	-3.5%	0.2%	101.41
	0.40	-20%	-0.8%	0.1%	87.60
$\mathbf{L = 16}$	0.45	-10%	-0.7%	0.1%	61.95
	0.55	+10%	-5.1%	0.5%	170.99
	0.60	+20%	- 6.9%	0.6%	902.68
	0.40	-20%	-1.7%	0.3%	38.11
$\mathbf{b = 100}$	0.45	-10%	-0.8%	0.2%	31.79
(k = *2.326*)	0.55	+10%	-5.7%	0.8%	40.11
	0.60	+20%	-19.8%	2.9%	105.85

Table 7.5: Comparison of Methods B–D in the case of misestimation of the return probability; Uniform time-to-return distribution; $\mu_D = 30$. *) results below 1% are not significant.

	$\hat{p}$	error	Methods **B**	 **C** rel. difference*	 **D** costs
Base case:	0.40	-20%	-2.1%	0.3%	37.23
$p = 0.5, T = 2.50,$	0.45	-10%	-0.7%	0.3%	31.45
$cv_D = 0.2, L = 4,$	0.55	+10%	-4.9%	0.4%	36.63
$h = 1,\ b = 50,\ k = 2.054$	0.60	+20%	-18.5%	1.1%	76.85
	0.64	-20%	-4.9%	0.9%	45.24
$\mathbf{p = 0.8}$	0.72	-10%	-2.4%	1.2%	34.08
	0.88	+10%	-34.0%	-1.0%	72.54
	0.96	+20%	-56.5%	-3.8%	394.72
	0.40	-20%	-3.6%	0.6%	39.97
$\mathbf{n = 4.50}$	0.45	-10%	-1.5%	0.4%	34.21
	0.55	+10%	-7.4%	0.9%	39.01
	0.60	+20%	-28.6%	2.8%	79.98
	0.40	-20%	-0.6%	0.0%	100.03
$\mathbf{cv_D = 0.8}$	0.45	-10%	-0.1%	0.0%	95.47
	0.55	+10%	-0.4%	0.0%	97.04
	0.60	+20%	-2.8%	0.1%	107.60
	0.40	-20%	-1.0%	0.1%	88.86
$\mathbf{L = 16}$	0.45	-10%	-0.7%	0.1%	63.27
	0.55	+10%	-5.7%	0.3%	164.27
	0.60	+20%	-7.9%	0.3%	857.01
	0.40	-20%	-1.9%	0.3%	40.39
$\mathbf{b = 100}$	0.45	-10%	-0.6%	0.4%	34.40
$(k = 2.326)$	0.55	+10%	-5.3%	0.4%	41.05
	0.60	+20%	-20.5%	1.4%	93.51

D and sometimes it is the other way around. From the numerical results we conclude that the effect of the expected lead time net demand dominates the effect of the variance.

Misinformation on the conditional expected time-to-return

We define the relative error in the estimated conditional time to return as $\frac{\hat{T}-T}{T} \times 100\%$. For the geometric distribution this leads to

$$\text{relative error} = \frac{1/\hat{q} - 1/q}{1/q} \times 100\% = (\frac{q}{\hat{q}} - 1) \times 100\%$$

and for the uniform distribution we have

$$\text{relative error} = \frac{(\hat{n}+1)/2 - (n+1)/2}{(n+1)/2} \times 100\% = \frac{\hat{n}-n}{n+1} \times 100\% \; .$$

According to Tables 7.6–7.7, misinformation of the conditional expected time-to-return has little effect if the return probability is small. For $p = 0.8$ though, both Methods B and C perform much better than the benchmark and are far more robust with respect to misinformation (Figure 7.4). Again the relative differences with respect to the benchmark is positively correlated with the return probability and expected time-to-return, and negatively correlated with the lead time and demand variation.

Figure 7.8: Misinformation (-30%,+30%) of the expected time-to-return (Geometric time-to-return distribution, $p = 0.8, q = 0.6, \mu_D = 30, cv_D = 0.2, L = 4, h = 1, b = 50$).

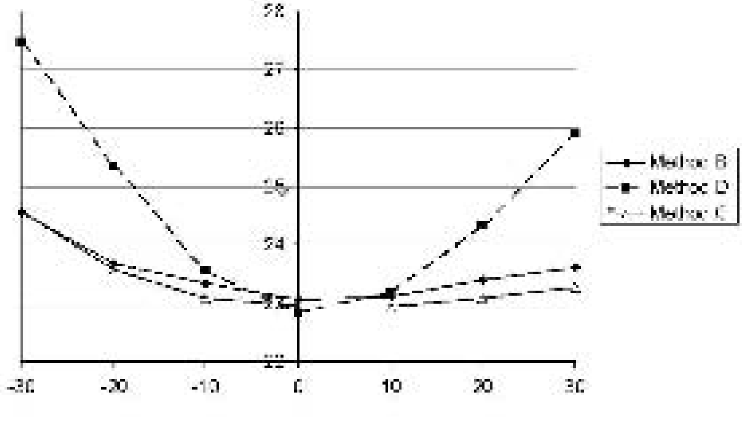


Table 7.6: Comparison of Methods B–D in the case of misestimation of the expected time-to-return; Geometric time-to-return distribution; $\mu_D = 30$. *) results below 1% are not significant.

			Methods		
			B	**C**	**D**
	$\hat{T}$	error	rel. difference*		costs
Base case:	1.33	-20%	-6.5%	-7.0%	25.34
$p = 0.8, T = 1.67,$	1.50	-10%	-0.9%	-2.0%	23.56
$cv_D = 0.2, L = 4,$	1.83	+10%	-0.2%	-1.1%	23.18
$h = 1$, $b = 50$, $k = 2.054$	2.00	+20%	-3.8%	-5.1%	24.33
	1.33	-20%	-0.4%	-0.6%	26.46
$\mathbf{p = 0.5}$	1.50	-10%	-0.1%	-0.3%	26.20
	1.83	+10%	0.1%	0.0%	26.05
	2.00	+20%	-0.5%	-0.2%	26.13
	2.00	-20%	-12.6%	-13.3%	30.69
$\mathbf{T = 2.50}$	2.25	-10%	-2.3%	-3.8%	26.96
	2.75	+10%	0.0%	-2.0%	26.41
	3.00	+20%	-4.8%	-6.2%	27.88
	1.33	-20%	-2.9%	-3.0%	39.95
$\mathbf{cv_D = 0.8}$	1.50	-10%	-0.4%	-0.8%	38.50
	1.83	+10%	-0.2%	-0.7%	38.30
	2.00	+20%	-2.3%	-2.9%	39.46
	1.33	-20%	-3.0%	-3.6%	32.63
$\mathbf{L = 16}$	1.50	-10%	-0.5%	-1.2%	31.65
	1.83	+10%	0.1%	-0.7%	31.35
	2.00	+20%	-3.4%	-4.3%	32.63
	1.33	-20%	-7.8%	-8.6%	28.30
$\mathbf{b = 100}$	1.50	-10%	-0.8%	-2.3%	25.86
($k = 2.326$)	1.83	+10%	0.4%	-0.8%	25.37
	2.00	+20%	-4.1%	-5.4%	26.75

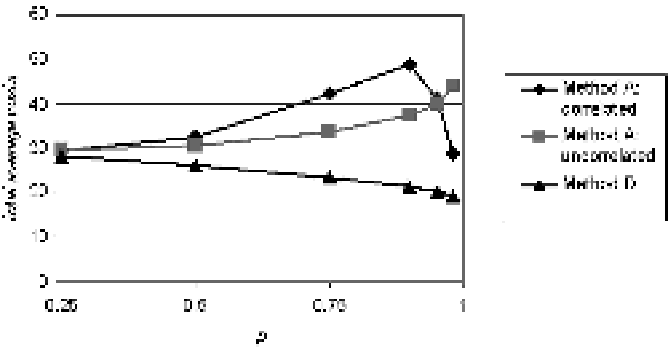
Table 7.7: Comparison of Methods B–D in the case of misestimation of the expected time-to-return; Uniform time-to-return distribution; $\mu_D = 30$. *) results below 1% are not significant.

			Methods		
			B	**C**	**D**
	$\hat{T}$	error	rel. difference*		costs
Base case:	3.50	-22%	-32.4%	5.3%	48.03
$p = 0.8, T = 4.50,$	4.00	-11%	-7.8%	2.7%	34.58
$cv_D = 0.2, L = 4,$	5.00	+11%	-4.6%	-6.6%	33.40
$h = 1,\ b = 50,\ k = 2.054$	5.50	+22%	-16.5%	-18.0%	38.45
	3.50	-22%	-3.4%	0.6%	32.75
$\mathbf{p = 0.5}$	4.00	-11%	-0.4%	0.4%	31.57
	5.00	+11%	-0.3%	-0.7%	31.49
	5.50	+22%	-2.6%	-3.0%	32.30
	3.50	-22%	-12.7%	2.0%	63.38
$\mathbf{cv_D = 0.8}$	4.00	-11%	-1.9%	0.8%	55.29
	5.00	+11%	-3.1%	-3.9%	56.38
	5.50	+22%	-9.8%	-10.7%	61.25
	3.50	-22%	-24.4%	4.5%	54.86
$\mathbf{L = 16}$	4.00	-11%	-6.7%	2.3%	43.69
	5.00	+11%	-4.6%	-6.4%	42.66
	5.50	+22%	-16.5%	-18.4%	49.24
	3.50	-22%	-3.4%	0.7%	36.21
$\mathbf{b = 100}$	4.00	-11%	-0.7%	0.4%	34.84
$(k = 2.326)$	5.00	+11%	-0.2%	-0.6%	34.56
	5.50	+22%	-2.6%	-2.9%	35.48

Extensions

Here we present a new adaptation of Method A and an extension of Method B. The disappointing performance of Method A is mainly due to the assumption that all returns during the lead time are correlated with the demands during the lead time. The other extreme, which we propose here, is to assume that all lead time returns are independent of the lead time demand. The expectation of lead time demand does not change, but the variance is then given as $\mathrm{Var}_A[ND_L(t)] = (1+p^2)\mathrm{Var}[D_L(t)]$. This method, denoted Method A$'$ - Average behavior with independence - will overestimate the variance in the lead time net demand, but it will generate less (costly) backorders (see Figure 7.5). Only if p is close to 1, Method A outperforms Method A$'$.

Figure 7.9: Performance of Method A both under perfect correlation and zero correlation (Geometric time-to-return distribution, $p = 0.5, q = 0.6, \mu_D = 30, cv_D = 0.2, L = 4, h = 1, b = 50$).



It was seen that Method B was rather robust under imperfect information of the time-to-return distribution. This suggests that Method B could be applied as a standard with a simple uniform distribution. The information requirement is then reduced to parameters p and n and there is no need to forecast the $\overline{p}_i$'s individually. This has significant managerial implications (as we stress below).

7.7 Discussion and managerial implications

Given perfect information, Method A performs in general very poorly and is not recommended for practical implementation. Thus, to *only* have knowledge on average behavior does not seem to be cost effective. Including information on the return distribution, however, does seem to provide a sufficient level of sophistication, as the performance of Method B shows. With respect to inventory related costs, the differences between Methods B, C and D are not such that they justify investments in recording detailed return data.

Both for misinformation on the return rate and on the return distribution, the differences between the methods become smaller with the decrease of the return probability and the increase of the lead time. Obviously, if there are few returns forecasting of the lead time returns is not really an issue. To understand the latter one should note that when L is large, most of the items that return during the lead time were also purchased during the lead time. The forecast of this type of returns is not based on historical data, so all Methods B–D give exactly the same forecast.

With respect to misestimating the return rate, in general it is better to underestimate the return rate than to overestimate, since stockouts are usually much more costly than overstocks. Therefore, if an interval estimate of the return rate is available, one may opt to use a value that is closer to the lowerbound rather than the upperbound.

The most robust method given misestimation of the return rate is Method B. Method B systematically outperforms Methods C and D if the return rate is misestimated by merely 10%,or more. The cost differences are particularly high if return rates are overestimated. With respect to misestimating the conditional time to return distribution, Method C and again Method B are much more robust than Method D.

The above results strongly suggest that Method B has a sufficient level of sophistication both in the case of perfect estimation and imperfect estimation. In the latter case Method B is far more robust than the most informed method, Method D. For the inventory management of the mail order company of Section 7.2 this means that orders only have to be based on the return distribution and realized demand per period, but there is no need to track individual returns.

Finally we observed that Method B was fairly robust given misspecification of the time-to-return distribution. Therefore the following practical adaptation of the use of Method B was proposed. Companies may opt to disregard the shape of the return distribution and to simply use Method B with a flat shape, i.e. a uniform distribution. The advantages are huge in terms of information spare. The company no longer has to estimate the return probability per period, i.e. the individual $\overline{p}_i$'s. It suffices to estimate the overall return probability and the max return period, i.e. p and n. These are actual the parameters for which companies more comfortably give estimates.

7.8 Summary of conclusions and further research

This chapter has reported on the impact of (mis)information on forecasting performance and performance with respect to inventory costs by analyzing four forecasting methods as proposed by Kelle and Silver (1989). All methods make use of the expectation and variance of the demand, but different levels of information with respect to returns. The least demanding method, Method A only uses the return rate. Method B also requires the return distribution. Method C additionally uses a periodic record of returns. Finally, Method D needs to track back the period in which each individual product return was sold.

Given perfect information, forecasting performance increases as the level of information increases, Method D naturally being the best method. Yet, from the analysis we have concluded that Method B presents a reasonable level of sophistication given perfect information and is exceptionally robust given misinformation in comparison with the other methods. Furthermore since the Method B is quite insensitive to the shape of the return distribution, the companies can simply employ the uniform return distribution, i.e. using Method B with a flat shape, that is by fitting an uniform distribution.

Method D does not appear to be very robust given misestimation. This leads to the conclusion that companies are not likely to recover investments on advanced return data with inventory savings, especially in volatile environments. Naturally, it is worth further investigating the value of return information, with respect to multiple criteria, like for instance production scheduling and human resource management (see Toktay et al., 2004 for a comparison of the methods with respect to order variability, "the bullwhip effect").

The huge gap in performance between Methods A and B suggests that refinements of Method A are possible. In this chapter an enhanced Method A, i.e. Method A' was put forward, where the variance during the leadtime is underestimated. In addition, there is an opportunity to look further for similar simple methods with low information requirements but a reasonable performance.

