WAGENINGEN UNIVERSITY AND RESEARCH CENTER

MASTER OF SCIENCE IN MANAGEMENT, ECONOMICS AND CONSUMER STUDIES

PLASTICS WASTE MANAGEMENT; LOGISTICS

"TODAYS WASTE IS NOT THE SAME AS YESTERDAYS"

BSc Thesis Operations Research and Logistics

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PREFACE

This Bachelor thesis, commissioned by the Operations, Research and Logistics chair group, is carried out by a student in Business Administration from Wageningen University. It contributes to the realization of the "Business Plan Nascheiding" of the Agrotechnology & Food Sciences Group (AFSG) and aims at developing a literature review of decision support models concerning the logistics behind the collection, sorting and processing technologies of plastics waste.

Hereby I would like to thank Dr. Rene Haijema and Dr. Jacqueline Bloemhof-Ruwaard for their guidance, support and help during my research. I also would like to thank Dr. Ulphard Thoden van Velzen, coordinator of the Knowledge Centre Netherlands (KCN), for his input and insights in the field of plastics waste management.

Remy Broeksema

Wageningen, January 29th, 2010

EXECUTIVE SUMMARY

This thesis comprises a literature review concerning the reverse logistics applied to the field of plastics waste management. The research was commissioned by the Operations, Research and Logistics chair group and contributes to the realization of the “Business Plan Nascheiding” of the Agrotechnology & Food Sciences Group (AFSG). The thesis aims to identify which logistical quantitative models, concepts and techniques are applicable to the reverse logistics (cycle) of plastics waste.

Due to environmental concerns, at the end of 2012 in The Netherlands, legislation prescribes that at least 42% of all 650 kiloton (Thoden van Velzen, 31st August 2009) plastics packaging waste must be recycled efficiently every year. This issue concerns the area of plastics waste management, trading off economic benefits with environmental and legislative incentives.

The logistical part of plastics waste management involves the logistical concepts of network design and location-allocation problems, including vehicle routing and decision making. These logistical concepts are directly related to the scope of plastics waste management: the field of reverse logistics and closed loop supply chains. Both constructs are intertwiningly used within the literature and encompass four main areas: network design, pre-processing, production planning and other strategic supply chain management issues. A closed loop supply chain makes a clear distinction in a forward and a backward channel comprising consumers, collectors and (re)distributors, recyclers and (re)producers/ suppliers.

Waste and consumer electronics are found to be the main research objects within the reverse logistics area. Researches on paper and glass could be exemplary for the plastics waste management, using mainly a case study or a mathematical modelling approach. There is a strong focus on operational research, transportation science and waste issues within these methodologies. The most progressive literature is found in the Netherlands. The USA and the UK and other European countries fill up the main corps of literature. Asian literature is growing, especially since 2008.

The reverse logistics activities can be grouped into recovery strategies and re-use options which seem to overlap with each other. For the application to plastics the methods of recycling (material recovery), parts recovery, product recovery, waste disposal and blending-off are most common and will have most value in an integrated waste management infrastructure.

Various solution techniques are applicable for the reverse logistics issues in plastics waste management. Mixed integer linear programming and mixed integer non linear programming techniques are especially applicable for network design problems and sometimes the location-allocation problems that occur therein. Multi objective linear programming is suited for the area of green supply chain management. Mixed integer goal programming is possibly useful for the case of plastics and concerning separation methods. Goal programming can be useful as a benchmark with the application of glass (Gonzalez-Torre and Adenso-Diaz, 2002). Heuristics, especially algorithms, are suitable to solve vehicle routing, location-allocation and

network design problems. Combinations between linear programming and heuristics are also reported.

The distinction between source separation and separation at the waste processing unit is made within current literature. Separation at the waste processing unit can be further divided into various mechanical waste separation technologies. However, a quantitative distinction in solving techniques cannot be given.

Trends since the leading work of Fleischmann et al. (1997) include a focus towards network design and a broadening of the categorization of the reverse logistics field. The reverse logistics are more dealt with a supply chain management approach, taking a more strategic perspective. From 2007 more stochastic models arose, taking uncertainty into account. Besides, the environmental awareness and impact is growing and Asian literature is coming up.

Recommendations in solution techniques are given concerning the minimization of costs in developing a network design while meeting certain criteria. The inclusion of uncertainty would accumulate to the principle of doing things right first time. Practical issues regarding containers could bring synergy effects with paper and glass at the household level.

Further research could include the valorisation and pricing of recovered plastics and other products. More focus on stochastic elements, including non-linearity could deepen the field of reverse logistics. Taking the concepts of energy footprint and transaction cost framework as another perspective broadens the scope of reverse logistics.

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1. INTRODUCTION

This research is carried out as part of the study Management, Economics and Consumer Studies at the Wageningen University. The conducted research is commissioned by the ORL chair group, which in turn contributes to the realization of the “Business Plan Nascheiding” of the Agrotechnology & Food Sciences Group (AFSG). It aims at developing a literature review of decision support models concerning the reverse logistics of (recycled) plastics within the field of plastics waste management. This thesis is a first literature research which gives insights in these concepts of logistic flows within the framework of plastics.

This chapter contains two paragraphs: the problem statement (1.1) and the research issue (1.2).

1.1 Problem statement

Waste plastics such as PET-bottles, foils and other packaging materials are separated in the Netherlands. More effective and efficient recycling of the plastics could seemingly benefit the environment. The Knowledge Centre Netherlands (KCN) has been formed in order to achieve scientific consensus on the value and importance of new technologies concerning the waste plastics (KCN, 2009). Grounds can be gained in terms of cost, revenue and environmental impacts. New technological possibilities lay within the option to sort the plastics at the source (households, retailers, etc.) instead of sorting at the processing units, the waste disposal companies.

Against this background the base for this thesis has originated. A first contribution is made to the theme “reverse logistics”, concerning the logistic flows of plastics waste and recycled plastics. The thesis contributes to the further development of the reverse logistics field, focusing on the relation with the area of plastics waste management. Although reverse logistics in general is a thoroughly researched area, there is very little literature zooming in on the reverse flows of plastics. The congregation of these two fields falls together in a literature review.

Next to the driver of theoretical development the environmental legislation concerning plastics waste is driving this research. More and more municipalities in the Netherlands are separating the plastics waste from the household waste due to European legislation. Next to this, recycling is a hot “green” topic linking to sustainable development, energy recovery and depletion of natural resources. Finally, the economic consequences for “environmental friendly activities” make this research useful for the plastics waste business and logistics industry. These environmental, social, legislative and economic incentives make this thesis worthwhile to conduct.

The research can be regarded as an introduction and guideline for further research, contributing to a PhD project, which is in turn part of the whole business plan of KCN. The focus is on logistics in which the use and function of Operations Research models are stressed.

1.2 Research issue

The following main research question is addressed in this thesis;

Which logistical quantitative models, concepts and techniques may be applicable to the reverse logistics (cycle) of plastics waste?

This main research question can be further divided into the following seven sub questions:

1. Which research objects can be found within literature concerning the field of reverse logistics?
2. What are the drivers, objectives, methodologies and logistical concepts used within this area of research?
3. Which levels of recovery and recycling can be discerned for the application to plastics waste?
4. Which methods for separation of plastics waste do exist and is there a differentiation pertaining quantitative models?
5. Which quantitative models and solution techniques apply to the various research objects and logistical concepts?
6. What is the scope of the crossing areas reverse logistics and plastics waste management?
7. What is the development over time within the field of reverse logistics?

Answering these questions leads to a literature review of the reverse logistics of plastic waste flows. This literature review can be further used as input for the business plan of KCN. A new contribution is given to the reverse logistics research field by adding the focus from a plastics waste management perspective. The environmental, societal, legislative and economic incentives drive the originating of this thesis.

This thesis is further organized as follows. Chapter 2 presents an introduction in the field of plastics waste management, primarily based on an expert interview. Chapter 3 elaborates on the literature review methodology to be used. Chapter 4 describes the outcomes of the literature review answering the seven sub questions. Finally, Chapter 5 concludes with conclusion, recommendations, discussion and suggestions for further research.

2. INTRODUCTION PLASTICS WASTE MANAGEMENT

This chapter presents an introduction into the field of plastics waste management comprising the subjects what plastics are (2.1), plastics waste from the Netherlands (2.2), the methods that are used for separation of the plastics waste (2.3), an example of separation at the source (2.4) and recent legislation (2.5) concerning this field. The main part of the information comes from an expert interview with U. Thoden van Velzen, coordinator of KCN, assessed on the 31st August, 2009.

2.1 What are plastics?

The raw material for all (thermo)plastics is oil. Oil can be reprocessed by refining and cracking processes into fuels and raw elements such as petroleum and ethane. The elements that are left over after these processes are monomers such as ethylene and propylene (Plastic Heroes, 2009a). Further processing of these monomers into synthetic polymers, producing long carbon chains, form various plastics such as polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET) and polystyrene (PS). This process is called polymerization and the method and catalysts used, vary according to the intended end use for the product (Howell, 1992). The different kinds of plastics have different applications: PE is used for e.g. plastic bags and shampoo packaging, PP e.g. for beer crates and butter cups and PET e.g. for soda bottles and vinegar packaging (Plastic Heroes, 2009b).

2.2 Plastics waste from the Netherlands

According to Dr. Thoden van Velzen (31st August, 2009), Coordinator KCN, each year about 650 kilotons of plastics household waste comes into the waste processing market of the Netherlands. These plastics consist of -in declining sequence- PP and PE foils, PE bottles and flacons, PET bottles and polystyrene packaging material. This entire amount of plastics can be divided over 7 million households, i.e. 93 kg per household on average. However, these almost 100 kilograms per household per year, is by far not collected by the waste processing industry. However, the stream of PET-bottles with deposit is an exception: this material is for 95% returned. The remaining big grey area is still not researched thoroughly and the businesses within the waste industry are reluctant in giving information about this closed industry.

Therefore, in the field of waste processing a high diversity in statistical outcomes arises. Dirty, clean, pressed or non-pressed waste give a high variance to the amounts of plastics found within the household waste. For instance, foreign objects like stone and sand can be found in the containers for plastics collection. Numbers vary from 20 to 150 kg per m^3 collected household waste, but the average figure is perceived to be 40 to 60 kg per m^3.

2.3 Separation methods

Other influences on the statistics are the methods of collection and separation. Collection can be implemented (with or without differentiated tariffs per households; litter taxes) in a way that the waste is collected at the households or that the households have to bring themselves their waste to a collection unit. Separation can take place in two ways; at the source level (e.g. households, collection containers and companies) or at the waste processing unit (WPU; e.g. incineration plants or waste processors). In the Netherlands both forms take place, however this differs per community. Separation at the source is becoming more and more adopted since 2009 due to legislation. The definitions of both concepts are as follows:

Separation at the source is the separation of a separate waste stream, such as plastics waste, at the level of the source i.e. the level of households, collection containers near flat buildings and at the retailer level.

Separation at the WPU is the process oriented separation and sorting, processing and reprocessing of plastics waste out of the municipal household waste (KCN, 2008).

Both separation methods flow through fixed nodes. The waste is collected (already separated or not) at the various collection points and are distributed to the municipal waste companies. From this point on the waste is distributed in bulk volumes to the (contingent) sorting centres and/or the processing industry. The processing industry recovers the materials and the materials get their re-use within recycling or another application such as energy from incineration plants or implementation within new products. Within these processes there is a lot of societal dumping.

The Dutch waste processing industry isn’t ready yet at the WPU level and is only able to upgrade the plastics with pollution percentages up to a maximum of 1%. This contrasts to the 6-8% pollution rate of carbon and wet materials found in the plastics waste, concerning the separation method at the WPU. This number excludes pollution of labels, caps etc. Therefore, most Dutch plastics waste is sorted and upgraded in Germany where technologies are more sophisticated.

Where almost each household collects its glass and paper and cardboard separately, separation at the WPU of these kinds of products is a rather unusual concept in the Netherlands and has to be assessed from an environmental and economic point of view.

2.4 Example of separation at the source: PET bottles

A special stream of separation at the source of plastics is the PET bottles stream with deposit. The reason of existence of this cycle is due to the high value of this plastic. They account for only 25 kilotons of the total 650 kilotons of plastics waste (i.e. 4%). About 95% of these bottles are returned at the retailer. The retailer returns them to the distribution centre (DC) and the DC passes the bottles on to the Foundation Returns Packaging Netherlands (HABE). HABE conveys it further to the three counting centres, where the retailer gets the deposit back via Electronic Data Interchange. The PET is reprocessed into RPET (recycled PET) with 75% efficiency (residue, label and cap pollution) and eventually 17% returns into its original form of PET bottles (Thoden van Velzen, 31st August, 2009).

The cycle of the PET-bottles in the Netherlands can be used as a benchmark. But in how far can one speak about recycling? In its most pure form only 17% is truly recycled and the majority gets a new application with possibly extra loads on energy use, CO_2 emission etc. In how far is PET recycling beneficial for the environment in practice? Therefore, the environmental aspect of reprocessing the RPET and other kinds of plastics into new applications should be taken into consideration.

2.5 Legislation plastics waste

The environmental aspects of (packaging) waste are taken into consideration on the EU and national level:

“No later than 31 December 2008 the following minimum recycling targets for materials contained in packaging waste should be attained:

(i) 60 % by weight for glass;
(ii) 60 % by weight for paper and board;
(iii) 50 % by weight for metals;
(iv) 22.5 % by weight for plastics, counting exclusively material that is recycled back into plastics
(v) 15 % by weight for wood” (Directive 2004/12/EC of the EP, 2004).

“At the end of 2012 in The Netherlands, at least 42% of all plastics packaging waste must be recycled efficiently” (Plastic Heroes, 2009c).

Due to environmental concerns, enforcement of EU legislation and national implementation of this legislation, plastics packaging waste has to be recycled at an increasing rate. In practice this leads to re-use of plastics into new applications such as fleece clothing, toys and mobile phones and less CO_2 emission due to less waste processing via incineration plants. So, environmental concerns are gaining ground with respect to pure economic incentives.

The plastics household waste as categorized in the main groups of PE, PP and PS is the research objective of this thesis. Glass and paper could be useful as a benchmark and municipal waste in general could delineate general frameworks, applicable to the stream of plastics.

3. METHODOLOGY

This chapter sets forth the research design and methodology to be used for this research. After a short introduction (3.1) the concept of desk-research is discussed (3.2), from which a proposed methodology follows. This methodology consists of five steps with the following central themes: selection databases and search terms (3.3), data collection (3.4) and coding form (3.5).

3.1 Introduction

The first methodology used is the expert interview with the coordinator of the KCN. This interview gains background information within the plastics waste management field (Chapter 2) and provides a solid ground for the keywords and search terms used within the second, main methodology of literature review. This methodology is presented in the sequel of this chapter.

3.2 Desk-research

Research designs are plans and the procedures for research that span the decisions from broad assumptions to detailed methods of data collection and analysis. The selection of a research design is based on the nature of the research problem or issue being addressed and encompasses procedures of inquiry (called strategies), specific methods of data collection, analysis and interpretation (Creswell, 2009). Due to the base of literature which is steadily growing at a seemingly ever increasing rate, keeping track of all relevant published articles becomes impossible. Therefore, a strong need for summaries of recent theoretical and empirical results arises.

Verschuren and Doorewaard (2007) describe the research strategy of desk-research, which apply to the nature of the problem statement as described in paragraph 1.1. A desk-research is recognizable for three matters; (1) use of existing material, in combination with reflection, (2) no direct contact with the research object and (3) use of material from another perspective than to which it was produced. Within desk-research the variants literature review (i) and secondary data analysis (ii) can be dissected. Literature review entails a swift screening of a large number of publications and secondary data analysis reorders existing data and analyses and interprets these data from a new point of view (Verschuren and Doorewaard, 2007). Both variants are intertwined used during this research.