In the analysis of misinformation, there was a static situation where a systematic error was introduced. This is natural for small errors, since it is difficult in general to reason whether observations indicate trend changes or mere stochastic behavior. However, large variations could be dealt with by an adaptive method. This is a topic for further research.

Appendix 1: Forecasting methods

Proofs can also be found in Kelle and Silver (1989).

We define

- μ_D, the expected value of Demand D
- σ_D^2, the variance of Demand D

which we use sometimes to simplify notation.

Method A - Average behavior

This method requires the following information:

- p, the overall return probability, i.e., the probability that a product is being returned eventually.

The expectation and variance of lead time net demand according to Method A are equal to

$$\mathrm{E}_A[ND_L(t)] = (1-p)\mathrm{E}[D_L(t)] \tag{7.4}$$

and its variance is

$$\mathrm{Var}_A[ND_L(t)] \quad = \quad (1-p)^2\mathrm{Var}_A[D_L(t)] + p(1-p)\mathrm{E}[D_L(t)] \tag{7.5}$$

Proof:

By definition, we have that,

$$\begin{aligned} \mathrm{E}_A[ND_L(t)] &= \mathrm{E}_A[D_L(t)] - \mathrm{E}_A[R_L(t)] && (7.6) \\ \mathrm{Var}_A[ND_L(t)] &= \mathrm{Var}_A[D_L(t)] + \mathrm{Var}_A[R_L(t)] \\ &- 2cov[D_L(t), R_L(t)] && (7.7) \end{aligned}$$

Let us first compute $\mathrm{E}_A[R_L(t)]$ and $\mathrm{Var}_A[R_L(t)]$ (Part A of the proof) and later the covariance, i.e. $cov[D_L(t), R_L(t)]$ (Part B of the proof).

Part A

$R_L(t)$ is a mixed binomial random variable, with a random number $D_L(t)$ of trials and known success probability p. Let each trial be called X_m, $m =$

$1, ..., D_L(t)$. Each trial has a probability of success p, independently of any other trials. Thus,

$$\begin{aligned} \mathrm{P}[X_m = 1] &= p \\ \mathrm{P}[X_m = 0] &= 1 - p \end{aligned}$$

and

$$var(X_m) = p(1-p)$$

Since

$$R_L(t) = \sum_{m=1}^{D_L(t)} X_m$$

it follows that (see Tijms, 2003, pg. 435)

$$\begin{aligned} \mathrm{E}_A[R_L(t)] &= \mathrm{E}[X_m]\mathrm{E}[D_L(t)] \\ \mathrm{Var}_A[R_L(t)] &= \mathrm{E}^2[X_m]\mathrm{Var}[D_L(t)] + \mathrm{Var}[X_m]\mathrm{E}[D_L(t)] \end{aligned}$$

$$\mathrm{E}_A[R_L(t)] = p\mathrm{E}[D_L(t)] \tag{7.8}$$

$$\mathrm{Var}_A[R_L(t)] = p^2\mathrm{Var}[D_L(t)] + p(1-p)\mathrm{E}[D_L(t)] \tag{7.9}$$

Part B

Let us now compute the covariance, $cov[D_L(t), R_L(t)]$.

By definition, we have that

$$cov[D_L(t), R_L(t)] = \mathrm{E}_A[D_L(t)R_L(t)] - \mathrm{E}_A[D_L(t)]\mathrm{E}_A[R_L(t)] \tag{7.10}$$

with

$$\begin{aligned} \mathrm{E}_A[D_L(t)R_L(t)] &= \sum_{k=1}^{i}\sum_{i=1}^{\infty} iG_{D_L(t)}k\frac{i!}{(i-k)!(k-1)!}p^k(1-p)^{i-k} \\ &= \sum_{i=1}^{\infty} iG_{D_L(t)}\sum_{k=1}^{i} k\frac{i!}{(i-k)!(k-1)!}p^k(1-p)^{i-k} \\ &= \sum_{i=1}^{\infty}[iG_{D_L(t)}][ip] \\ &= p\sum_{i=1}^{\infty} i^2 G_{D_L(t)} \\ &= p\left[\mathrm{E}_A[D_L(t)]\right]^2 \\ &= p\left[\mathrm{Var}_A[D_L(t)] + [\mathrm{E}_A[D_L(t)]]^2\right] \end{aligned}$$

where we used that, E(Y)=i · p when Y is a random variable binomially distributed with parameters (i,p).

Substituting, the above and 7.8, in 7.10, we obtain the following

$$cov[D_L(t), R_L(t)] \quad = \quad p\,[\mathrm{Var}_A[D_L(t)]] \tag{7.11}$$

To finalize the proof, let us substitute 7.8, 7.9, and 7.11 in 7.6 and 7.7 as adequate. We get that

$$\begin{aligned}\mathrm{E}_A[ND_L(t)] &= (1-p)\mathrm{E}_A[D_L(t)]\\ \mathrm{Var}_A[ND_L(t)] &= (1-p)^2\mathrm{Var}_A[D_L(t)] + p(1-p)\mathrm{E}_A[D_L(t)]\end{aligned}$$

□

Method B - Return distribution

Suppose that we are at the end of period t. This method requires information on previous demand per period and the knowledge of the return distribution as follows:

- u_i, purchased amount during period $i \leq t$.
- p_j, the probability of an item being returned exactly after j periods, $j = 1, ..., n$, with n being the largest j for which the return probability is non-zero.

The expectation and variance of lead time net demand according to Method B are

$$\mathrm{E}_B[ND_L(t)] \quad = \quad L \cdot \mu_D - \left[\sum_{i=i_m}^{t} u_i R_i + \mu_D \sum_{i=t+1}^{t+L-1} R_i\right] \tag{7.12}$$

$$\begin{aligned}\mathrm{Var}_B[ND_L(t)] &= \sigma_D^2 + \sum_{i=i_m}^{t} u_i R_i (1-R_i)\\ &\quad + \sum_{i=t+1}^{t+L-1} \left\{\sigma_D^2 (1-R_i)^2 + \mu_D R_i (1-R_i)\right\}\end{aligned} \tag{7.13}$$

with $i_m = \max\{1, t-n+1\}$ and R_i the success probability of having products from past demand u_i returning during any of the the lead time periods $t+1, t+2, \cdots, t+L$:

$$R_i = \begin{cases} 0, & \text{for } i < t - n + 1 \\ \sum_{j=1}^{j_m} p_{t-i+j}, & \text{for } i_m \leq i \leq t \\ \sum_{j=1}^{j_n} p_j, & \text{for } t < i < t + L \end{cases}$$

where $j_m = \min\{L, n + i - t\}$ and $j_n = \min\{n, t - i + L\}$

Proof:
Let $z_{i,j}$ be the number of products sold in period i and returned in period j, $j = 1, ..., n$. The $z_{i,j}$, $j = 1, ..., n$ are a sequence of multinomial trials with the respective distribution as follows:

$$\begin{aligned} P(z_{i,1} &= k_1, ..., z_{i,n} = k_n, z_{i,\infty} = u_i - \sum_{j=1}^{n} k_j) \\ &= \frac{u_i!}{k_1!...k_n!(u_i - \sum_{j=1}^{n} k_j)!} p_1^{k_1} ... p_n^{k_n} p_\infty^{u_i - \sum_{j=1}^{n} k_j} \end{aligned}$$

where $z_{i,\infty}$ represents the number of products sold in period i that will never return.
We are interested in computing the total number of returns during the lead time. Let W_i be the total number of returns during the lead time periods, i.e. $t + 1, ...t + L$, coming from u_i. We have that

$$\begin{aligned} W_i &= z_{i,t+1-i} + ... + z_{i,t+L-i}, \qquad i \leqq t \\ W_i &= z_{i,1} + ... + z_{i,t+L-i}, \qquad t < i < t + L \end{aligned}$$

Being W_i a sum of multinomial trials, W_i follows a Binomial distribution, with u_i number of trials, and with a success probability given by R_i as previously defined.

Let now $\daleth_{t,L}$ be the total number of returns during the lead time periods, $t + 1, ..., t + L$. $\daleth_{t,L}$ is the sum of independent W_i with $i \leq t + L - 1$.

Let us distinguish between returns that come from periods until t, and returns that come from lead time demand.

First part: $i \leq t$

The u_i, for $i \leq t$, are observed values. Thus the expected value and variance of the correspondent total number of returns, that come back during the lead time, are as follows:

$$\begin{aligned}
\mathrm{E}_B[R_L(t)]^{(1)} &= \sum_{i=1}^{t} \mathrm{E}[W_i] &= \sum_{i=i_m}^{t} u_i R_i \\
\mathrm{Var}_B[R_L(t)]^{(1)} &= \sum_{i=1}^{t} \mathrm{Var}[W_i] &= \sum_{i=i_m}^{t} u_i R_i (1 - R_i)
\end{aligned}$$

with $i_m = max\{1, t - n + 1\}$

Second part: $i > t$

Here, u_i, for $i > t$, have not been observed yet. Therefore, we use $\mathrm{E}[D_L(t)] = \mu_D$ and $\mathrm{Var}[D_L(t)] = \sigma_D^2$. We obtain

$$\begin{aligned}
\mathrm{E}_B[R_L(t)]^{(2)} &= \sum_{i=t+1}^{t+L-1} \mathrm{E}[W_i] &= \sum_{i=t+1}^{t+L-1} \mu_D R_i \\
\mathrm{Var}_B[R_L(t)]^{(2)} &= \sum_{i=t+1}^{t+L-1} \mathrm{E}[W_i] &= \sum_{i=t+1}^{t+L-1} \left[R_i^2 \sigma_D^2 + \mu_D R_i (1 - R_i)\right]
\end{aligned}$$

Finally, the expected value of the net demand during the lead time is given as follows:

$$\begin{aligned}
\mathrm{E}_B[ND_L(t)] &= \mathrm{E}[D_L(t)]^{(2)} - \left[\mathrm{E}_B[R_L(t)]^{(1)} + \mathrm{E}[R_L(t)]^{(2)}\right] \\
&= \sum_{i=t+1}^{t+L} \mu_D - \left[\sum_{i=i_m}^{t} u_i R_i + \sum_{i=t+1}^{t+L-1} \mu_D R_i\right] \\
&= L \cdot \mu_D - \left[\sum_{i=i_m}^{t} u_i R_i + \mu_D \sum_{i=t+1}^{t+L-1} R_i\right]
\end{aligned}$$

and the variance is given by

$$\begin{aligned}
\mathrm{Var}_B[ND_L(t)] &= \sigma_D^2 + \sum_{i=i_m}^{t} u_i R_i (1 - R_i) \\
&+ \sum_{i=t+1}^{t+L-1} \left\{\sigma_D^2 (1 - R_i)^2 + \mu_D R_i (1 - R_i)\right\}
\end{aligned}$$

where equality 7.5 was used and with $i_m = max\{1, t - n + 1\}$

□

Method C - Return distribution & return information per period

Suppose that we are at the end of period t. In addition to the requirements of method B, this method makes use of observed data on aggregated returns:

- u_i, purchased amount during period $i, i \leq t$.
- p_j, the probability of an item being returned exactly after j periods, $j = 1, ..., n$, with n being the largest j for which the return probability is non-zero.
- y_i, the total amount of returned products in each period $i, i \leq t$.

The expected lead time net demand according to method C is

$$\mathrm{E}_C[ND_L(t)] = \mathrm{E}_B[ND_L(t)] - \underline{c}\, T^{-1}(\underline{y} - E(\underline{y})) \tag{7.14}$$

and the variance is

$$\mathrm{Var}_C[ND_L(t)] = \mathrm{Var}_B[ND_L(t)] - \underline{c}\, T^{-1}\underline{c}^{\dagger} \tag{7.15}$$

with $\underline{y} = (y_t, y_{t-1}, ..., y_{t-n+2})$ the vector of recent aggregated returns, T the covariance matrix of vector $\underline{y}$ and T^{-1} its inverse matrix; and $\underline{c}$ a vector of covariances defined, for $j = 1, 2, \ldots, n-2$, by

$$\begin{aligned} c_j &= Cov\left(\sum_{i=i_m}^{t-1} W_i\, y_{t-j+1}\right) \\ &= -\sum_{i=i_m}^{t-j} u_{t-n+i}\, p_{n-j+1-i} \sum_{m=1}^{j_m} p_{n-i+m} \end{aligned}$$

with $\underline{c}^{\dagger}$ being the transpose of vector $\underline{c}$ and $j_m = \min\{i, L\}$
And, the elements of matrix T, $T_{j,k} = cov(y_{t-j+1}, y_{t-k+1})$, are defined as follows.

$$\begin{cases} T_{j,k} = -\sum\limits_{j=i_j}^{t-k} p_{t-j+1-i}\, p_{t-k+1-i}, & \text{for } j = 1, ..., n-2,\ j \leq k \leq n-2 \\ T_{k,j} = T_{j,k}, & \text{for } k < j \\ T_{j,j} = \sum\limits_{j=i_j}^{t-k} p_{t-j+1-i}\,(1 - p_{t-j+1-i}), & \text{for } j = 1, ..., n-2 \end{cases}$$

with $i_j = \max\{1, t-j+1-n\}$

Proof: This method makes use of the observed total amount returned in each period up to t, i.e. $y_t, y_{t-1}, ..., y_{t-n+2}$. Recent aggregated returns are correlated with the returns during the lead time. Thus, this method makes use of the conditional expectation and variance of these returns as follows:

$$\mathrm{E}_C[R_L(t)^{(1)}] = E\left[\sum_{j=i_m}^{t-1} W_i \mid y_t, y_{t-1}, ..., y_{t-n+2}\right] \quad (7.16)$$

$$\mathrm{Var}_C[R_L(t)^{(1)}] = Var\left[\sum_{j=i_m}^{t-1} W_i \mid y_t, y_{t-1}, ..., y_{t-n+2}\right] \quad (7.17)$$

The above expressions cannot be expressed in an exact analytical form. However, a multidimensional normal vector gives a good approximation, if demand is reasonably large and if $n \geq 4$. The approximation allow us to write the expression 7.16 and 7.17 as follows (see Kelle and Silver, 1989):

$$\mathrm{E}_C[R_L(t)^{(1)}] = E(\sum_{j=i_m}^{t-1} W_i) + \underline{c}\, T^{-1}(\underline{y} - E(\underline{y})) \quad (7.18)$$

$$\mathrm{Var}_C[R_L(t)^{(1)}] = Var(\sum_{j=i_m}^{t-1} W_i) - \underline{c}\, T^{-1}\underline{c}^{\dagger} \quad (7.19)$$

with $\underline{y} = (y_t, y_{t-1}, ..., y_{t-n+2})$, T, and $\underline{c}$ as defined before, and T^{-1} being the inverse matrix of T, and $\underline{c}^{\dagger}$ being the transpose of vector $\underline{c}$.