It goes beyond the boundaries of this research to conduct a full meta-analysis, which is a common form of desk-research. However, the definition and specification of the stages of the concept meta-analysis by Schulze (2004) and Lipsey et al. (2001) are very useful concerning the methodology of this research. According to Schulze (2004) meta-analysis is a method for systematic literature reviews on a certain substantive question of interest. He obscures five stages: problem formulation, data collection, data evaluation, analysis and interpretation and public presentation. Lipsey et al. (2001) state that meta-analysis can be understood as a form of survey research in which research reports, rather than people, are surveyed. A coding form is developed, a sample or population of research reports is gathered, and each research study is interviewed by a coder who reads it carefully and codes the appropriate information about its characteristics and quantitative findings.

Combining these two concepts conveys the methodology to be used for this research, consisting of the following five steps:

1) Problem formulation
2) Selection databases and search terms
3) Data collection
4) Coding form
5) Data evaluation, analysis and interpretation

After the problem formulation within Chapter 1 and the introduction into the field of plastics waste management in Chapter 2 (step 1), the selection of databases and the selection of search terms are executed and processed in paragraph 3.3 (step 2). The data collection outcomes are shortly notified in 3.4 (step 3) and 3.5 presents the coding form (step 4). In between, Chapter 3 gives an introduction into the field of plastics waste management. Chapter 4 encompasses the literature review in which the found articles are evaluated, analyzed, summarized and presented (step 5). Chapter 5 ends with conclusions, recommendations and suggestions for further research.

3.3 Selection databases and search terms

This paragraph elaborates on step 2 of the proposed methodology, the selection of databases and the search terms to be used within the search strategy.

Selection of databases
The most common databases that is suitable to search for data concerning the plastics waste management is Web of Science. This database encompasses journals that relate to the plastics waste management and include among others the areas operational research, waste management and reverse logistics.

Due to time constraints it is infeasible to search various databases. Only the well-known general accepted database of Web of Science is searched through in the first place, because this generates the most specific logistical data. After the collection of data, the references of the set of articles are screened for further relevant articles, possibly from other databases than Web of Science. In this way, a most comprehensive analysis of relevant articles is presented. To check the relevance within the set of articles, also the amount of references within Web of Science is tracked.

Search strategy
Below the list of search terms is presented. This list is developed synchronous to the expert interview. After an initial literature study and expansion during the course of research the list comes to the following form:

Reverse logistics

- ✓ Reverse AND logistics
- ✓ Reverse AND logistics AND plastics
- ✓ Reverse AND logistics AND glass
- ✓ Reverse AND logistics AND paper
- ✓ Reverse AND logistics AND quantitative AND model
- ✓ Closed AND loop AND supply AND chain AND plastics
- ✓ Closed AND loop AND supply AND chain
- ✓ Green AND supply AND chain AND management

Level of recovery

- ✓ Recycling AND plastics
- ✓ Recycling AND glass
- ✓ Recycling AND paper
- ✓ Reusing OR reuse AND glass OR paper
- ✓ Recovered AND plastics

Waste management

- ✓ Waste AND management AND plastics
- ✓ Waste AND management AND logistics AND plastics
- ✓ Waste AND management AND network AND logistics
- ✓ Waste AND management AND logistics
- ✓ Waste AND plastics AND collection
- ✓ Waste AND plastics AND processing
- ✓ Waste AND plastics AND separation
- ✓ Waste AND plastics AND sorting
- ✓ Sustainable AND waste AND management AND plastics
- ✓ Plastics AND source AND separation

The search terms are grouped into the fields of reverse logistics, waste management and level of recovery. Within these sets, next to the research object plastics, the products paper and glass are examined. These products form a proper benchmark due to their current status as existing reverse logistics cycle. Also the processes within this cycle such as collection, separation, processing and sorting are set forward.

3.4 Data collection

Step 3 of the proposed methodology concerns the data collection in the Web of Science database. The data collection has a rule of thumb a maximum of 100 hits per search term allowed. However, when the first hits seemed promising, this rule of thumb is ignored.

Using the search terms of paragraph 3.3 within the selected database, eventually 45 relevant articles came to front from various journals. (See further Appendix A.) Three articles out of this set were not available in full text. The literature review covers published research up until 2009. Several appendixes give different overviews and are used within the literature review:

- ✓ Appendix A gives an overview of the entire set of selected articles
- ✓ Appendix B presents the research objects, drivers and keywords
- ✓ Appendix C includes the scope of the articles, containing the kind of OR-problems, research methods and solution techniques
- ✓ Appendix D sums up the journals in which the articles were published
- ✓ Appendix E gives an overview of the citations within the set of articles, as well as within the database of Web of Science
- ✓ Appendix F presents extra references, useful for further research.

3.5 Coding form

This paragraph describes step 4 of the proposed methodology, the coding form. The articles were sorted by different characteristics:

- ✓ *Author:* The researcher(s) that made an academic contribution in the form of an academic published article. (See Appendix A.)
- ✓ *Title of the article:* States the subject of the research. (See Appendix A.)
- ✓ *Year of publication:* Makes explicit in which timeframe the research should be viewed. (See Appendix A.)
- ✓ *Journal:* Makes a distinction to which research area the article contributes. (See Appendices A and D.)
- ✓ *Objective:* The problem or issue of an article defined in one sentence. (Outlined in paragraph 4.1.)
- ✓ *Research object:* The product or case under research. (See Appendix B.)
- ✓ *Drivers:* What are the incentives for the realization of the article? (See Appendix B.) These drivers are segmented into the following categories:
    - economical incentives
    - environmental (including social) incentives
    - legislative incentives
    - theoretical development
- ✓ *Research method:* The methodology that is used to research the objective. The following categorization within the set of articles is made: (See Appendix C.)
    - case study
    - empirical research
    - literature review
    - mathematical model
    - combinations
- ✓ *OR-problem:* An issue belonging to the Operations Research (OR) field. These problems are clustered into four main logistical areas and blends. (See Appendix C.)
    - network design problem
    - location-allocation problem
    - vehicle routing problem
    - decision making
    - combinations

- ✓ *OR solution techniques:* The quantitative methods used for solving the pertinent OR-problem. These can be grouped into four main areas, encompassing several specific techniques. (See Appendix C.)
    - o linear programming
    - o goal programming
    - o heuristics
    - o other solution techniques
    - o combinations
- ✓ *Country of the articles' content:* The research object within the setting of a certain country. (Outlined in paragraph 4.1.)
- ✓ *Country where written:* The country of the research institutes to which the authors are affiliated. (Outlined in paragraph 4.1.)
- ✓ *Ten keywords:* These were selected for categorization and further processing of the articles into the literature review of Chapter 4 and are grouped into scope, level of recovery and material. (See Appendix B.)

  Scope
    - o Reverse logistics
    - o Closed loop supply chain
    - o Network design

  Level of recovery
    - o Product recovery
    - o Recycling
    - o Separation

  Material
    - o Waste (management)
    - o Plastics
    - o Paper
    - o Glass
- ✓ *Referred to within set of articles:* The reference list of articles within the set of 45 articles. (See Appendix E.)
- ✓ *Cited within Web of Science:* A tracking of the amount of times the article is cited in other articles of this database. (See Appendix E.)
- ✓ *Interesting references:* Extra articles that could be relevant for further research were extracted from the references of the 45 articles. (See Appendix F.)

Now the coding form is clear, the next step of literature review, step 5 of the proposed methodology, is presented in Chapter 4.

4. LITERATURE REVIEW

This chapter presents a critical analysis of current literature pertaining to the research issues being addressed; step 5 of the proposed methodology. This literature review answers the research question of which logistical quantitative models, concepts and techniques applicable are within the reverse logistics (cycle) of plastics waste. The review elucidates what kind of products arouse, to which level these are recovered, which quantitative techniques are applicable within the scope of the reverse logistics field and the evolution in this field. The chapter is organized as follows: research objects (4.1), drivers, objectives and methodologies (4.2), level of recovery (4.3), methods of separation (4.4), solution techniques (4.5), reverse logistics and closed loop supply chains (4.6) and a contemplation on the development over time (4.7).

4.1 Research objects

Introduction

Within the scope of reverse logistics several product groups apply. This paragraph makes a cross section through the products or research objects found within the set of articles. (See further Appendix B.) Sub question 1 is addressed within this paragraph:

1. Which research objects can be found within literature concerning the field of reverse logistics?

Product categories

The research objects are divided into the following areas: waste in general, plastics, paper, glass, consumer electronics, automotive industry, more than one product, other products and the category “not specified” without any appearance of a product at all.

One out of seven articles discusses the product of waste, such as municipal waste, plastics waste or just waste in its broadest sense (Ambrose et al., 2002; Bautista and Pereira, 2006; Coates and Rahimifard, 2009; Hu et al., 2002; Lunde, 1995; Repoussis et al., 2009). All articles use a mathematical modelling or empirical research approach to minimize the network design costs or to model the waste streams.

With diverse research approaches the topic of plastics is handled (Ambrose et al., 2002; Heng et al., 2008; Howell, 1992; Mellor et al., 2002; Menges, 1996). The focus is laid on waste plastics, PVC, polymers and just plastics.

Paper is researched within mathematical modelling and case studies (Fleischmann et al., 2001; Frota Neto et al., 2008; Kumar Pati et al., 2008; Salema et al., 2007). The products vary from the pulp and paper industry to a copier and paper manufacturer to paper recycling and office documents.

One article researches the glass industry in Spain, featuring a mathematical model plus a case study (Gonzalez-Torre and Adenso-Diaz, 2002).

One out of seven articles focus on consumer electronics (Blackburn et al., 2004; Fleischmann et al., 2001; Frota Neto et al., 2009; Hu and Bidanda, 2009; Lee and Chan, 2009; Sheu et al., 2005). Partly this comes forth from EU legislation: The Waste Electrical and Electronic Equipment (WEEE) directive, making producers responsible for their end-of-life products. The common research methods are case studies and mathematical modelling.

Articles treating products from the automotive industry are tackled by various methods (Krikke et al., 1999; Üster et al., 2007; Wells and Seitz, 2005). In all three articles the automotive industry as a whole is captured.

For the main part literature reviews are used to capture various kinds of products and to summarize them into general frameworks (Akcali et al., 2008; Beamon and Fernandes, 2004; Fleischmann et al., 1997; Pokharel and Mutha, 2009; Srivastava, 2008). Most products fall into the fields of waste management, product recovery and reverse logistics.

Remaining products are respectively blood containers, wheelchairs, used products, raw materials and nuclear power (Alshamrani et al., 2007; Chouinard et al., 2008; Fleischmann et al., 2000; French and LaForge, 2006; Neiva de Figueiredo, 2008; Sheu, 2008). Different research methods are used.

Pure mathematical models and some literature reviews consider the field of reverse logistics and related subjects such as network design and green supply chain management and do not specify the products under research (Easwaran and Üster, 2009; Lee and Dong, 2009; Lieckens and Vandaele, 2007; Rubio et al., 2008; Salema et al., 2009; Sbihi and Eglese, 2007; Srivastava 2007; Yang et al., 2009). These articles are all more abstract researches of the last three years.

All in all, waste and consumer electronics are the most studied research objects. Where it concerns one specific product mostly a mathematical model and/ or case study is applied; several products are mostly treated in a literature review. Next to the literature found on the plastics products, paper and glass could be used as a benchmark.

Countries

Within the set of articles, chiefly European researches are found, comprising 50% of the articles, followed by 27% American articles (mostly USA) and 23% Asian articles. Of all case studies, whether or not supplemented by a mathematical model, the main part comes from European countries (50%), followed by American countries (30%) and Asian countries (20%).

One out of seven of all articles come from The Netherlands, focusing on various products. An equal number comes from the UK, mainly focusing on plastics waste. Germany focuses in two articles on waste and plastics, Spain on glass and municipal waste, Belgium and France on various products. Norway has an article about waste, Greece on waste lube oils, Portugal on office documents.

Articles from the USA treat the products consumer electronics, automotive industry and various products. An article from Canada is about wheelchairs and the article from Brazil concerns tires.

Taiwan treats within three articles hazardous waste and notebooks, India treats paper and various products, Iran and Cambodia focus on plastics and China and Singapore do not specify their research objects. Except Taiwan, all literature comes from 2008 and 2009.

Conclusion
Waste and consumer electronics are found to be the main research objects. Besides, the researches on paper and glass could be exemplary for the plastics waste management. Mostly a case study or a mathematical modelling approach is used. The most progressive literature is found in the Netherlands. The USA and the UK and other European countries fill up the main corps of literature. Asian literature is growing, especially since 2008.

4.2 Drivers, objectives and methodologies

Introduction
Now the research objects are clear, a broad overview and introduction is presented to capture a comprehensive view of the drivers behind this research, the objectives being addressed and the methodologies being used. (See further Appendices B and C.) A starting point is given to demarcate the boundaries of the reverse logistics field and to elucidate upon the field under research. The question under research is as follows:

2. What are the drivers, objectives, methodologies and logistical concepts used within this area of research?

Drivers
Increasing interest in re-use of products and materials is one of the consequences of growing environmental concern throughout the past decades (Fleischmann et al., 2000). In the EU a growing body of community directives obliges its members to recover and recycle many products and components (Bautista and Pereira, 2006). Governments have changed the "end-of-pipe" environmental laws to more comprehensive ones, broadening the responsibility of producers (Frota Neto et al., 2009). Producers have to make trade-offs between the social concerns for the environmental impacts of an economic activity and its subsequent costs. Against this background of economical, environmental (including social) and legislative incentives, researches have been executed in order to deal with issues concerning recycling networks and the trade-offs therein.

Objectives
Most objectives being addressed have the aim to minimize costs. It concerns to a high extent network design and location-allocation problems and to a lesser extent vehicle routing problems and (economic) decision making. The threefold of drivers as mentioned above are all set forth within the set of articles. In most articles it is an interplay of the economic profit and the environmental burden, whether or not prescribed by legislation.

Logistical concepts categorization
As mentioned, the logistical concepts categorization falls apart into network design problems, location-allocation problems, vehicle routing problems and (economic) decision making. Network design problems consist in its simplest form of a set of points connected by

links. The points are called nodes and represent e.g. a physical place such as a distribution centre and the links can represent material flows and related economic and environmental costs and transportation costs between two places. The nodes are already given. With a location-allocation problem you start from scratch and have to decide where to place the nodes and the lines to form the network. There is a slight difference; however within the reviewed literature both concepts are intertwiningly used. A vehicle routing problem seeks to determine the routes to be used by a fleet of vehicles to serve a set of users (Ghiani et al., 2004). The last category is broadly defined as decision making, concerning mostly economic decisions that are questioned or supported.

Network design problems

Chouinard et al. (2008) provide a stochastic programming approach, minimizing costs and improving valorised product accessibility in the design of supply loops, illustrated by a case for wheelchairs in Canada. Frota Neto et al. (2009) present an exploratory study assessing eco-efficiency illustrated by the design of a German recycling network. Frota Neto et al. (2008) develop a framework for the design and evaluation of sustainable logistics networks exemplified by the paper and pulp industry.

Various scholars present different cost minimization models for optimisation of the reverse logistics network design for different kinds of products under varying conditions (Hu et al., 2002; Krikke et al., 1999; Lee and Chan, 2009; Lee and Dong, 2009; Lieckens and Vandaele, 2007; Neiva de Figueiredo and Mayerle, 2008; Salema et al., 2009; Srivastava, 2008; Üster et al., 2007). Sheu (2008) and Sheu et al. (2005) view the same network design issues from a different angle based on the concept of green supply chain management. Salema et al. (2009) take another perspective by maximizing the global supply chain profit incorporating production and storage planning. Yang et al. (2009) depict the formulation and optimization of the equilibrium state of a closed loop supply chain network.