Thus, the expected value and variance of the total returns during the lead time corresponds to

$$\begin{aligned}\mathrm{E}_C[ND_L(t)] &= \mathrm{E}_C[R_L(t)^{(1)}] + u_t R_t + \mathrm{E}_B[R_L(t)^{(2)}] \\ &= \mathrm{E}_B[R_L(t)] - \underline{c}\, T^{-1}(\underline{y} - E(\underline{y})) \quad (7.20)\end{aligned}$$

$$\begin{aligned}\mathrm{Var}_C[R_L(t)] &= \mathrm{Var}_C[R_L(t)^{(1)}] + u_t R_t(1 - R_t) + \mathrm{Var}_B[R_L(t)]^{(2)} \\ &= \mathrm{Var}_B[R_L(t)] - \underline{c}\, T^{-1}\underline{c}^{\dagger} \quad (7.21)\end{aligned}$$

Please note that $\mathrm{E}_C[R_L(t)]$ is as $\mathrm{E}_B[R_L(t)]$ but corrected with the term $\underline{c}\ T^{-1}(\underline{y} - E(\underline{y}))$. Similarly, $\mathrm{Var}_C[R_L(t)]$ is as $\mathrm{Var}_B[R_L(t)]$ but corrected with the term $\underline{c}\ T^{-1}\underline{c}^{\dagger}$. Therefore, we have that the expected value and the variance of the net demand during the lead time is as given next.

$$\begin{aligned} \mathrm{E}_C[ND_L(t)] &= \mathrm{E}_B[ND_L(t)] - \underline{c}\, T^{-1}(\underline{y} - E(\underline{y})) \\ \mathrm{Var}_C[ND_L(t)] &= \mathrm{Var}_B[ND_L(t)] - \underline{c}\, T^{-1}\underline{c}^{\dagger} \end{aligned}$$

□

Method D - Return distribution & tracked individual returns

Let t be the last observed period. Besides the requirements of Method B this method requires to track back in what period each individual return has been sold:

- u_i, purchased amount during period $i, i \leq t$.
- p_j, the probability of an item being returned exactly after j periods, $j = 1, ..., n$, with n being the largest j for which the return probability is non-zero.
- Z_i^t, the observed total number of product returns from each past purchase $u_i, i < t$.

To simplify notation we use next Z_i instead of Z_i^t.

The expected value and variance of the lead time net demand according to method D are respectively

$$\begin{aligned} \mathrm{E}_D[ND_L(t)] &= L \cdot \mu_D \\ &- \left[\sum_{i=i_m}^{t-1} (u_i - Z_i)Q_i + u_t R_t + \mu_D \sum_{i=t+1}^{t+L-1} R_i\right] \end{aligned} \tag{7.22}$$

$$\begin{aligned} \mathrm{Var}_D[ND_L(t)] &= \sigma_D^2 + \sum_{i=i_m}^{t-1} (u_i - Z_i)Q_i\,[1 - Q_i] + \; u_t R_t\,[1 - R_t] \\ &+ \sum_{i=t+1}^{t+L-1} \left\{\sigma_D^2\,[1 - R_t] + \mu_D R_i\,[1 - R_i]\right\} \end{aligned} \tag{7.23}$$

with $Q_i = \frac{R_i}{1 - \sum_{j=1}^{t-i} p_j}$, the success probability associated with the binomial conditional random variable W_i given Z_i, the returned amount from past demand $u_i, i \leq t$.

$$\mathrm{Var}_D[ND_L(t)] = \sigma_D^2 + \sum_{i=i_m}^{t-1} (u_i - Z_i)Q_i\,[1 - Q_i] + \; u_t R_t\,[1 - R_t]$$

$$+ \sum_{i=t+1}^{t+L-1} \left\{ \sigma_D^2 \left[1 - R_t\right] + \mu_D R_i \left[1 - R_i\right] \right\} \tag{7.24}$$

Proof:

As before, we are interested in computing the expected value and the variance of the net demand during the lead time. For returns coming from the demand during the lead time itself, the expected value and variance of these returns is given as in Method B, i.e. by $\mathrm{E}_B[ND_L(t)^{(2)}]$ and $\mathrm{Var}_B[ND_L(t)^{(2)}]$ (also used by Method C, for these returns). For returns coming from previous demand, Method D makes use of conditional return probabilities, as it observes the returns of any particular period up to time t.

The W_i, total return during the lead time, is conditioned by Z_i, the observed total number of product returns from each u_i. We have, for $i < t$,

$$\begin{aligned} \mathrm{E}[W_i \mid Z_i] &= u_i - Z_i \\ \mathrm{Var}[W_i \mid Z_i] &= \frac{R_i}{1 - \sum_{j=1}^{t-i} p_j} \end{aligned}$$

Thus, we have that

$$\mathrm{E}_D[R_L(t)] = \sum_{i=i_m}^{t-i} (U_i - V_i) Q_i + u_t R_t + \mathrm{E}_B[ND_L(t)^{(2)}] \tag{7.25}$$

$$\begin{aligned} \mathrm{Var}_D[R_L(t)] &= \sum_{i=i_m}^{t-1} \left[(U_i - V_i) Q_i (1 - Q_i)\right] + \\ &= u_t R_t (1 - R_t) + \mathrm{E}_B[ND_L(t)^{(2)}] \end{aligned} \tag{7.26}$$

with

$$Q_i = \frac{R_i}{1 - \sum_{j=1}^{t-i} p_j}$$

Finally, we obtain

$$\mathrm{E}_D[ND_L(t)] = L \cdot \mu_D - \left[\sum_{i=i_m}^{t-1} (u_i - Z_i) Q_i + u_t R_t + \mu_D \sum_{i=t+1}^{t+L-1} R_i \right]$$

$$\begin{aligned}\text{Var}_D[ND_L(t)] &= \sigma_D^2 + \sum_{i=i_m}^{t-1}(u_i - Z_i)Q_i\,[1-Q_i] + \ u_tR_t\,[1-R_t] \\ &+ \sum_{i=t+1}^{t+L-1}\left\{\sigma_D^2\,[1-R_t] + \mu_D R_i\,[1-R_i]\right\}\end{aligned}$$

□

Appendix 2: Forecasting performance

In the following please note that

$\pi_i = \sum_{j=1}^{t-i} p_j$, $Q_i = R_i/(1-\pi_i)$,

and

$\mathcal{E}_{R|D}\{Z_i\} = u_i\pi_i$.

For simplicity write '$\sum$' for '$\sum_{i=t-n+1}^{t-1}$'.

Analysis regarding the expectation of lead time net demand

Using 7.12, i.e.

$$\text{E}_B[ND_L(t)] = L\cdot\mu_D - \left[\sum_{i=i_m}^{t} u_iR_i + \mu_D\sum_{i=t+1}^{t+L-1} R_i\right]$$

and 7.22, i.e.

$$\begin{aligned}\text{E}_D[ND_L(t)] &= L\cdot\mu_D \\ &- \left[\sum_{i=i_m}^{t-1}(u_i - Z_i)\,Q_i + u_tR_t + \mu_D\sum_{i=t+1}^{t+L-1} R_i\right]\end{aligned}$$

we have

$$\begin{aligned}E_{\{BD\}} &= \widehat{\text{E}}_B[ND_L(t)] - \text{E}_D[ND_L(t)] \\ &= \sum\left[(u_i - Z_i)\,Q_i - u_i\widehat{R}_i\right] \qquad (7.27)\\ E_{\{DD\}} &= \widehat{\text{E}}_D[ND_L(t)] - \text{E}_D[ND_L(t)] \\ &= \sum(u_i - Z_i)\left(Q_i - \widehat{Q}_i\right) \qquad (7.28)\end{aligned}$$

Now we analyze the cases EXP1–EXP4 as defined in section 7.5.1 with respect to the performance measure $F_{\{E\}}$ as defined in relation (7.2). Let $X \succsim Y$ denote that method X performs at least as good as method Y.

Case EXP1: $E_{\{BD\}} > 0$ and $E_{\{DD\}} > 0$

Proof:

We have that

$$\begin{aligned}
F_{\{E\}} &= \sum \left[(u_i - Z_i)\, Q_i - u_i \widehat{R}_i - (u_i - Z_i)(Q_i - \widehat{Q}_i) \right] \\
&= \sum \left[(u_i - Z_i) \widehat{Q}_i - u_i \widehat{R}_i \right] \\
&= \sum \left[(u_i - Z_i) \widehat{Q}_i - u_i \widehat{R}_i \right] \\
&= \sum \left[(u_i - Z_i) \frac{\widehat{R}_i}{(1 - \widehat{\pi}_i)} - u_i \widehat{R}_i \right] \\
&= \sum \left[(u_i - u_i \pi_i) \frac{\widehat{R}_i}{(1 - \widehat{\pi}_i)} - u_i \widehat{R}_i \right] \\
&= \sum \left[(u_i \widehat{R}_i \frac{(1 - \pi)}{(1 - \widehat{\pi}_i)} - u_i \widehat{R}_i \right] \qquad (7.29) \\
&= \sum \left[(u_i \widehat{R}_i \left(\frac{(1 - \pi)}{(1 - \widehat{\pi}_i)} - 1 \right) \right] \qquad (7.30)
\end{aligned}$$

and since $E_{\{DD\}} > 0$, follows from 7.28 that

$$Q_i \;>\; \widehat{Q}_i \qquad (7.31)$$

because Z_i, the observed total number of product returns from past demand u_i, is by definition smaller or equal than u_i (so $u_i - Z_i$ is always larger or equal than 0).

It follows immediately from 7.31 that it is infeasible to consistently overestimate the return probabilities $pj's$. In the opposite case (to consistently underestimate the return probabilities $pj's$) it follows that $F_{\{E\}} \leq 0$ meaning that $B \succsim D$.

□

Case EXP2: $E_{\{BD\}} < 0$ and $E_{\{DD\}} < 0$

Proof:

With similar steps as used in 7.30, we have that

$$F_{\{E\}} \quad = \sum \left[(u_i \widehat{R}_i \left(1 - \tfrac{(1-\pi)}{(1-\widehat{\pi}_i)} \right) \right] \tag{7.32}$$

and since $E_{\{DD\}} < 0$, follows from 7.28 that

$$Q_i \quad < \quad \widehat{Q}_i \tag{7.33}$$

It follows immediately from 7.33 that it is infeasible to consistently underestimate the return probabilities $pj's$. In the opposite case (to consistently overestimate the return probabilities $pj's$) it follows that $F_{\{E\}} \leq 0$ meaning that $B \succsim D$.

□

Case EXP3: $E_{\{BD\}} < 0$ and $E_{\{DD\}} > 0 \Longrightarrow B \succsim D$

Proof:

We have that

$$F_{\{E\}} \quad = \quad \sum u_i \left(\widehat{R}_i (1 + \frac{(1-\pi)}{(1-\widehat{\pi}_i)}) - 2R_i \right) \tag{7.34}$$

and since $E_{\{DD\}} > 0$, follows from 7.28 that

$$Q_i \quad > \quad \widehat{Q}_i$$

It follows immediately from 7.35 that it is infeasible to consistently overestimate the return probabilities $pj's$. In the opposite case (to consistently underestimate the return probabilities $pj's$) it follows that $F_{\{E\}} \leq 0$ meaning that $B \succsim D$.

□

Case EXP4: $E_{\{BD\}} > 0$ and $E_{\{DD\}} < 0 \Longrightarrow B \succsim D$

Proof:

We have that

$$F_{\{E\}} \quad = \sum u_i \left(2R_i - (1 - \tfrac{(1-\pi)}{(1-\widehat{\pi}_i)}) \widehat{R}_i \right) \tag{7.35}$$

and since $E_{\{DD\}} < 0$, follows from 7.28 that

$$Q_i \quad < \quad \widehat{Q}_i$$

It follows immediately from 7.36 that it is infeasible to consistently underestimate the return probabilities $pj's$. In the opposite case (to consistently overestimate the return probabilities $pj's$) it follows that $F_{\{E\}} \leq 0$ meaning that $B \succsim D$.

□

In summary, if we consistently overestimate or underestimate the return probabilities pj's, then $B \succsim D$.

From cases EXP1–EXP4 it is also clear that the difference between the methods increases as the R_i get bigger. In other words, for higher return rates the differences between the methods are also larger (with respect to the forecasts of the expected lead time net demand).

Chapter 8

Reverse Logistics research: what does the future bring?

> Change is the law of life.
> And those who look only
> to the past or present
> are certain to miss the future.
>
> John F. Kennedy

8.1 Introduction

The field of Reverse Logistics has been expanding fast with many technical contributions, case studies and some theoretic literature arising from research (see previous chapters). Yet, it remains an academic field in formation, where concepts and theories are not as vivid as in better established research fields like supply chain management (see Melissen and De Ron, 1999).

In this chapter, we propose a reflection on the future development of reverse logistics, mainly as an academic field. In this way, we assist in giving priorities to research in the field. At the end we evaluate reverse logistics issues with respect to research impact and complexity.

We carried out a Delphi Study with an international panel of academics working on reverse logistics issues as a means to reflect on the future of reverse logistics as an academic field. The Delphi study consisted of two rounds of anonymous questionnaires with an intermediary feedback phase. In short, every member received information on the answers to the first questionnaire, which they could rank and rate.

The overall analysis allows us to make recommendations concerning research and teaching about reverse logistics. Furthermore, we find evidence of different contributions to the field, depending on whether the researcher is a senior, junior or a researchers working “accidentally” in the area. In addition, we explore the impact of the differences the between European and North American researchers.

This chapter is organized as follows. First, Section 8.2 describes the employed methodology. Section 8.3 reports on an exploratory study that served as input for the Delphi study. Section 8.4 presents the specific design of this Delphi study. In Section 8.5 we display the profile of reverse logistics researchers and the profile of the participants of the study. Then in Section 8.6 we discuss the insights that this study brings about reverse logistics. Section 8.7 put into evidence the specific added-value to the field of senior, junior and accidental researchers. In Section 8.8 we split the analysis according to the European versus North American participants. Before the end, we glance over the rest of the world. The last section puts together the conclusions. An earlier report on this study has appeared in De Brito and van Wassenhove (2003).

8.2 Methodology

The employed methodology for the main investigation was a Delphi study, which is described in more detail below. Prior to the Delphi study, we carried out an exploratory study, which brought awareness to the potential pitfalls of the main study. For the exploratory study, we employed the Nominal Group Technique (NGT).

Both NGT and Delphi are techniques to structure communication among a group of individuals. The NGT is appropriate for the exploratory phase as it allows us to follow the process *in loco* at the same time that helps communication to flow in a structured way. By following the process, insights are gained on how to structure communication in follow-up studies. In our case, we obtained insights on how to build up the Delphi questionnaire. The Delphi itself is a suitable method to reflect on the future of a field, as it calls upon the views of experts.

8.2.1 An exploratory study

For the exploratory study, we employed the Nominal Group Technique (NGT) to structure the interactions of a group of reverse logistics researchers. Their task was to come up with ideas on "What are promising areas for future research on reverse logistics?" The study took place during the annual workshop of the European working group on Reverse Logistics, called RevLog (see RevLog, online), in the end of the summer in 2002. The outcome of this exploratory study is reported in the Section 8.3.

NGT is a technique to structure communication among a group of individuals. To summarize, after having a question/task, the discussion process follows the following steps(with some variations): Step 1- Silent generation of ideas; Step 2 - Round-robin record of ideas; Step 3 - Clarification of each idea and discussion within each group; Step 4- Individual voting (ranking or rating) and wrap-up. The process has been designed 1) to assure creativity; and 2) to balance participation among members (see Delbecq et al., 1975).

The NGT is a technique to structure group meetings, and therefore, it will achieve structured output. Nonetheless, this is still raw material and very likely not rich in detail, since participants are stimulated to be brief in stating their ideas. Any analysis of the results should take into account the group formation and how the discussion proceeded. Special caution should go in taking overall conclusions. For instance, to pool rankings/ratings is very dangerous. Note that groups vote from their own set of ideas.

8.2.2 The Delphi study

Delphi is another method to structure communication among a group of individuals, also called panel. Delphi studies are well fit for purposes like problem solving, policy-making and proposal review among others (Linstone and Turoff, 1975). Experts or stakeholders on the subject in study constitute the panel. Applying the Delphi method basically involves the following. Several rounds of questions and feedbacks are sent to the panel. Each feedback includes both the mild and the extreme panel standpoints relatively to the previous round of questions. Individual comments/answers remain anonymous to the group. Through the process, each member of the panel has the chance to refine his/her own answers or comments.

Since the first published Delphi study in the sixties (Dalkey and Helmer, 1963), Delphi has been employed in many fields of research like technology, marketing, supply chain management and so on (see Boks and Tempelman, 1997; Smit and Popma, 2002; Akkermans et al., 2003). For a review on Delphi studies, we refer to Linstone and Turoff (1975).

In the literature, many have pointed out the advantages over face-to-face meetings. For instance, in face-to-face meetings, winning an argument is sometimes more important than to look for a better understanding of the problem. With the Delphi, since anonymity is guaranteed, a participant can quietly change his/her mind without losing face (see Martino, 1972). Besides this, other advantages are (see Kenis, 1995): to balance participation (avoiding the follow-the-leader effect); to avoid a reactive chain of ideas (avoiding stagnation around the first welcomed idea); and to make participants free of the burden of interpersonal relationships (being free from social-emotional concerns and accordingly behavior). Sceptics of the Delphi study have also exposed the disadvantages, especially directed to the original Delphi format. The critics accuse the method of being illusorily over simplistic and an easy temptation for being sloppy (see Slackman, 1975). Two pillars of the Delphi study are 1) the concept of expert; 2) the questionnaires and respective summarized feedbacks. Thus the researcher(s) carrying out Delphi studies has to be extremely careful with respect to the sampling process and the constructing of the questionnaires and follow-up summaries.

For this study, experts on reverse logistics and related areas were chosen, based on their relevant scientific research and other experts' judgement. The exploratory study, carried out a priori, delivered us helpful input on potential traps, and guided the questionnaire as well (see Section 8.3). Furthermore, it helps to check the questionnaire by posing for instance the following questions: are the questions too vague?; are the questions too precise?; or, perhaps biased?; is the question by any chance too demanding, or is it within reach for an expert? (see Dillman, 1978). It is imperative to fine-tune the questionnaire with the expert panel. Besides this, the validity of Delphi cannot be guaranteed if the feedbacks do not represent the true answers of the panel.

8.3 An exploratory study

8.3.1 Implementation and discussion

The study took place during the annual workshop of the European working group on Reverse Logistics, called RevLog (see RevLog, online), in the end of the summer in 2002. Fifteen participants were involved in this study, 13 belonging to RevLog. The two guests, outside the RevLog group, were a senior and a more junior researcher. All the participants of this study, either RevLog members or not, were familiar with the work of the RevLog group (see Dekker et al., 2004). The participants were less-junior (e.g. Assistant Professors) and more-junior researchers (PhD candidates), who use to publish in internationally renowned scientific journals. The senior researchers of the RevLog group did not participate. This was thought to be more adequate. RevLog senior researchers are experts in Reverse Logistics, who would dominate the results, even by only causing unintentional inhibition in the more junior researchers. Since this phase had an exploratory character, we favored to give freedom to the more junior researchers. An earlier report on this study has appeared in De Brito (2003).

Three groups of 5 people each, were put together. In each group, a moderator was nominated. In making the groups we aimed to have a diversity of research backgrounds in each group. During the workshop, each group met at the same time, but in separate rooms. The moderators welcomed the participants stating that the meeting would serve to gain insights on the future of reverse logistics research. The discussion followed the general four steps of the NGT. The moderators did also participate in all the steps; they count as participants as well.

The moderators met before the workshop to discuss the formulation of the question. The questions were brought down to the following two:

- What are promising areas for future research on reverse logistics?
- What are promising research areas to include in a follow-up RevLog project?

The moderators auto-tested the question. The test showed that the second question would lead to highly individually-centered research subjects while the first would give more room for other research subjects than the ones each respondent is individually involved with. Since this was important to the objective of discussing promising areas for future research on reverse logistics, and some were invited participants (not members of RevLog) the first question was chosen.

Figure 8.1 represents the sheet of paper given to the participants. Participants were instructed to list any idea on promising ideas for future research on reverse logistics, on a sheet of paper. They were instructed to synthesize their ideas in a few words (one short statement). The participants were given 5 minutes to generate ideas individually and in silence, which was respected. After that, the ideas were recorded in a round-robin fashion. This means going around the table asking for one idea from one member, recording it on a flip-chart, and then another idea from the next participant, and so on. Arguments for/against a given idea, or the motivation for it, should not be given at this point in time. It is also up to the participant that gives the idea, the wording of his/her own idea.

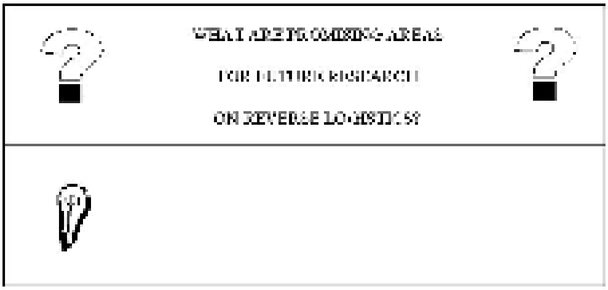


Figure 8.1: Representation of the sheet of paper given to the participants.

Every group generated between 12 to 25 ideas for promising areas for future research on reverse logistics. After the round robin, there was a clarification of the ideas listed in the flip chart. Everyone should understand what is meant by it. Arguments in favour/against could be expressed (not necessarily by who has suggested it). The participants used diverse arguments against/in favor of each item. Table 8.1 lists just a few

Table 8.1: Employed arguments during NGT.

“This area is growing” - “This area publishes”
“That issue is really important for practice”
“I personally would not do such research” / ”I want to do something I like”
“I wouldn’t want to work with psychologists”
“We should have competence to do it” - “That area is outside our scope”
“We can include one item a bit out of our competence, but not more than one.”
“I do not see why the military needs special focus” - ”Too broad” - “Too detailed”
“Many problems in this area have not been solved or even stated until now”
“Important issue, even more important in the future”
“Already much research has been done in this area”

During the voting phase, participants were first asked to write down the five most important items and rank them from 1 to 5 (1 being the most important). A At this point, an opportunity was given to re-discuss some of the items that are perceived as receiving “too many” or “too few” votes. Finally participants were once again asked to pick the five most important items and to rate them in a 0 to 10 scale (being 10 the most important).

When two or three participants considered an item as of rank 1 or 2, later more participants rated this item. To this may have contributed, on the one hand, valid arguments during the second round of discussion, and, on the other hand, an inherent search for group consensus. In contrast, we also observed that some items were highly but single-rated. This seems to indicate that some participants do not give up from the subjects that are most dear to them.

8.3.2 Observations and input for the Delphi Study

It is not our purpose here to report on the ideas listed as being the promising areas for future research on reverse logistics. It is to be kept in mind that this was an exploratory study to thwart the way for the main study, i.e. the Delphi. The objective was to gain insights on possible pitfalls or on helpful hints to conduct the Delphi study.

We observed that many of the items did not have to do with logistics alone. Words like integration, coordination, acquisition, marketing, and accounting were among the ideas of the participants as promising areas for future research on Reverse Logistics. This announces that researchers in the field are conscious of the multidisciplinary character of reverse logistics. Besides this, participants anticipate the development of the field in the direction of Integrated Reverse Logistics (in words like co-ordination, strategic) or even Extended Reverse Logistics (in words like acquisition and marketing). This would demand co-ordination with other research fields and therefore alliances with researchers with other core expertise than reverse logistics. With this in mind, the invited panel for the Delphi included not only specialized reverse logistics researchers but also other researchers in related areas.

From some of the arguments used during the NGT discussion (see Table 8.1), one notices that the ideas are biased by personal opinions and preferences (e.g. "I personally would not do such research"). Therefore, the Delphi questionnaire was designed with a group of questions on the participant's view of the state of the art of reverse logistics research. On the one hand, participants were asked about what they considered to be 1) important past research contributions, and 2) major limitations in reverse logistics research (see Table 8.2). Furthermore, when asking on promising areas for future research, participants were asked about areas of 1) their own expertise, but also 2) outside their own expertise.

8.4 Design and implementation of the Delphi

A team of four researchers put together this research project. The general structure of the Delphi study was as follows: a first questionnaire was sent to a panel of experts; after receiving the answers, those were processed and a second communication was sent to the panel. The second communication served to inform the panel on the obtained answers. At the same time, the panel was asked to rank and rate the answers.

Before selecting the panel of experts, we discussed the range of the questionnaire. A group of international academics active in reverse logistic issues was chosen since the object of the study is primarily the development of reverse logistics as a research field. All the 35 invited academics accepted to participate. The participants are associated either with European or North American universities.

The first questionnaire included three groups of six questions about *research*, *theory/modelling*, and *pedagogy*. The aspects covered by the research and modelling/theoretical questions were: major research contributions so far, limitations of current research, topics for future research, research trends and breakthroughs. The questions about pedagogy were about the main challenges in teaching and on what could ease the task of teaching (see Table 8.2). Many of the questions were related. For instance, some of the questions about research (in general) and theory/modelling issues were very much the same, stimulating answers enriched by further details. The questionnaire was tested for wording and understanding PhD students on the logistics and other areas. The improved questionnaire was given to all the participants.

Table 8.2: Topics covered by the Delphi questionnaire.

<table>
<tr><th>Research</th><th>Theory/Modelling</th><th>Pedagogy</th></tr>
<tr><td colspan="2">· major research contributions so far;
· limitations of past research;
· topics for future research (own expertise);
· topics for future research (others' expertise);
· research trends;
· research breakthroughs;</td><td>· challenges;

· utilities to ease the teaching tasks;</td></tr>
</table>

During the analysis of the answers, we proceeded to grouping in some degree (e.g. when the same was said by means of different words), but several answers were unique. Both were reported to the panellists in the 2nd questionnaire, which was in itself a feedback on the first. The answers for each question were handed over, varying between 8 and 22 items depending on the degree of concordance. At this stage, the participants were generally asked to rank and rate, the top answers, with respect to importance. Regarding trends, the panel was asked to rank them first and then rating them with respect to impact. A similar procedure was asked to breakthroughs, which were rated with respect to likelihood. Concerning pedagogy, the panel was asked to rate the answers according to the priority that they should have. Out of the initial 35 panellists, 26 filled-out the 2nd questionnaire.

8.5 Reverse Logistics researchers and the panel

To be aware of the profile of reverse logistics researchers is very relevant because the researchers are in fact the resources that have to carry out the future research in the field. Concordantly, any suggestions coming out of the Delphi study have to be within their reach. In the reverse logistics field, we roughly recognize three standing kinds of researchers as follows:

- the junior
- the senior
- the accidental

Table 8.3 describes the main strengths and the foremost weakness of these three research-types. Please note that this is rather a caricature-approach than a rigorous characterization.

The panel was constituted by 35 invited academics, 16 associated with European universities and 19 with North American universities. From the two continents, both senior and more junior researchers participated in the Delphi study. These researchers are experienced in teaching and they publish in internationally renowned journals like Management Science, Harvard Business Review, California Management Review, Operations Research and so forth. Most of the researchers have a strong background in operations research and operations management. Among the panel there were also other researchers of which much of their work is focused on supply chain management, industrial ecology, systems dynamics and environmental management, among others. In sum, the panel incorporated the three types researchers (Table 8.3).

Table 8.3: Reverse Logistics: describing three kinds of researchers.

	The Junior	**The Senior**	**The Accidental**
Strengths	· Sound knowledge on RL issues; · Solid modelling skills; · Highly motivated;	· Sound knowledge on RL issues; · Broad business perspective of RL; · Solid background on modelling;	· Sound knowledge on related fields; · Innovative ways of looking to RL as a research field;
Weakness	· Too focused on their own topic;	· Highly tied-up with various compromises;	· Shortage of background knowledge on RL issues;

8.6 Reverse Logistics: past, present and future

8.6.1 Research

Table 8.4 summarizes the panel's perspective over the following issues:

- past research contributions,
- current limitations, and
- future opportunities

This is discussed below. During this discussion, we present more details on the contents of the participants' answers.