To summarize, scholars of current literature in the field of network design problems, aspire to design a cost efficient network for the reverse logistics of various products.

Location-allocation problems

Several articles treat diverse location-allocation problems. Bautista and Pereira (2006) determine the optimal design to locate collection areas for municipal waste, minimizing the set of collection points and their incurred costs. Beamon and Fernandes (2004) explore the economic opportunities for product recovery systems aiming at minimal costs in developing and analyzing a location model. Gonzalez-Torre and Adenso-Diaz (2002) examine a reallocation problem and model an efficient distribution of containers for glass recycling.

The location-allocation problems dovetail closely to the network design problems, but have a more specific focus towards the location of facilities.

Vehicle routing problems

Some articles stress especially the vehicle routing problem within the bigger whole of formulating a network design. Alshamrani et al. (2007) propose a model in order to minimize the costs of vehicle routing of blood containers for the American Red Cross. Repoussis et al. (2009) present a vehicle routing system to plan and monitor needs of collection and distribution operations for waste lube oils. Sbihi and Eglese (2007) determine combinatorial optimization problems in the area of waste management in which vehicle routing and scheduling prevail.

(Economic) decision making
In the field of waste management various decision making articles can be found. Ambrose et al. (2002) describe the environmental project of mechanical recycling of 100% post-consumer plastics waste into high-quality products. Heng et al. (2008) identify the willingness to separate plastics waste before recommendations can be given to the Cambodian government for the policy they should pursue. Lunde (1995) promotes information exchange and cooperation on energy recovery from municipal solid waste.

Other articles stress explicitly the economic profits of recycling and recovery networks. Blackburn et al. (2004) aim to minimize the loss of commercial value by creating a value stream of product returns. Hu and Bidanda (2009) model effective decision making in order to maximize long term profitability in product lifecycle evolution. Mellor et al. (2002) describe a methodology for efficient modelling the flow of re-used materials.

Combinations
A beautiful integration of a network design problem, a location-allocation problem and vehicle routing problem comes from Easwaran and Üster (2009). They have the objective to minimize network design costs in closed loop supply chains by determining the optimal routing and location. Kumar Pati et al. (2008) optimize the trade-offs among reverse logistics costs, product quality and environmental benefits in paper recycling.

Theoretical development
A separate driver for research is “for the sake of science” or to summarize the evolution in current literature. This driver is recapped under the umbrella theoretical development.

State-of-the-art research has been executed by Fleischmann et al. (1997, 2000 and 2001). Within the set of 42 articles (three articles were not available in full text) their articles are referred to subsequently 18, 16 and 12 times. In 1997 they evaluated the emerging field of reverse logistics and absorbed it into a general framework for reverse logistics. In 2000 an identification of characteristics and categorization of product recovery networks was presented. And in 2001 the impact of product recovery on logistics network design was thoroughly explored. He is the most cited first author in the field of reverse logistics and product recovery; see Table 1 on the next page. (See Appendix E for the total overview.)

Next to these three prominent articles, several overview papers give comparable outlines. Rubio et al. (2006) and Pokharel and Mutha (2009) determine also at different time scales the current evolution of research in the field of reverse logistics. In addition, Srivastava (2007) presents an integrated view of green supply chain management from a reverse logistics perspective. French and LaForge (2006) execute an exploratory study identifying re-use practices in process industries from a producer's perspective following a closed loop supply chain approach. Wells and Seitz (2005) delineate different typologies of the closed loop supply chains. Akcali et al. (2008) provide a bibliography of models and solution approaches to optimize network design problems for reverse and closed loop supply chains.

Table 1: Citation index Fleischmann et al.

Nr.	Author(s)	Article	Year	Cited within set of 42 articles	Cited in Web of Science
12	Fleischmann, M; Bloemhof-Ruwaard, JM; Dekker, R; van der Laan, E; Nunen, JAEE; van Wassenhove, LN	Quantitative models for reverse logistics: A review	1997	18	307
10	Fleischmann, M; Krikke, HR, Dekker, R; Flapper, SDP	A characterisation of logistics networks for product recovery	2000	16	110
11	Fleischmann, M; Beullens, P; Bloemhof-Ruwaard, JM; van Wassenhove, LN	The impact of product recovery on logistics network design	2001	12	72

Finally, theoretical development finds place at a more technical level. Coates and Rahimifard (2009) describe the development of a theoretical optimal modelling approach to waste streams processing, Howell (1992) evaluates the field of plastics recycling and Menges (1996) assesses the PVC recycling management.

Methodologies

The elaborations on and application of the aforementioned logistical concepts are all treated in the form of mathematical modeling and case studies and blends between these two. There is a strong focus on operational research, transportation science and waste management within these methodologies. (See further Appendix D.) The theoretical development finds place at the level of literature reviews and some empirical research in order to seize a broader view of the recently emerged field.

Conclusion

Grasping the key objectives of the fields of reverse logistics, it appears that the main drivers are economic, environmental (and social) and legislative incentives. Researchers have to analyze these trade-offs between drivers. This explains why most methodologies concern mathematical modelling, case studies and combinations thereof. There is a strong focus on operational research, transportation science and waste issues within these methodologies. Next to this threefold of incentives, the field of study enriches itself with literature reviews and to a lesser extent empirical research for the sake of theoretical development. This is done in order to summarize current evolution and to delineate further research. The logistical part of plastics waste management involves the logistical concepts of network design and location-allocation problems, including vehicle routing and decision making.

4.3 Level of recovery

Introduction

Within the plastics waste management there are different intended end goals for the plastic entity within the closed loop supply chain. Products can for instance be recovered, remanufactured and re-used, recycled or destroyed. Especially the level of recovery differs herein. The options for plastics waste is investigated, supplemented by benchmarking with other research objects/products as delineated in paragraph 4.1. Sub question three reads as follows:

3. Which levels of recovery and recycling can be discerned for the application to plastics waste?

Options for plastics waste

Recycling is just one option for the disposing of polymeric wastes. Energy recovery by incineration, landfilling where there is sufficient space, use of degradable polymers where warranted, and the cracking of plastics into useful chemicals are all feasible alternatives. Source reduction and increased re-use of polymeric products will also impact the economic viability of plastics recycling. Research has shown that because of transportation and processing economics, polymer recycling will be of most value when it is part of an integrated waste management infrastructure encompassing all feasible options within a confined greater municipal area (Ellis, 1995).

Categorization

It is useful to think of the reverse logistics activities in two major categories: recovery strategies and re-use options. The recovery strategies in process industries involve network design and product acquisition. The re-use options impact operations management activities in inventory, production planning and control, and scheduling (French and LaForge, 2006).

Recovery strategies

Blackburn et al. (2004) group four options for the disposition process of consumer electronics: renew or restock, repairing or refurbishing, parts recovery or disassembly and scrap or recycling. Because of deterioration a product should be renewed and restocked. Repair of a product could be due to damage during shipment. Parts recovery could involve expensive parts and units that need to be filtered out. Recycling implies “the recovery of the material without conserving any of the product’s structure” (Gonzalez-Torre and Adenso-Diaz, 2002). So, recycling refers to the secondary use of materials, which may be “downcycled” into a lower grade application (Wells and Seitz, 2005).

Beamon and Fernandes (2004) present a categorization of product recovery options which all imply collection, reprocessing and redistribution. The presented options are repair, refurbishing, remanufacturing, cannibalization and recycling. Repair is simply to return failed products to “working order” by fixing or replacing broken parts. Refurbishing involves replacement of critical modules if needed. The quality and service life of refurbished products are still lower than the quality and service life of new products. Remanufacturing returns the product to “as new” condition through product disassembly and rigorous inspection of all modules. Worn-out or out dated parts and modules are replaced and tested. Technological upgrades may also be included. Remanufacturing tends to be performed in-house by manufacturers, since specific product knowledge is required. Cannibalization consists of recovering only some parts from used products to be used in other products or components. Recycling requires product disassembly for material separation without conserving any product structures. This detailed categorization comes close to the proposed classification of Blackburn et al. (2004).

So, recovery strategies vary from recycling, which is simply material recovery, through parts recovery, until recovery of the entire product meant for re-stocking. Between these extremes various recovery strategies apply.

Re-use options

The most common re-use options are disposal as waste and blending-off into the same or similar product. In addition, sometimes repackaging, blending whole batches to meet specifications, finding an alternative customer or market or blending off at some percentage into a different product are appropriate options (French and LaForge, 2006).

Mellor et al. (2002) define the "cascade of uses": inclusion of use and re-use of materials in a series of different applications. Frequently these successive applications will have progressively lower performance specifications. Thus, the first use of a material has higher performance requirements than the second or third use. This typically dovetails with the blending off option and the deterioration of the product quality.

Fleischmann et al. (1997) first categorize the types of items that are recovered and than splits the different forms of re-use into direct re-use, repair, recycling and remanufacturing. He combines here product recovery and re-use options. Srivastava (2007) delineates remanufacturing into re-use, product recovery and material recovery. So, both typologies of re-use options and recovery strategies seem to overlap.

Conclusion

The reverse logistics activities can be grouped into recovery strategies and re-use options which seem to overlap with each other. For the application to plastics the methods of recycling (material recovery), parts recovery, product recovery, waste disposal and blending-off are most common and will have most value in an integrated waste management infrastructure.

4.4 Methods of separation

Introduction

The distinction between two separation methods, namely separation at the source versus separation at the waste processing unit is made. Little literature gives insights into these differing methods covering waste management and plastics related subjects. Therefore, the following issue is addressed:

4. Which methods for separation of plastics waste do exist and is there a differentiation pertaining quantitative models?

Separation techniques

Source separation schemes exist in various European countries and in the USA for collecting recyclable materials, particularly paper and glass, from households. A number of countries also have schemes for separate collection of an organic fraction for either composting or treatment in an anaerobic digestion to produce energy. An alternative approach, which is becoming popular, particular in the USA, is not to have source separation at the household, but use handpickers to recover recyclables from the waste at a sorting plant. The main advantage of this approach is the lower cost, but the materials which are recovered are not as clean as those from source separation schemes, although they are still marketable (Lunde, 1995). Kumar Pati et al. (2008) make the same distinction: waste composition versus segregation at source. In Srivastava (2007) sorting can be carried out either at the point/ time of collection itself or afterwards (at collection points or at remanufacturing facilities). Collection schemes are classified according to whether materials are separated by the consumer (i.e. separation at source) or centralized (i.e. mixed waste processed). It can be concluded that all three articles proclaim the same "separation" in separation techniques.

Separation technologies

Howell identified already in 1992 a separation technology making use of a magnet, mill, zigzag classifier, sieve, moistening and dryer. Coates and Rahimifard (2009) discern the following mechanical waste separation technologies: screening, magnetic separation, non-ferrous separation, air classification and dense media separation. The waste is separated on parameters such as particle size, magnetic susceptibility, conductivity, mass and density. All these technologies are examples of separation at the waste processing unit.

Quantitative models

There is too little literature available to make useful recommendations concerning the separation methods. The only solution technique that occurs within the separation related literature is the mixed integer goal programming technique; furthermore no model or statistics are applied.

Conclusion

The distinction between source separation and separation at the waste processing unit also appears within the current literature. Separation at the waste processor can be further divided into various mechanical waste separation technologies. A differentiation pertaining quantitative models can not be made.

4.5 Solution techniques

Introduction

Closing the loop with the objectives being addressed in this field of research, various solution techniques apply for different products and problems. The solution techniques are grouped into four different categories: linear programming (18 articles), goal programming (2 articles), heuristics (14 articles) and other techniques (3 articles). The (twelve) articles that don't contain a specific solution technique are all literature reviews and empirical researches. Five articles contain two solution techniques and one article combines three techniques. (See further Appendix B.) Sub question 5 summarizes the matter to tackle:

5. Which quantitative models and solution techniques apply to the various research objects and logistical concepts?

Linear programming

A general linear programming (LP) approach is proposed in order to solve a reverse logistics cost minimization model (Hu et al., 2002) and to create a decision-support framework for material recovery, recycling and cascaded use (Mellor et al., 2002).

Within ten articles a mixed integer linear programming (MILP) technique is used (Akcali et al., 2008; Beamon and Fernandes, 2004; Chouinard et al., 2008; Easwaran and Üster, 2009; Fleischmann et al., 2001; Krikke et al., 1999; Salema et al., 2009; Salema et al., 2009; Srivastava, 2007; Üster et al., 2007). Interestingly, all ten articles intend to solve a network design problem, sometimes including a location-allocation problem.

A variant is the mixed integer non linear programming (MINLP) technique which in all three articles have the objective to solve a network design problem (Akcali et al., 2008; Lee and Dong, 2009; Lieckens and Vandaele, 2007).

Three articles make use of multi objective linear programming (MOLP) in order to serve the area of sustainable logistics networks within green supply chain management (Frota Neto et al., 2008; Sheu, 2008; Sheu et al., 2005).

Goal Programming

On one occasion a mixed integer goal programming (MIGP) model was used to make a trade-off between reverse logistics costs, product quality and environmental benefits for a paper recycling system (Kumar Pati et al., 2008). The article itself claims that this model could very well be extended and used to other similar reverse logistics problem areas involving the environmental issues and conservation of natural resources such as recycling of plastics waste.

Another benchmark can be made to the application of glass. A (pre-emptive) goal programming (GP) approach is used to solve the efficient distribution of recycling containers (Gonzalez-Torre and Adenso-Diaz, 2002). Here, a clear location-allocation problem is treated.

Heuristics

Most articles that use heuristics as a solution technique, apply algorithms (Alshamrani et al., 2007; Bautista and Pereira, 2006; Chouinard et al., 2008; Frota Neto et al., 2009; Lee and Chan, 2009; Lieckens and Vandaele, 2007; Neiva de Figueiredo and Mayerle, 2008; Repoussis et al., 2009; Yang et al., 2009). All have the objective to minimize the costs in different settings of vehicle routing, location-allocation and network design.

Hu and Bidanda (2009) model effective decision making in order to maximize the long term profitability using algorithms. Within the group of algorithms the special technique of Benders decomposition is used twice (Easwaran and Üster, 2009; Üster et al., 2007). In both articles the aim is minimizing the network design costs of closed loop supply chains.

Sbihi and Eglese (2007) sum up various heuristics to solve combinatorial optimization problems. Lee and Dong use the simulated annealing heuristics in order to model a dynamic network design problem. Easwaran and Üster (2009) also use the tabu search heuristics to minimize the network design costs.

All in all, heuristics are well suited to solve network design problems. Nevertheless, also location-allocation and vehicle routing problems can be parked under this solution technique.

Other

Hu and Bidanda (2009) also use a Markov decision process, which is a form of dynamic programming. Coates and Rahimifard (2009) and Heng et al. (2008) both use statistical techniques respectively to develop a modeling approach to waste streams processing and to identify the willingness to separate plastics waste.

Combinations

Except one, all six articles that contain two solution techniques, are combinations of linear programming and heuristics. All articles seek to research (a combination of) network design and location-allocation problems. The sixth article is a form of dynamic programming pursuing decision making.