Past research contributions

The panel considered the following issues as being the most important past research contributions in the field of reverse logistics, up to now:

- modelling,
- recognition of the field as a new body of knowledge, and
- a better understanding of reverse logistics practices

Table 8.4: Reverse Logistics research: past, present and future.

Past Contributions	Present Limitations	Future Opportunities
1) Modelling; 2) Recognition of the field; 3) Understanding the practice;	1) Ties with practice; 2) Employed methodology; 3) Development of theory; 4) Lack of resources (e.g. data);	1) Links with other fields; 2) Modelling; 3) Strengthening the field; 4) Empirical work;

This actually reflects the way the field of reverse logistics has germinated. The bulk of academic literature on reverse logistics is in quantitative modelling (see Dekker et al., 2004 for a recent compilation of quantitative approaches for reverse logistics). Network design, acquisition, inventory control, production planning and transportation were the most mentioned modelling items by the panel. This is not at all surprising since most quantitative work concerns these items (see e.g. Fleischman et al, 2004; Guide and Van Wassenhove., 2001; Van der Laan et al, 2004; Inderfurth et al., 2004; Beullens et al., 2004).

The initial quantitative approach has put forward the complexity of reverse logistics problems and the way they differ from the ones in traditional logistics. This has helped to the recognition of the importance of the field. Besides that, researchers have backed up their insights with realism by carrying out empirical work (see Chapter 3). Researchers working in reverse logistics are comfortably familiar with the practice and the panel gives top weight to that.

Other items like coordination, environmental aspects of reverse logistics, value of information, advanced planning systems, information technology (IT) were also mentioned by the panel. This acknowledges that :

- the field has a multidisciplinary character,
- the fields is gaining a reasonable degree of maturity.

Current Research Limitations

With respect to the current research limitations, on top of the list are the following items:

- Ties with practice
- Methodology

- The development of theory
- The lack of resources (e.g. data).

Though researchers are aware of how reverse logistics functions in practice, modelling has not been sufficiently linked with that understanding. The panel recognized this by mentioning that, on the one hand, the models have many times unrealistic assumptions, and, on the other hand, no major policy implications come out of the models. These two comments are indeed related, but the essence of it is that the panel faces any short of realism or relevance as being a limitation to reverse logistics research. Similarly, the panel called for more research rigor by bringing to charge unsatisfactory methodology, like the dominance of mono-disciplinary and case-by-case approaches with overemphasis on details.

Besides this, reverse logistics as a new body of research suffers from the ordinary entanglements of any new field of research. To start with, there is lack of theoretical thickness in reverse logistics. The panel touched upon two items: insufficient differentiation with respect to forward logistics and the lack of an integrated theory. Besides that, there is a lack of resources, namely data and problems in accessing the research of other research groups (low visibility among research groups).

Both the researchers' criticism and the more inherent consequences of a novel research field raise many questions that have to be dealt with. Rather than a denial of the field, this is a sign that the reverse logistics academic community is ready to strive after more.

Research Opportunities

According to the panel the top *opportunities for future research* on reverse logistics are:

- links with other fields,
- modelling,
- strengthening the field, and finally
- empirical work.

The message is a sort of

"let's keep doing what we have been doing, but let's improve it."

The way to do it, was also pointed out by the panel. On the one side, by stopping being so narrow and therefore making links with other disciplines and with practice. The highlighted disciplines/theories were marketing, design, and the extended product concept. This hints that the field is stretching itself, accompanying developments like the extended supply chain management concept (already noticed in the exploratory study, see Section 8.3).

Regarding modelling, the panel pointed at more holistic optimization taking into account ecological, informational, technological, and public matters. The call for links with other disciplines, in particular through holistic models is consistent with the previously identified limitation of mono-disciplinary procedures. On the other side, researchers have to work in the inner-self of the field to strengthen it. Some directions to do that as referred by the panel include clearly identifying the drivers for reverse logistics, the advantages over traditional forms of logistics, and urging on theoretical build-up for reverse logistics.

8.6.2 Trends and breakthroughs

The panel was also asked about trends and what would be found as a research breakthrough. Table 8.5 synthesizes top trends with high impacts and, the top breakthroughs with high likelihood.

By "top" and "high" we refer to items that fall in the 50% upper-tail of the total rankings/ratings. Thus, Table 8.5 resumes all the research trends that simultaneously respect this criterion for ranking and then for rating (according to impact). Analogously for breakthroughs, but in this case the rating was with respect to likelihood. The reader should keep in mind that similar approaches were used to construct coming tables in this and following section.

The panel identifies the following two items as the top research trends with high impact.:

- the shift from operational to strategic issues, and
- the intensification of tactic-operational issues

At first, the two may appear contradictory but not if one bears in mind that the shift into strategic issues is likely to be relative. After all, the majority of researchers in the panel has a strong background on operations (see Section 8.5). *IT tools* is also considered to be a top trend with high impact.

The field seems moving towards integration with forward logistics, as *coupling reverse and forward logistics* is considered to be a top trend with high

Table 8.5: Top research trends and breakthroughs with high impact and likelihood.

	Top Trends	Top Breakthroughs	
	· More on behavior of parties and co-ordination;	· Integrating most relevant disciplines;	
	· Coupling reverse and forward logistics;	· A set of simple models explaining behavior of parties;	
High	· Theoretical development;	· A coherent theory;	**High**
	· IT tools;	· Showing competitiveness;	
Impact	· Shift from operational to strategic issues;	·Critical factors for reverse logistics;	**Likelihood**
	Intensification of tactic-operational issues;		

impact. However, the field by no means can aim at such integration without proper consideration of *behavior of parties* and respective *co-ordination*, which are as well identified as top trends with high impact. Indeed, the panel considers *a set of models explaining behavior of parties* as a high research breakthrough, and attainable. Moreover the panel expects that bringing a holistic perspective to reverse logistics by *integrating most relevant disciplines* is plausible.

The development of a *coherent theory* is contemplated as a top trend, with high impact. It is interesting to note that the panel trusts that to put together a coherent theory is only a matter of time, and it will be a valuable breakthrough for the field. Other weighty breakthroughs and within reach are *to identify the critical factors for reverse logistics* and *showing competitiveness*. The panel is therefore confident that academics will be able to point out and announce how to manage the barriers and the stepping stones of reverse logistics.

8.6.3 Pedagogy

Table 8.6 condenses the top *challenges* in teaching reverse logistics, for which the panel considers that high priority should be given. In addition, it exhibits top *utilities* that would extenuate the difficulties of this task.

Table 8.6: Top pedagogic challenges and utilities with high priority.

	Top Challenges	**Top utilities**	
	· Good materials (few);	· Text book + exercises (basic/ advanced models)	
High	· Identifying clear lessons without going into much details;	· Overview Books (e.g. Carnegie Mellon & RevLog)	**High**
Impact	· Finding interesting cases;	· Material demonstrating strategic impact on firms;	**Impact**
	· Establish significance - Motivate (business) students	· Case material, with possible use of multimedia.	

Since reverse logistics is a relatively recent field of research, teaching reverse logistics has been very much at the ad hoc level with teachers having to start from scratch while preparing their own material for classes. Textbooks on logistics begin to present a few pages dedicated to reverse logistics, but exercises and in-depth cases are nearly non-existent. Finding *interesting cases* and few *good materials* are two challenges deserving high priority. Accordingly, the panel suggests that top priority is given to instruments like *textbooks with exercises and case material*. Two *overview books* to be published this year are specifically mentioned (see Guide and van Wassehove, 2003; Dekker et al., 2004). Reverse logistics issues are many times taught as an appendix of another course like logistics, supply chain, operations, production, and environmental management. Time is thus a pressure factor, contributing to difficulties, as *identifying clear lessons without going into much details* and to establish the significance/motivating the students. The panel believes that *material demonstrating strategic impact* on firms would relieve some of the pressure.

In the questionnaire, we also included a question on which case studies or real examples researchers use when they teach about reverse logistics. In another part of the questionnaire we also asked the panel to name 2 or 3 successful examples of reverse logistic practices. For those that answered both questions, around 60% mentioned examples from car industry and the remanufacturing of single-use cameras (mostly associated with Kodak). Around 40% also mentioned the remanufacturing of photocopiers (associated with Xerox and Océ). However, when compared with the cases that they use in class, there was some discrepancy with an average 20% decrease in teaching the 3 aforementioned successful reverse logistics practices. Partially the panel explained this discrepancy by affirming that they use in class "their own cases." Possibly some of these cases are carried out by Master students for their final thesis. That researchers want to use them in class is understandable because they will be far more familiar with their own cases, than someone else'cases. And, since time is a pressure factor, as mentioned before, the "successful cases" are likely to be sacrificed. But, when this happens, it is not surprising that business students will be easily motivates. Ironically, "motivate (business) students" is considered by the panel as a top challenge in teaching reverse logistics and "case material" as a top utility. These issues are among those that should have top priority, according with the panel.

How can we then give top priority to these issues? An approach is to increase the knowledge of teachers on "successful cases." As one researcher stated "I would use Kodak camera and Xerox asset management cases if they were available in detail." To facilitate the accessibility to "successful cases," we suggest the organization of educator's days/sessions in workshops or conferences on the topic and with special attention for dissemination of successful reverse logistics practices.

8.7 The senior, the junior and the accidental

This section looks at the differences in ratings (2nd round), with respect to the future research opportunities.

According to the panel the top *opportunities for future research* on reverse logistics are (see Section 8.6):

- strengthening the field and empirical work (*Realism*),
- modelling (*Rigor*), and
- *links* with other fields,

Table 8.7 exhibits the average ratings of the items, by type of researcher, i.e. senior, junior and accidental.

Table 8.7: Realism, rigor and links: average ratings.

	Realism	**Rigor** (Modelling)	**Links**
Senior	**14.0**	11.9	22.0
Junior	9.8	**13.3**	17.8
Accidental	7.8	8.75	**20.5**

One can observe that there are no perfect clusters of researcher type and rated research opportunities. Yet, we observe the following:

- the highest average rating for realism is by the senior group
- the highest average rating for rigor is by the junior
- the highest average rating for links is the accidental

Concluding, the senior researcher is likely to bring more realism than any other type, the junior will put more rigor into the research, and what the accidental type has most to offer are the links with other disciplines.

8.8 European vs. North American researchers

Since the early nineties several books about Reverse Logistics have been supported by the Council for Logistics Management (Stock, 1992, Kopicky, 1993, Stock, 1998, Rogers and Tibben-Lembke, 1999). Yet, the academic community in Europe "gave in" sooner to reverse logistics as a new field of research (see Thierry et al., 1995, Fleischmann et al., 1997, RevLog, 1998-). In Europe, environmental issues brought early attention to the potential benefits of recovering products (Corbett and van Wassenhove, 1993). Recovery quotas and packaging directives by the European Union deepened the academic and company interest on reverse logistics.

Actually, by comparing the practice of reverse logistics in North American and European, one observes that the prime driver in most North American cases has been profit while in Europe legislation has also been important (see Chapter 3). Thus, the evolution of reverse logistics has been different in the two continents (for instance U.S. environmental practices still rely heavily on policies from the eighties, see Murphy and Poist, 2003).

It is therefore not eccentric to conceive that reverse logistics research is also at a different stage in either of them. If so, the two communities may account dissimilarly to the future of reverse logistics research. We elaborate more on this by distinguishing between the answers of researchers associated with European (E) universities versus North American (NA) ones.

The distance between the relative ratings of *recognition of the field*, *description of practice*, and *modelling* is much smaller for the North American panel than for the Europeans (see Figure 8.2). This is not surprising. The North American research community is beginning to be convinced about the importance of the field, especially since the publication of the book of Rogers and Tibben-Lembke (1999). The book is an extensive description of the American business practices of reverse logistics. As stated there, according to the Logistics Council, bad management of reverse logistics was then costing billions of dollars to American companies. In Europe, the recognition of the field of reverse logistics is for long a settled matter. E.g., already since years a specialized research group on reverse logistics has been active in Europe (see RevLog, 1998-). The core of European research has been dedicated to intense quantitative modelling. Although much case study research has taken place in Europe (see De Brito et al., 2003), it is natural that European researchers remain weighting to a high degree their bulk of research, i.e. modelling.

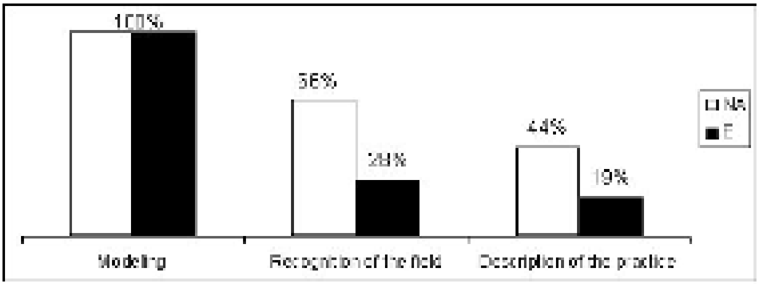


Figure 8.2: Past research contributions: relative ratings; 100% corresponds to the highest sum of ratings

For the North American participants the current top limitation of reverse logistics research is the lack of ties with practice followed by methodology and the other way around for the European panel. The lack of theory is more emphasized by the Europeans, who have been for long investigating reverse logistics issues. Therefore, they presumably have waited longer for the theoretical development of the field giving more weight to it (see Figure 8.3).

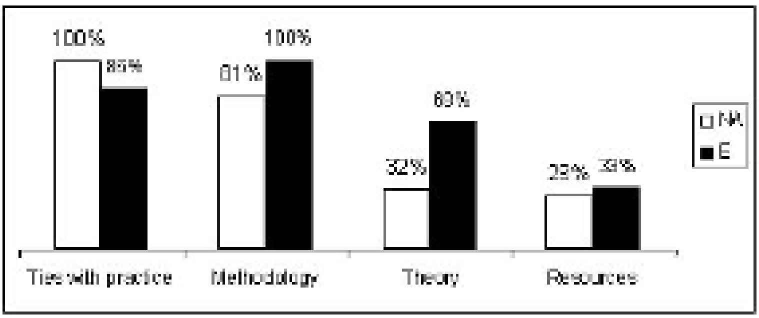


Figure 8.3: Current research limitations: relative ratings; 100% corresponds to the highest sum of ratings.

The central opportunities according to the North American panel are the *links with other fields* of research (actually, also for Europeans, see Figure 8.4). By doing that, North American researchers increase the chance of drawing attention to reverse logistics, granting further recognition (a matter not entirely resolved in North America). The favored discipline to establish a link was marketing, followed by the extended product concept. This goes along with important values in North America like market, and service. The questions here associated are: What about the marketing of recovery products? Is the consumer receptive to recovered products? How recovered products can compete with brand new ones? Can we serve customers better if we offer them recovered products?; and so on.