Deterministic versus stochastic

Another distinction that can be made is between deterministic and stochastic models. Nearly all mathematical models up until 2006 are deterministic, leaving no room for random uncertain events. Within the literature, five articles are found that implement stochastic elements. Alshamrani et al. (2007) model uncertainties of supply and processing of used products associated with product recovery systems. Hu and Bidanda (2009) formulate a product lifecycle evolution system based on stochastic dynamic programming. Lee and Dong (2009) developed a two-stage stochastic programming approach, extending a deterministic model to account for the uncertainties within network design. Eventually this turned out into new hybrid processing facilities. Lieckens and Vandaele (2007) account for dynamic aspects like lead times and inventory positions and the higher degree of uncertainty inherent to reverse logistics. Pokharel and Mutha (2009) include in their analysis research papers that considers stochastic demand for remanufactured products and supply of used products by the consumer. Concluding, there is a growing body of literature incorporating stochastic elements and uncertainty.

Conclusion

Mixed integer linear programming and mixed integer non linear programming techniques are especially applicable for network design problems and sometimes the location-allocation problems that occur therein. Multi objective linear programming is suited for the area of green supply chain management. Mixed integer goal programming is possibly useful for the case of plastics and concerning separation methods. Goal programming can be useful as a benchmark with the application of glass. Heuristics, especially algorithms, are suitable to solve vehicle routing, location-allocation and network design problems. Combinations between linear programming and heuristics also seem very likely.

4.6 Scope

Introduction
The scope of plastics waste management points so far to the constructs of reverse logistics and closed loop supply chains. In this paragraph these constructs are explained and categorized answering sub question 6:

6. What is the scope of the crossing areas reverse logistics and plastics waste management?

Reverse logistics
Reverse logistics encompasses the logistics activities all the way from used products no longer required by the user to products again usable in a market. First of all, this involves the physical transportation of used products from the end user back to a producer, thus distribution aspects. The next step is the transformation by the producer of the returned products into usable products again. From a logistical point of view the focus is on inventory management. In addition, production planning aspects appear to pursue again usable products (Fleischmann et al., 1997). Fleischmann categorizes reverse logistics into the scope of distribution planning, inventory management and production planning.

About ten years later, in Rubio et al. (2008) reverse logistics is defined as "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". Rubio categorizes the reverse logistics field into three areas: recovery and distribution of end-of-life products, production planning and inventory management, and supply chain management issues. Their focus lays especially at a supply chain management perspective.

In Srivastava (2007) a similar definition from a more "green" perspective is given: "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." He identifies the processes of collection, inspection and sorting, pre-processing and location and distribution (i.e. network design) within the reverse logistics.

A last definition comes from a quote from Gonzalez-Torre and Adenso-Diaz (2002): "A system of reverse logistics may be defined as a supply chain that is redesigned so as to efficiently manage the flow of products destined for remanufacturing, re-use, recycling or disposal, using all its resources efficiently".

Unlike the use of the term "reverse" suggests, these four articles all agree to include the forward channel. Although Gonzalez-Torre and Adenso-Diaz (2002) stop in their definition at the point that the recovered products or materials will be destined for a new use or disposal, they also incorporate just like the other authors the forward channel of re-manufacturing, re-use and recycling into "new" applications.

Pokharel and Mutha (2009) recently extended the view on reverse logistics by considering important features such as product acquisition, pricing, collection of used products, reverse logistics network structure vis-à-vis the integration of manufacturing, and remanufacturing facilities of location of facilities for inspection and consolidation activity.

Summarizing, the reverse logistics system is perceived to consist of a reverse and a forward channel, just as the first article in this field of Fleischmann et al. in 1997 claimed, comprising the following actors:

- ✓ Reverse channel: consumers, collectors and (re)distributors, recyclers, (re)producers/ suppliers
- ✓ Forward channel: suppliers, producers, distributors, consumers

Combining the categorizations of reverse logistics, this can be captured into the following four main areas:

- ✓ Network design
- ✓ Pre-processing
- ✓ Production planning
- ✓ Supply chain management issues

Not only the definition, but also the categorization of reverse logistics from Fleischmann et al. (1997) more or less still holds. Distribution planning is broadened towards *network design* and also encompasses location planning and recovery and collection of products in the reverse chain. Inventory management is enlarged to *pre-processing* and takes more aspects into account such as product acquisition, inspection, selection, sorting, finally the transformation into usable products, consolidation, pricing and possibly disposal of products. *Production planning* is more or less the same, accompanied by remanufacturing and integration with manufacturing. *Supply chain management issues* is an extension from Rubio et al. (2008) and concerns those works that analyze the strategic decisions, which the existence of a reverse flow of products generates in the management of the supply chain. Thus, questions such as the long-term behavior of closed-loop supply chains, the role of IT, the impact of environmental regulation and the environmental management of reverse logistics, among others, are included in this topic.

Closed loop supply chains

Rubio et al. (2008) mentioned the long-term behavior of closed-loop supply chains, but what are exactly closed loop supply chains?

Closed-loop supply chain management is the design, control and operation of a system to maximize value creation over the entire life-cycle of a product with dynamic recovery of value from different types and volumes of returns over time (Guide et al., 2006).

Akcali et al. (2008) focus on the network design of closed loop supply chains and state that it is concerned with establishing an infrastructure to manage both forward and reverse channels in a coordinated manner. They make a distinction between pure reverse supply network designs in that it is concerned with establishing an infrastructure to manage the reverse channel only. This is categorized as an open loop model. Closed loop supply chain networks also include forward activities and forward flows, along with the reverse channel.

The set of forward activities include manufacturing and distribution operations, and the set of flows includes the forward flows among the forward activities as well as the flows among the forward and reverse activities. Easwaran and Üster (2009) make the same distinction into forward and reverse flows.

Open loop versus closed loop characterizes the relation between incoming and out-going flows of a network. In a closed loop network sources and sinks coincide so that flows “cycle” in the network. An open loop network, on the other hand, has a “one-way” structure in the sense that flows enter at one point and leave at another (Fleischmann et al., 2000). Chouinard et al. (2008) distinguishes closed supply loop products that are reintegrated into the original supply chain and open supply loop products that are introduced into alternative markets. Hu and Bidanda (2009) however, categorizes an open loop system only as a forward channel and the closed loop as forward and reverse.

Beamon and Fernandes (2004) study a closed loop supply chain of consumer electronics in which manufacturers produce new products and remanufacture used products. Decisions that have to be made, regard location problems, distribution and collection issues and recovery. Wells and Seitz (2005) embody reverse logistics and remanufacturing within the construct of closed loop supply chains.

Lee and Chan (2009) summarize as follows: Reverse logistics, which is the management or return flow due to product recovery, goods return, or overstock, form a closed-loop supply chain. The success of the closed-loop supply chain depends on actions of both manufacturers and customers. So, reverse logistics form a closed loop supply chain. This transactional perspective is exactly pointing out what all other scholars together claim.

All in all, the construct closed loop supply chain is very similar to the construct of reverse logistics, stressing the viewpoint of network design and incorporating manufacturing and distribution. However, when the term of closed loop supply chain is chosen, mostly the discrimination between the forward and reverse loop is emphasized. An open loop supply chain consist of only one channel, whether forward or reverse, whether integrating into the same or other loops. Before 2000 only the term reverse logistics was used, from 2001 and further on the term closed loop supply chain became just as common and was interwoven used.

Conclusion

The scope within plastics waste management concerns the field of reverse logistics i.e. the field of closed loop supply chains. Both constructs are intertwiningly used and encompass network design, pre-processing, production planning and other supply chain management issues. A closed loop supply chain falls clearly apart in a forward and a backward channel.

4.7 Development over time

Introduction

To conclude the literature review, the main trends since the leading work of Fleischmann et al. in 1997 will be given. This article is taken as a starting point, because within the set of 42 researched articles it is 18 times cited (i.e. 43%). Of all 27 articles that do contain references to other articles within the set of 42, 18 articles (i.e. 67%) refer to Fleischmann et al. (1997). Moreover, 24 out of 27 articles (i.e. 89%) refer to at least one article with Fleischmann as the first author. So, Fleischmann et al. can be seen as the founder of the reverse logistics area. From this point off the following question is answered:

7. What is the development over time within the field of reverse logistics?

Trends

The literature pertaining to reverse logistics has grown significantly since 1997. The field has broadened since the first categorization into distribution planning, inventory management and production planning. Network design has taken a more central place within reverse logistics and inventory management is recapped under the umbrella of pre-processing and its main features and processes.