The links with other fields is also looked upon by the European panel as the upmost topic for future research, where design, extended product concept and strategy were often mentioned topics. For the European panel *modelling* is still a prominent opportunity (very much attached to their core competencies). Within modelling, they mentioned IT tools to a high degree. This indicates that Europeans believe to be prepared to support reverse logistics with advanced tools. Such confidence is certainly lifted up by the prolonged contacts that European researchers have with the practice of reverse logistics. *Empirical work* is considered to be more of a research opportunity for the North American panel, than for the European (relatively to other items).

In the past, North American research on reverse logistics has been very much theoretically driven. For instance, as put by Drejer et al. (2002), U.S. research has sacrificed realism to be more focused on precision and generalizability. However, North American researchers are willing to deviate from this traditional research paradigm, as they reasonably rate field research as a research opportunity.

Table 8.8: Top research trends: North America vs. Europe.

North America		**Europe**
· Theoretical development; · Shift from operational to strategic issues; ·Multidisciplinary approaches; · Intensification of tactic-operational issues;	**High** **Impact**	· Theoretical development; · More on behavior of parties ; and co-ordination · Shift from operational to strategic issues; · IT tools; · Coupling reverse and forward logistics · Intensification of tactic-operational issues;

Table 8.9: Top research breakthroughs with high likelihood: North America vs. Europe.

North America		**Europe**
· A set of simple models explaining behavior of parties; · A coherent theory; · Showing competitiveness; · Critical factors for reverse logistics;	**High** **Likelihood** .	· IT support for RL; · Integrating OR models with RL's strategy · A set of simple models explaining behavior of parties; A clear distinction between; forward and reverse logistics · Integrating most relevant disciplines · A coherent theory; · Showing competitiveness; · Critical factors for reverse logistics;

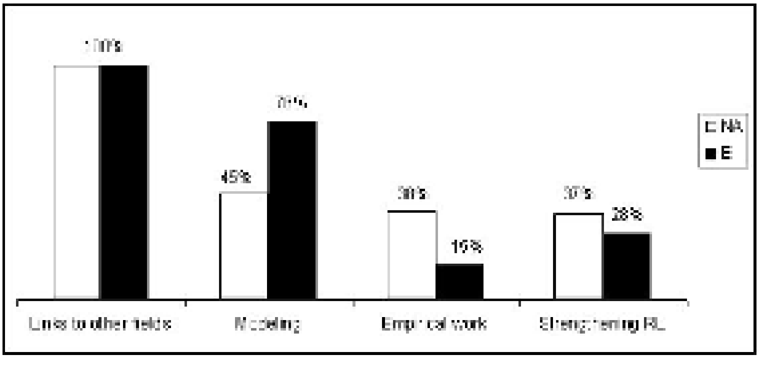


Figure 8.4: Future research opportunities: relative ratings; 100% corresponds to the highest sum of ratings.

Table 8.8 presents the top trends with high impacts and Table 8.9 presents top breakthroughs with high likelihood. The items that are mentioned alone by the European or by the North American researchers are underlined. As mentioned before (Section 5), more on behavior of parties and co-ordination is a natural consequence of coupling reverse with forward logistics. The North America participants also agree that these two items are a top research trend but they attribute it a lower relative impact. The North American panel accredits to multidisciplinary approaches more impact than to e.g. theoretical development of the field. IT Tools is thought to be a top trend with high impact for Europeans but not for North American researchers.

The European panel is more condescending with respect to the plausibility of top research breakthroughs. The long experience of the European research community is likely to contribute to this.

8.9 A glimpse on the rest of the world

In this chapter we proposed a reflection on the future of reverse logistics as an academic field (see section 8.1). To do so, we carried out a Delphi study with experts in research on the field of reverse logistics, and related fields. These experts happen to be affiliated with either with North American or European universities, as most of the work in the area has been done there. We would like to remark that we do not imply that the future of reverse logistics depends exclusively on the developments in these two continents. Throughout these thesis, some research contributions coming from other geographic areas have been as well referred to (Yuan and Cheung, 1998, see Chapter 4); (Díaz and Fu (1997); Chang and Wei, 2000; Gupta and Chakraborty, 1984, see Chapter 3).

Some of the aforementioned references reported on real life examples. Díaz and Fu (1997) applied an inventory model to a case of spare parts management at the subway system Caracas, Venezuela. Chang and Wei (2000) discussed the recycling network for household waste of the city of Kaohsiung in Taiwan. Gupta and Chakraborty (1984) reported on the rework taking place in a glass plant in India.

Though Europe is leading in pro-environmental legislation, the environmental awareness (and ergo behavior) by governmental institutions is becoming a wider phenomena. In Asia, Japan and Taiwan are leading regions on this matter (see De Koster et al, 2003), though other regions in Asia have a long history on recycling.

As remarked by Breukering (2001) India has been using waste paper as raw material in the glass industry as from the 1950's and China (including Hong Kong) imports more than 90% of the total plastic waste traded internationally, which is recycled. The author discussed recycling from the perspective of international trade and how governmental entities (re)act on it. For instance, during the nineties, India increased the import tax on paper waste putting the paper recycling industry in trouble. Similarly and around the same time, China prohibited the import of waste plastics. Both actions were later revised as they were not sustainable for the recycling industry. The conclusion by the author is that there is a lack of understanding on international trade of secondary materials, leading to a overemphasis of negative aspects rather than looking to the positive ones. The same applies to other regions in the world.

Wamiti (2001) defends the great potential that reverse logistics has in Kenya. The author goes over several examples: 1) the collection of barley spent grains in the beer industry for further use in farming ; 2) the imports of second-hand shoes and clothing; 3) replacement of engines in used cars; 4) rethreading of tyres. Only the first example is considered really successful. The other cases suffer from governmental policy to protect the (inefficient) local industry.

8.10 Summary and conclusions

We observed that the view of the panel on past research contributions reflected the way the field has been growing up. The panel pointed out current limitations of reverse logistics research. Some of those are inherited from reverse logistics being a young field of research. In addition, the panel exposed that more research rigor, more realism and more relevance need to be brought to the field; otherwise it will remain very restricted. By the opportunities pointed out, the field seems to be stretching itself and becoming rather linked with other fields of research like marketing. The panel showed confidence in the plausibility of strengthening the field by e.g. identifying critical factors for reverse logistics and putting together a coherent theory (see Section 8.6.1.

With respect to teaching reverse logistics, the main challenges are, according to the panel: *i)* finding *interesting cases*, as well as *ii) good materials.* Accordingly, the panel suggests that top priority is given to instruments like *textbooks with exercises and case material.* Time is a pressure factor as reverse logistics issues are many times taught as an appendix of another course. The panel believes that *material demonstrating strategic impact* on firms would relieve some of the pressure of *identifying clear lessons without going into much details.* We also noticed that there was some discrepancy between the successful reverse logistics cases and the examples discussed in class. A plausible reason is that teachers lack of in-depth familiarity with those successful practices.

Aligned with this, we suggest the organization of *educators' days/sessions* in workshops or conferences on the topic with special attention for the dissemination of successful reverse logistics practices. These sessions should aim to support reverse logistics teaching. Therefore, it is expected that the format will be somewhat different from the traditional workshop/conference presentations.

In addition we indicated how close the views of the European and North American participants are. The North American research community is starting to accept the importance of the field, giving appreciable importance to recognition of the field, description of practice, and modelling as past contributions. The Europeans, who have been for long investigating reverse logistics issues, have waited longer for the theoretical development of the field giving more weight to it as a current limitation. As the top research opportunity, both North American and European agree that it is to link reverse logistics with other fields. The favored discipline to establish a link for the NA researchers is marketing, followed by the extended product concept, reflecting how important values like market, and service are in North America. Europeans give also substantial weight to future modelling as an opportunity, and within it they often mentioned IT. This indicates that Europeans believe to be prepared to support reverse logistics with advanced tools. Such confidence is certainly a result of their a long history of contacts with practice.

In the past, North American research on reverse logistics has been very much theoretically driven. However, North American researchers are willing to deviate from this traditional research paradigm, as they reasonably rate field research as a research opportunity. Finally, the European panel was more condescending with respect to the plausibility of top research breakthroughs. Again, the long experience of the European research community with reverse logistics is likely to contribute to this.

We have assessed which future academicians expect for reverse logistics as a research field. In essence the panel claimed for

- more *realism*,
- more *rigor*, and
- more *links* with other disciplines.

These are undoubtedly ambitious aspirations. The question that remains is: how can we work so this becomes reality? First of all, the fact that there is willingness and belief is very positive. This especially because the panel had the representation of the three types of researchers: the senior, the more junior and the accidental (see Section 8.5). We would like to advance that as a matter of fact only a coordinated exploitation of the three research types can bring through the desired future for reverse logistics research. Putting it plane, the senior researcher will bring *realism*, the junior *rigor*, and the accidental researcher will further facilitate the *links* with other disciplines. Especially if this takes place in a inter-continental fashion, we foresee *relevance* (see Figure 8.5).

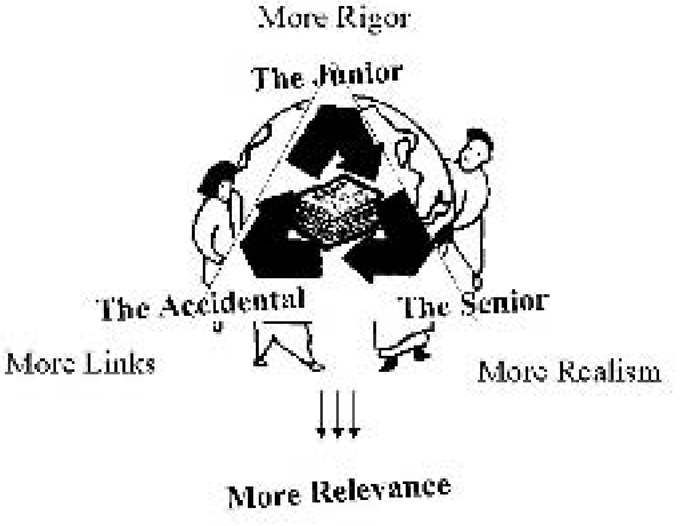


Figure 8.5: Achieving relevance for Reverse Logistics.

Besides this, the development of reverse logistics research also depends on how it develops in practice, which will be the stressed aspects and where. As we commented (see Section 8.9), environmental awareness is not an European exclusive phenomenon, and reverse logistics has growing opportunities throughout the world.

Chapter 9

Concluding remarks

Now this is not the end.
It is not even the beginning of the end.
But it is, perhaps, the end of the beginning.

Sir Winston Churchill

The research presented in this thesis was designed to provide a better understanding of reverse logistics. We brought insights to reverse logistics decision-making and we laid down a theoretical ground for the development of reverse logistics as a research field.

This thesis aimed at

- structuring reverse logistics as a research field,
- a better understanding of reverse logistics practices,
- structuring and supporting reverse logistics decision-making, and
- conjecturing about the future development of reverse logistics as a research field.

In the remainder of this chapter, we summarize the main findings. Besides that, we go over the limitations and put forward opportunities for further research.

9.1 Summary and conclusions

Here we recapitulate the findings of this thesis. To do so, we consider the chapters one by one.

Chapter 2: To structure the field and to provide an overall understanding of reverse logistics.

This chapter provided an overall understanding of reverse logistics by structuring the field. In fact, we put together a framework for reverse logistics, i.e. a basic conceptional structure for reverse logistics, as follows: we identified the elementary ingredients (dimensions) of reverse logistics, we structured them, and we described their relations to each other.

To build the framework we employed three sources of input: *selective literature*, a *review of case studies* (Chapter 3 of this thesis), and the *knowledge* on reverse logistics that was *accumulated* throughout the whole PhD trajectory.

To build up the framework for reverse logistics five key dimensions were considered:

- Why products go back in the supply chain i.e. *Why- returning*;
- Why companies become active with reverse logistics, i.e. *Why-receiving*;
- *What* is being returned? The analysis comprised, on the one hand crucial *product characteristics* for reverse logistics, and on the other a classification of *products types*;
- *How* are returns processed? In this respect we described the overall *processes* in a reverse logistics process, and we gave special attention to *recovery options*;
- *Who* is executing reverse logistic activities? Here, the enquiry was on the *actors* and their *roles* in implementing reverse logistics;

More specifically, we have differentiated three driving forces for reverse logistics:

- *economics*,
- *legislation*, and
- *corporate citizenship.*

We have also stressed that the economic gains can either be direct or indirect. Furthermore, the three drivers are also interlinked and boundaries are sometimes blurred, as reverse logistics is often carried out for a mix of motives.

The return reasons were organized according to three supply chain stages:

- *manufacturing returns*, which embrace raw material surplus, quality-control returns, and production leftovers or by-products.
- *distribution returns*, which include product recalls, returns coming back due to commercial agreements (B2B commercial returns), internal stock adjustments and functional returns.
- *customer returns*, which comprise reimbursement guarantees, warranty returns, service returns, end-of-use and end-of-life returns.

The recovery options can be organized in great concordance with Thierry et al, 1995, that is product level (repair); module level (refurbishing); component level (remanufacturing); selective part level (retrieval); material level (recycling); energy level(incineration).

On product characteristics, we qualified three main product features affecting reverse logistics:

- the *composition* of the product,
- the *deterioration* process, and
- the *use-pattern*.

On product types, the typology presented was inspired by the work of Fleischmann et al. (1997) and the UN product's classification, and the following types were differentiated:

- civil objects,
- consumer goods,
- industrial goods,
- ores, oils and chemicals,
- packaging and distribution items,
- spare-parts, and
- other materials (like pulp, glass and scraps).

Regarding actors in reverse logistic systems, we divided them in three groups:

- typical *forward supply chain actors*,

- *specialized reverse chain players*,
- *governmental institutions*, and
- *opportunistic players.*

With respect to their roles, we detected 1) actors that are actually *responsible* for operations in the reverse logistics chain; 2) others, that set up or combine operations, they have a role of an *organizer*; 3) many parties are busy carrying out the processes, like the collectors, so they play an *executer* role; 4) there is the sender/giver that facilitates the product for recovery and the future client that will acquire recovered products, without which recovery would not make practical sense, so they have an *accommodator* role.

We stressed that the combination and characterization of the five dimensions determine to a large extent the kind of issues that arise in implementing, monitoring and managing such a system. This was illustrated with a collection of typical cases.

Chapter 3: To provide a diversity of reverse logistics activities (and to help constructing the framework).

One cannot provide proper insights into reverse logistics without being familiar with how firms are dealing with it in practice, which are the trade-offs during decision-making, how decisions are being supported, and so on.

We have provided a content analysis of more than 60 cases reported in the literature dealing with reverse logistics aspects. The study was organized according to the following topics 1) Network Structures, 2) Relationships, 3) Inventory Management, 4) Planning and Control, and 5) Information Technology.

We remarked that Reverse Logistics Network Structures are well organized around the typologies on the *how* and the *who.* The cases found included the following:

- Networks for re-distribution/re-sale,
- Networks for remanufacturing,
- Networks for Recycling - *Public Networks*, and
- Networks for Recycling - *Private Networks.*

The cases showed that there are quite different incentive tools to enforce certain desired behavior: 1) deposit fees; 2) buy back options; 3) trade-in'; 4) acquisition price; 5) timely and clear information; 6) power; 7) appealing for environmental responsibility; 8) appealing for social responsibility.

Some incentives are also part of sales contracts, while others require the customer to buy another product in exchange. There are also tools that are not directly coupled to a selling activity like a gift to a non-profit organization. Actually, it seems that only *deposit fees* are specific for product recovery. The other mentioned tools are also used to attract customers in general.

Concerning Inventory Management, the *why-returning* typology seemed a natural way of grouping and discriminating the reverse logistics issues raising from the cases. We found cases for

- Commercial returns,
- Service returns,
- End-of-use, and
- End-of-life.

We found case studies on planning and control of product recovery in the following categories: 1) the separate collection of (parts of) products for recovery 2) the separate processing of (parts of) products for reuse or disposal 3) the combined planning and control of collection of products for recovery and distribution of new products 4) the combined planning and control of processing products for recovery and production of new products

For each of the above decision-making areas, we concluded that some of the dimensions of the framework (see Chapter 2) are predominantly important, as follows

- Networks ⇔ Recovery option (*How*) and Actor (*Who*)
- Relationships ⇔ Actor (*Who*)
- Inventory Management ⇔ Return reason (*Why-returning*) and Product type (*What*)
- Production Planning ⇔ Recovery option (*How*) and Actor (*Who*)

Besides the analysis per decision-making area, we also presented the cases organized by return reason (*why-returning*) vs. recovery option (*how*), and the cases organized by driver vs. recovery option. This analysis revealed some relations and issues. For instance, end-of-life returns appear to be highly correlated with recycling. If products or their modules would be designed for remanufacturing, however, remanufacturing would likely be more attractive, even at the end of life. The main driver for recycling is legislation. Actually, current legislation does not seem to be able to stimulate other forms of recovery. However, if legislation would also pro-actively focus on product design issues, rather than dealing with recovery in a reactive way, other recovery options than recycling would likely be more stimulated.

In addition, we reported on cases describing the use of IT to support reverse logistics. We found cases reporting evidence for IT support in all the stages of the life-path of a product: product development, the supply chain loop, and at the customer. For instance the data logger technology (see EUREKA, 2003) 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. The cases also show that 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.

We observed a lack of cases on reimbursement returns. However, with the growth of the catalogue industry (also in the Internet), posing new challenges. Ergo, field research in this area is likely to growth as well.

The majority of the case studies dealt with one aspect of a real reverse logistics situation but they did not give the overall business environment, which made insights rather one-dimensional. Thus, we pointed out the need for conducting more integral case study research, by mapping the business context together with more broad information on critical factors, trade-offs and implications.

Besides that, the lack of theory for reverse logistics (see Dowlatshahi, 2000) or even for supply chain management (Croom et al., 2000) adds to companies' inability of knowing what matters in reverse logistics. Therefore the development of theory should be on top of the research agenda to support reverse logistics decisions.

Chapter 4: To put forward the state-of-the-art of quantitative models for return handling and to identify opportunities for future research

Though available quantitative models can be adapted to support warehousing return handling, this has been largely ignored up to now. For a number of research areas, we highlighted how forward models can be extended or new models can be launched to include return handling in areas such as:

- facility layout & design,
- outsourcing,
- integrating operations (return policy and reusable packaging),
- inventory management,
- internal (return) transport,
- information systems,
- inventory, storage and order picking control, and
- vehicle planning and scheduling.

We brought to the attention several research opportunities, which can be turned in a research agenda, as follows: What is the impact that return flows have on 1) the warehouse layout; 2) material handling systems (e.g., whether dedicated return handling systems do pay off); 3) vehicle planning and scheduling (mind sequencing restrictions); 4) storage and picking procedures (e. g. route combination of returns' storage and pick ups). Furthermore we suggested the use of the Mathematical Programming problem with Equilibrium Constraints (MPEC) formulation to e.g. help retailers deciding upon the return policy. A new direction to inventory modelling was also put forward by categorizing customers in two classes, i.e. less- and more- profitable depending on whether the customer (systematically) returns, or not, merchandize.

Chapter 5: To identify the main factors contributing whether, or not, to combine forward and reverse flows during return handling.

The identified factors during transport to the warehouse, the receipt at the warehouse, and, storage are respectively as follows: to have, or not, stores; the return volume; and, the future market for returns.

In more detail, we conjectured that:

- For retailer organizations that supply (a sufficient number of) stores it is more efficient to collect the returned products, carriers and waste to the distribution center with the same truck that delivers the products.
- For retailers that handle a high volume of returns, it is more efficient to unload and sort returns in a separate area of the distribution center.
- If the market for returns is different from the original market then product to store returns in a different area from those of purchased products is preferable.
- If the market for returns is the same then storage of product returns is likely to be combined with purchased products. Exceptions will be found in the case of high-desired control over returned products

Before we started this specific research project we suspected that the combination of volume and product diversity would have an impact on the storage decision. From the analysis though it came out that the complicating factor was the decision of controlling returns. Yet, both volume and product diversity can be a point of further research since they might not be a complicating factor alone but be so when combined with other factors. Furthermore, to have a relevant degree of return monitoring and control, a separate module for returns in the warehouse management system is desirable as it is already the case for mail order companies.

Chapter 6: To inquire the validity of common assumptions in the inventory management literature with product returns.

We established a framework for the statistical testing of common assumptions in the inventory management literature with product returns, i.e.

- the demand process is a Homogeneous Compound Poisson Process (HCPP).
- the return process is a Homogeneous Compound Poisson Process (HCPP).
- the time elapsing between return and demand occurrences follows a negative exponential distribution;

With the developed methodology it was possible to carry out the desired testing including small (below 20) sample sizes. Only for extremely small sample sizes, the methodology does not work. It is unambiguous that in the last case, either the proposed or any other statistical framework cannot guarantee rigor. We employed the framework to three sets of real data, as follows

Case 1: data from an in-company warehouse with internal returns in Switzerland (CERN).

Case 2: data from a mail-order company with commercial returns in the Netherlands (referred to as MOC).

Case 3: data from an in-company warehouse in the Netherlands (referred to as RF).

We found products for which the common assumptions on the theoretical models fit reasonably, but also products for which they do not. Regarding the (non-)validity of the common assumptions, we empirically observed that:

- Demand may not behave as an HCPP due to seasonality or over long periods of time;
- In non-stationary environments, the return process may behave as an HCPP;
- Time to return may not behave as an exponential distribution due to a long tail or on account of the short-lag returns;

Concerning inventory management and control, we suggested that companies would separate short-lag returns from long-lag returns. Then, to proceed to netting of the short-lag returns and to monitor the long-lag returns (return distribution, the return rates and register return reasons). The most gains of feeding inventory policies with detailed information on product returns are likely to be in medium well-behaved environments.

Chapter 7: To assess the impact of (mis)information on inventory management

In the literature there are not many references related to research on the impact of information on inventory management with product returns. The ones that exist generally assume known return probabilities or consider specific cases where the most-informed method leads to the best forecast. However, in environments where data is scarce or unreliable, or in environments that are volatile, information may be misleading. This motivated us to assess the impact that misinformation has on inventory management.

In order to bring the first insights on this matter, we focused on a static environment where consistently the forecasted return rate or the return distribution does not correspond to the true behavior. We considered a single product, single echelon, periodic review inventory system. We followed the approach of Kelle and Silver (1989). Accordingly, we employ a base-stock policy and four different methods are used to forecast the net demand during the lead time. The four methods use different levels of information, with respect to returns:

- *Method A - Average behavior.* This method estimates returns during the lead time through the overall return probability. Demand and returns during the lead time are simply netted. No historical information is used with respect to demands and returns, so in a static environment the resulting base stock level is constant in time.
- *Method B - Return distribution.* This method makes use of the return distribution (return probabilities, per period) to determine the number and moment of the returns during the order lead time.
- *Method C - Return distribution & return information per period.* This method updates the number of items that have returned, which are observed, and takes this into account to compute future returns.
- *Method D - Return distribution & tracked individual returns.* To employ this method, one has to be able to trace back the returns, i.e. to know from which order period each specific return is coming from.

We identified situations in which the most informed method does not necessarily lead to the best performance. This is the case when one consistently overestimates or underestimates the return rate per period.

Both for misinformation on the return rate and on the return distribution, the differences between the methods become smaller with decrease of the return probability and an increase of the lead time.

The most robust method given misestimation of the return rate is Method B. Method B systematically outperforms Methods C and D if the return rate is misestimated by merely 10%,or more. The cost differences are particularly high if return rates are overestimated. With respect to misestimating the conditional time to return distribution, Method C and again Method B are much more robust than Method D.

The findings strongly suggested that Method B has a sufficient level of sophistication both in the case of perfect estimation and imperfect estimation. In the latter case Method B is far more robust than the most informed method, Method D.

Chapter 8: To assess which future do academicians expect for reverse logistics as a research field

The field of Reverse Logistics has been expanding fast and it remains a field in formation. To reflect on the future of reverse logistics as an academic field, we carried out a Delphi Study with an international panel of academics working on reverse logistics issues. The study consisted of two rounds of anonymous questionnaires with an intermediary feedback phase. In short, every member received information on the answers to the first questionnaire, which they could rank and rate. The overall analysis allows us to evaluate reverse logistics issues with respect to research and teaching.

We observed that the view of the panel on past research contributions reflected the way the field has been growing up. The panel pointed out current limitations of reverse logistics research. Some of those are inherited from reverse logistics being a young field of research. In addition, the panel exposed that more research rigor, more realism and more relevance need to be brought to the field; otherwise it will remain very restricted. By the opportunities pointed out, the field seems to be stretching itself and becoming rather linked with other fields of research like marketing. The panel showed confidence in the plausibility of strengthening the field by e.g. identifying critical factors for reverse logistics and putting together a coherent theory.

With respect to teaching reverse logistics, the main challenges are, according to the panel, finding *interesting cases* as well as *good materials*. Accordingly, the panel suggests that top priority is given to instruments like *textbooks with exercises and case material*. Time is a pressure factor as reverse logistics issues are many times taught as an appendix of another course. The panel believes that *material demonstrating strategic impact* on firms would relieve some of the pressure of *identifying clear lessons without going into much details*. Besides this, we also noticed that there was some incoherency between the successful reverse logistics cases and the examples that teachers discuss in class. Thus, to facilitate the accessibility to successful cases," we suggested the organization of educators days/sessions in workshops or conferences.

In addition we compared the views of the European and North American participants are. The North American research community is starting to accept the importance of the field, giving appreciable importance to recognition of the field, description of practice, and modelling as past contributions. The Europeans, who have been for long investigating reverse logistics issues, have waited longer for the theoretical development of the field giving more weight to it as a current limitation. As the top research opportunity, both North American and European agree that it is to link reverse logistics with other fields. The favored discipline to establish a link for the NA researchers is marketing, followed by the extended product concept, reflecting how important values like market, and service are in North America. Europeans give also substantial weight to future modelling as an opportunity, and within it they often mentioned IT. This indicates that Europeans believe to be prepared to support reverse logistics with advanced tools. Such confidence is certainly a result of their long history of contacts with practice. On this, and in the past, North American research on reverse logistics has been very much theoretically driven. However, North American researchers are willing to deviate from this traditional research paradigm, as they reasonably rate field research as a research opportunity. Finally, the European panel was more condescending with respect to the plausibility of top research breakthroughs. Again, the long experience of the European research community with reverse logistics is likely to contribute to this.

We assessed which future academicians expect for reverse logistics as a research field. In essence the panel claimed for more *rigor*, more *realism* and more *relevance* of the field at the same time that *links should be made with other disciplines*. These are undoubtedly ambitious expert aspirations. We also stressed how we can work to make this happen. First of all, the fact that there is willingness and belief is very positive. This because the panel had the representation of the three types of researchers: the senior, the more junior and the accidental. We advanced that as a matter of fact only a coordinated exploitation of the three research types can bring through the desired future for reverse logistics research. Putting it plainly, the senior researcher will bring *realism*, the junior *rigor*, the accidental researcher will facilitate the *links with other disciplines*: all together produces *relevance*.

9.2 Raising questions and further research

This thesis was carried out throughout three phases: 1) design, 2) data collection and analysis, and 3) reflection. During the design phase a careful plan was put together with input both from experts on reverse logistics and from the literature of the field. The next phase, data collection and analysis was organized in several projects, tuned with the pre-set objectives. In each of these projects, there was collaboration with one or more researchers from the European Working Group on Reverse Logistics, RevLog . This provided triangulation with respect to the role of the researcher. Triangulation is in essence a plural approach to research, aiming at diminishing research biases. This thesis benefited not only from investigator triangulation, but also from data triangulation (different sources of data as both professional and academic renowned journals) and combination of different methods (e.g. analytical and simulation). During the reflection phase, we followed the standard informal procedure of the Erasmus University Rotterdam: each chapter in turn was discussed with the promoters and revised accordingly. Special attention was paid to coherence, significance, and lacunas, improving the internal, the construct, and the internal validity of this thesis.

However, a scientific research project and its findings is also meant to raise questions, otherwise it would not meaningfully contribute to the advance of scientific knowledge. Every chapter of this thesis ends with research limitations and/or research opportunities. Next, we propose overall directions for future research on the field of reverse logistics, based on two main questions that arise after a reflection on this thesis.

How can scientific reverse logistics research support decision-making in practice?

In our view, the course to tackle this is twofold: 1) on the one hand, to learn more about reverse logistics practices, 2) on the other hand, to adapt/develop methods to aid specific critical decisions. Obviously, the first would be an input to the second. To learn more about practice, one can employ qualitative research methodologies, such as comparative case study research. We suggest the use of theoretical sampling, i.e. having in mind the foreseeable degree of understanding that the case study in question brings to the field. Regarding decision-making methods, a great help can come from quantitative models. Yet, as the Delphi study showed, more realism is needed (see Chapter 8). There is a need to break with the traditional assumptions, for instance in the literature on inventory modelling with returns. A necessary direction is to develop models suitable for the non-stationary (real) situations, as it happens in the presence of seasonal products (see Chapter 4).

How can scientific reverse logistics research contribute to establish a reverse logistics theory?

It seems inevitable that reverse logistics will grow as a research field and that its scope will widen. In Chapter 1 we described how the definition of reverse logistics changed over time. We are confident that a reverse logistics theory can be established but to do that both inner and outer approaches are needed. By an inner-approach we mean a focus on the essence of reverse logistics, by paying special attention to consistency and meaningfulness with respect to reverse logistics management. The framework for Reverse Logistics presented in Chapter 2 can be the departure platform to put forward propositions, which upon testing can lead to the identification of critical factors for reverse logistics and therefore to a theory. By an outer-approach we imply the following: to relate the field with other fields of research, like the Delphi study suggested (see Chapter 8). Both similarities and contrasting points should be brought forward, so reverse logistics can be a field with its own individuality.

We would like to recall that this research project benefited from cooperation with many European researchers in this topic (especially within the RevLog group). This in itself is an added-value, and we hope that other researchers can benefit from similar working groups in the future. On the other hand, this gives the research a remarkable European flavor, which can be seen by some sort of limitation. A way to reduce geographic bias is to establish bridges with researchers in other continents. Between Europe and North America, there is already a semi-formal and structured collaboration on the field, as the recent book of Guide and van Wassenhove (2003) attests. Besides that, in the conferences on the field, contributions from colleagues from other continents are not unusual. Reverse logistics is a worldwide phenomenon (see Chapter 8) and we can be optimistic with respect to a wider collaboration especially embracing areas that systematically lag behind. For instance the European Association of OR Societies (EURO, 2003) is helping African researchers to revive scientific research in Africa. A living example is the set up of AORN, 2003, the African Operational Research Network.

As final words, we come back to the initial question of this thesis:

Managing reverse logistics
or
reversing logistics management?

It goes without saying that reverse logistics is also logistics, so *a priori* one can also transfer lessons from traditional logistics management to the management of reverse logistics. On the other hand, traditional logistics management mainly thinks "forward." Logistics managers are ultra-focused on dispatching the goods, on moving them forward to the client. They are not to blame, after all, this has been the formula to keep businesses going, and many companies have reward schemes based on it. But this is not going to be enough in the future, where companies are eager to add value to their products, by providing more service and by becoming "corporate citizens."

As reverse logistics stretches out worldwide, in all the layers of the supply chain, some actors in the chain are forced to take products back, while others will do so pro-actively (attracted by the value in used products). One way or the other, reverse logistics is a key competence in modern supply chains.

Thus, in managing reverse logistics, one also has to be able of reversing traditional logistics management:

Logistics cannot go forward without thinking *reverse*!

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Samenvatting

In het verleden zorgden supply chains voor de logistieke fine-tuning van de *voorwaartse* goederenstromen van grondstof tot de uiteindelijke klant. Vandaag de dag echter vloeit een groeiende stroom producten terug in de keten. Bedrijven moeten dus ook de retourlogistiek beheren. Toch denken managers voornamelijk in 'voorwaartse' termen, waarbij de nadruk ligt op het leveren van goederen aan de klant. De vraag is of bedrijven door kunnen gaan met deze benadering of dat de focus meer moet worden gericht op retourlogistiek. In andere woorden: Is het een zaak van 'managing reverse logistics' of van 'reversing logistics management'?

Dit proefschrift draagt bij aan een beter begrip van retourlogistiek en wel met betrekking tot de volgende hoofdlijnen:

1. retourlogistiek als (wetenschappelijk) onderzoeksgebied,
2. beslissingsondersteuning en praktijk van retourlogistiek.

De belangrijkste doelen van het verrichtte onderzoek zijn

- het structureren van retourlogistiek als onderzoeksgebied,
- een beter begrip kweken van de praktijk van retourlogistiek,
- het structureren en ondersteunen van beslissingen in retourlogistiek,
- speculeren over de toekomstige ontwikkeling van retourlogistiek als onderzoeksgebied.

In het bijzonder werden verscheidene onderzoeksprojecten opgezet om specifieke doelstellingen te bereiken. Elk hoofdstuk geeft een verslag van één van deze doelstellingen en wel als volgt.

Hoofdstuk 2: Het structuren van het onderzoeksgebied en het kweken van globaal begrip van retourlogistiek.

Dit hoofdstuk kweekt een globaal begrip van retourlogistiek door middel van een structurering van het onderzoeksgebied. In feite construeren we een raamwerk, dat wil zeggen een conceptionele structuur, voor retourlogistiek: we identificeren de elementaire ingrediënten (dimensies) van retourlogistiek, we structureren deze en beschrijven hun onderlinge relatie.

Voor het raamwerk gebruiken we drie bronnen van input: *selectieve literatuur* die het onderzoeksgebied structureert, een bespreking van *case studies* (Hoofdstuk 3), en de *kennis* van retourlogistiek die is geaccumuleerd gedurende het gehele onderzoekstraject.

De dimensies en typologieën van het raamwerk voor retourlogistiek geven niet alleen context voor retourlogistieke situaties. Ook hun combinatie bepaalt voor een groot gedeelte het soort issues dat een rol speelt bij het implementeren, beheersen, en controleren van zulke situaties. Dit wordt geïllustreerd aan de hand van een verzameling typische situaties in de retourlogistiek.

Hoofdstuk 3: Het aangeven van een diversiteit van retourlogistieke activiteiten en het helpen structureren van het framework.

Dit hoofdstuk analyseert meer dan 60 casussen uit de literatuur die handelen over retourlogistieke aspecten. De studie is georganiseerd met betrekking tot de volgende onderwerpen: 1) Netwerk structuren, 2) Relaties, 3) Voorraadbeheer, 4) Planning & Control, en 5) Informatie technologie.

De analyse heeft een aantal relaties en issues aan het licht gebracht. Zo lijken end-of-life retouren bijvoorbeeld sterk gecorreleerd te zijn met recycling. Als producten of modules zouden zijn ontworpen voor remanufacturing echter, dan zou remanufacturing waarschijnlijk attractiever zijn, zelfs aan het einde van de levenscyclus. De belangrijkste driver voor recycling is wetgeving. In feite lijkt de huidige wetgeving niet in staat te zijn om andere vormen van hergebruik te stimuleren. Echter, als wetgeving zich meer pro-actief zou richten op product-ontwerp vraagstukken in plaats van zich reactief te richten op hergebruik, dan zouden andere vormen van hergebruik dan recycling waarschijnlijk meer worden gestimuleerd.

Voor elk van de bovengenoemde beslisgebieden zijn die dimensies geïdentificeerd die overwegend belangrijk zijn en zijn richtlijnen gegeven voor verder onderzoek.

Hoofdstuk 4: Het aangeven van de state-of-the-art van kwantitatieve modellen voor de afhandeling van retouren en het identificeren van mogelijkheden voor toekomstig onderzoek.

Dit hoofdstuk

- bouwt een beslissingsraamwerk voor de afhandeling van retouren, en
- identificeert modellen voor beslissingsondersteuning.

De analyse laat zien dat tot nog toe expliciete modellen voor beslissingsondersteuning ten behoeve van de afhandeling van retouren in het magazijn zijn veronachtzaamd. Voor een aantal onderzoeksgebieden geven we aan hoe voorwaartse modellen kunnen worden uitgebreid, of hoe nieuwe modellen zouden kunnen worden opgezet, om retouren mee te nemen. Verscheidene onderzoekshiaten worden geïdentificeerd en gevat in een onderzoeksagenda.

Hoofdstuk 5: Het identificeren van de belangrijkste factoren voor het al of niet combineren van voorwaartse en retour stromen bij de afhandeling van retouren.

Deze exploratieve studie helpt mee aan de ontwikkeling van theorie voor de afhandeling van retouren en geeft aanbevelingen voor de praktijk als ook wetenschappelijk onderzoek. Met betrekking tot de factoren voor het al of niet combineren van voorwaartse en retour stromen introduceren we drie veronderstellingen. Deze veronderstellingen geven relaties tussen de volgende zaken:

1. het beleveren van winkels & de transport fase beslissing,
2. het retour-volume & de ontvangst in het magazijn,
3. de markt voor retouren & de opslag beslissing.

Hoofdstuk 6: Het onderzoeken van de validiteit van gangbare aannames in de literatuur van voorraadbeheer voor retouren.

In dit hoofdstuk wordt een raamwerk opgezet voor het statistisch toetsen van gangbare aannames in de literatuur van voorraadbeheer voor retouren. Met de ontwikkelde methodologie is het mogelijk om zelfs voor kleine steekproeven de gewenste toetsen uit te voeren. We gebruiken data sets van producten van drie verschillende Europese bedrijven. We vinden producten waarvoor de gangbare aannames lijken te gelden, maar ook enkele waarvoor ze niet gelden. Op basis van de analyse geven we theoretische inzichten en implicaties voor de praktijk. Bovendien geven we aan welk onderzoek nog nodig is.

Hoofdstuk 7: Het evalueren van de waarde van (mis-)informatie m.b.t voorraadbeheer.

Dit hoofdstuk onderzoekt de waarde van (mis)informatie met betrekking tot voorraadbeheer. We beschouwen een voorraadmodel met één product en één echelon, waarbij elke periode een bestelling kan worden geplaatst om de voorraadpositie aan te vullen tot een van tevoren bepaald niveau. Hierbij wordt rekening gehouden met de retouren die zullen binnenkomen gedurende de levertijd. Om deze te schatten worden vier methodes gebruikt, elk met een bepaalde informatiebehoefte.

Met behulp van analytische resultaten en simulatie identificeren we situaties waarin de meest geavanceerde methode niet noodzakelijkerwijs de beste prestaties levert. Dit is bijvoorbeeld het geval als systematisch de retour intentie wordt onderschat of overschat.

De analyse geeft vervolgens aanleiding tot een aantal implicaties voor management, in het bijzonder informatie management.

Hoofdstuk 8: Het evalueren van de toekomst van retourlogistiek als onderzoeksgebied.

Dit hoofdstuk presenteert een Delphi studie, ondernomen door een panel van academici die werken op het gebied van retourlogistiek, met het doel om te reflecteren op de toekomst van het vakgebied. De analyse maakt het mogelijk om aanbevelingen te doen over onderzoek en onderwijs binnen de retourlogistiek. Het blijkt dat het type onderzoek afhankelijk is van het type onderzoeker (junior, senior, accidental). Ook geven we aan wat mogelijke consequenties zijn van de verschillen tussen Europees onderzoek en dat in de Verenigde Staten.

Het spreekt voor zich dat retourlogistiek ook een vorm van logistiek is, zodat *a priori* lessen uit de traditionele logistiek ook kunnen worden doorgetrokken naar retourlogistiek. Aan de andere kant denken traditionele managers voornamelijk in termen van voorwaartse stromen. In de toekomst zal dit niet voldoende blijken. Aangezien retourlogistiek zich wereldwijd uitspreidt in alle lagen van de supply chain, worden sommige actoren in de keten *gedwongen* om producten terug te nemen, terwijl anderen dit *pro-actief* doen De laatsten worden ofwel aangetrokken tot de waarde die gebruikte producten nog vertegenwoordigen, ofwel aangetrokken door hun institutionele verantwoordelijkheid. Hoe dan ook, retourlogistiek is een cruciale competentie in moderne supply chains.

Logistiek kan niet vooruit zonder 'terug' te gaan!

Curriculum Vitae

Marisa P. de Brito studied Statistics and Operations Research at the University of Lisbon in Portugal. On her last year, she visited the Econometric Institute at the Erasmus University Rotterdam (EUR) where she wrote her thesis on the topic of Inventory Control. On graduating in 1997, she enrolled for a 1-year post-graduation on Operations Research at the University of Lisbon in Portugal. During the same academic year, she was a full-time Assistant Professor of the department of Quantitative Methods at the Institute of Business Administration, ISCTE in Lisbon, Portugal. In October 1998 she got engaged with an International Master on Urban Management at EUR, having received the diploma one year later.

In October 1999 she became an assistant researcher at the Econometric Institute (EUR), being a PhD candidate associated with the Erasmus Research Institute of Management (ERIM). Her research was nested in the European Working Group for Reverse Logistics (RevLog), financially supported by the European Commission. Within the RevLog network, she visited the Business School INSEAD of Fontainebleau in France for a 2-month period, at which she worked with Prof. Luk van Wassenhove. Furthermore, during her PhD, she followed international courses associated with the European Doctoral School on Knowledge and Management (EUDOKMA), the European Institute for Advanced Studies in Management (EIASM) and the European Logistics Association (ELA). Her PhD was financially supported by the Portuguese Foundation for the Development of Science and Technology, "Fundação Para a Ciência e a Tecnologia," as from January 2000.

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Managing Reverse Logistics or Reversing Logistics Management?

Traditionally, supply chains fine-tune the forward logistics from raw material to the end customer. Today an increasing flow of products is going back in the chain, so companies have to manage reverse logistics as well. This thesis contributes to a better understanding of reverse logistics. The thesis brings insights on reverse logistics decision-making and it lays down theoretical principles for reverse logistics as a research field. In particular, it puts together a framework for reverse logistics identifying the elementary dimensions, providing typologies, and structuring their interrelations. With respect to aiding decision-making, this thesis comprises return handling and inventory management. Regarding the first, the focus is on identifying critical factors that determine if forward and reverse flows should be combined, or if should be dealt with separately. Regarding the second, the main research issue is the value of information. One of the findings is that more informed methods do not necessarily lead to the best performance in case of misinformation. Furthermore, this thesis proposes a reflection on the future development of the field. Through a Delphi study with an international panel of academics working on the area, recommendations are made concerning both research and pedagogy.
This thesis also poses the following question: how should we deal with reverse logistics? Is it a matter of simply managing reverse logistics or of reversing logistics management?
The message is: logistics cannot go forward without reverse thinking!

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