Moreover, the reverse logistics area has improved in taking a perspective more from a supply chain management angle. There is more focus on strategic and tactical decisions, instead of stressing the operational activities. Besides, the construct closed loop supply chain is put in place and is used interwoven within the current literature of reverse logistics.

Since 1997 there is far more awareness of environmental impacts and more environmental regulation has been put in place. Almost no articles are found that purely stress the economic and commercial incentives; almost all articles tackle the trade-off between economic activities and its environmental and social consequences, whether or not prescribed by legislation.

Up to including 2006, uncertainty is not taken into account within mathematical modelling methodologies. Especially in 2009 more articles treat the stochastic events that occur within the network design of reverse logistics.

The last evolution in current research is that Asian literature is growing steadfast, especially since 2008. More and more developing countries such as India, Singapore and China are trampling to make a contribution to the field of reverse logistics and its application areas such as waste management, product recovery and transportation science.

Conclusion

Trends since Fleischmann et al. (1997) include a focus towards network design and a broadening of the categorization of the reverse logistics field. The reverse logistics are merely dealt from a supply chain management approach, taking a more strategic perspective. From 2007 more stochastic models aroused, taking uncertainty into account. Besides, the environmental awareness and impact is growing and is Asian literature coming up.

5. CONCLUSION AND RECOMMENDATIONS

The thesis contributes to the further development of the reverse logistics field, focusing on the relation with the area of plastics waste management. Although reverse logistics in general is a thoroughly researched area, there is very little literature zooming in on the reverse flows of plastics. The congregation of these two fields falls together in this literature review. Environmental concerns, societal incentives, EU legislation and business activities drove this thesis to its current form. The research can be regarded as an introduction and guideline for further research, contributing to the business plan of KCN.

This chapter presents the conclusion (5.1), recommendations (5.2), discussion (5.3) and suggestions for further research (5.4), providing an adequate answer to the following main research question:

Which logistical quantitative models, concepts and techniques may be applicable to the reverse logistics (cycle) of plastics waste?

5.1 Conclusion

The field of reverse logistics and closed loop supply chains is directly related to the scope of plastics waste management. The most progressive literature is found in the Netherlands. The USA and the UK and other European countries fill up the main corps of literature, while Asian literature is growing. The focus is on operational research, transportation science and waste issues.

The main research objects within reverse logistics are waste and consumer electronics. Reverse logistics, which is gradually intertwiningly used with the term closed loop supply chain, encompass four main areas: network design, pre-processing, production planning and other supply chain management issues of a merely strategic level. The construct closed loop supply chain within the literature makes a clear distinction in a forward and a backward channel/loop comprising consumers, collectors and (re)distributors, recyclers and (re)producers/suppliers.

The logistical part of plastics waste management involves chiefly the logistical concepts of network design and location-allocation problems and to a lesser extent vehicle routing and decision making. These four concepts are the most applicable within the reverse logistics of plastics waste.

The main drivers crossing the fields of reverse logistics, plastics waste management and network design are: economic, environmental (and social) and legislative incentives. Trade-offs between these drivers must be made, resulting in mainly mathematical modelling, case studies and combinations as common methodologies. Next to this threefold of incentives, the field of study enriches itself with literature reviews and to a lesser extent with empirical research in order to summarize current evolution and to delineate further research.

The reverse logistics activities can be grouped into recovery strategies and re-use options, which however partly seem to overlap. Regarding the application to plastics, the methods of recycling (material recovery), parts recovery, product recovery, waste disposal and blending-off are most common and will have most value within an integrated waste management infrastructure. Besides, case studies on paper and glass, comprising mathematical techniques to minimize costs in developing a network design while meeting certain criteria, could be exemplary for the plastics waste management.

Mixed integer linear programming and mixed integer non linear programming techniques are especially applicable for network design problems and sometimes also for the location-allocation problems that occur within the field of plastics waste management. Heuristics, especially algorithms, are suitable to solve vehicle routing, location-allocation and network design problems. Combinations between linear programming and heuristics are also very likely to be applied within the reverse logistics of plastics waste. A quantitative distinction concerning the different separation methods cannot be given.

Trends since Fleischmann et al. (1997) include a focus towards network design and a broadening of the categorization of the reverse logistics field. The reverse logistics issues are more dealt from a supply chain management approach at the strategic level. From 2007 onwards, more stochastic models aroused, taking uncertainty into account. Besides, the environmental awareness and impact is growing and is Asian literature rising, especially since 2008.

5.2 Recommendations

Recommendations can be made concerning the implementation of a network design for the reverse logistics of plastics waste. The objective in this issue is to minimize costs in developing such a network design while meeting certain criteria, i.e. the constraints.

To do things right first time, it is advisable to include uncertainty within the model. Lee and Dong (2009) and Lieckens and Vandaele (2007) propose such as stochastic model including linear programming and heuristics to solve a network design problem/ location-allocation problem. Both propose a mixed integer non linear programming approach supplemented by an algorithm to obtain solution. This goes further than the traditional mixed integer linear programming, by adding non-linearity to tackle the dynamic and uncertain elements within the reverse logistics network. The constraints within the model concern potential facility locations and their fixed costs, transportation, supply, demand, capacity and include inventory and penalty costs. These models make it possible that not only one loop is taken into account, but that processing and collection facilities become intermediate depots in a hybrid form, absorbing the forward as well as the backward channel.

Integrating a vehicle routing problem within the reverse logistics network design could be tackled by using algorithm heuristics. The route design-pickup strategy planning problem should be considered within a multi-period planning horizon.

Another possible technique would be to benchmark with the mixed integer goal programming, provided by Kumar Pati et al. (2008). This could be very useful for the case of plastics and concerning separation methods, because of the great similarity with paper as a household waste product. The goals would cover the minimization of the reverse logistics costs, the minimization of the quantity of low quality non-relevant plastics and the maximization of plastics recovery at the source. Costs constraints, recovery targets, demand constraints, throughput constraints, capacity constraints, integrality constraints and non-negativity constraints should form the structure of this model.

Next to the paper industry, the goal programming technique from Gonzalez-Torre and Adenso-Diaz (2002) should be taken into consideration. Because of the commodity glass, this can be useful as a benchmark with the application to plastics. The model seeks to maximize the amount to be collected, including capacity constraints, location constraints and transportation constraints. For an effective location-allocation problem, this model is exemplary.

Furthermore, the technique of multi objective linear programming is suitable for the area of green supply chain management. This takes into consideration the extra objective to minimize the environmental impact. This can be further researched in how far this will be applicable for the future, taking into account the growing environmental concerns.

Another more practical avenue could be the option to vertically integrate the management of the collection and sorting centres together with remanufacturers. In this way, a more hybrid form of reverse logistics is created, enhancing an effective and efficient throughput of the plastics waste.

The waste processing industry should examine the possibility to create different containers for the waste products glass, paper and plastics. A three-way bin at the household level could be an effective solution. Near flat buildings or certain neighborhoods containers could be placed next to the glass and paper recycling containers.

5.3 Discussion

Reliability refers to the credibility of the outcomes of the research and can be perceived high as results can be replicated by other researchers on other occasions (de Vaus, 2001). The reliability of this research is considered to be high. The course of research is meticulous tracked and the results are perceived to be replicable.

Internal validity is the extent to which the structure of a research design enables to draw unambiguous conclusions from the results (de Vaus, 2001). The internal validity of this research is perceived to be reasonable, because it is demarcated to only one database. However, by using a wide spectrum of articles, the component content validity is considered to be high.

External validity concerns the extent to which results from a study can be generalized beyond the particular study (de Vaus, 2001). The external validity of this research is expected to be moderate. The results could be generalized to other reverse logistics cycles; however for every single case, for every other waste stream or for another product, a new logistical quantitative model should be built.

A more general remark concerns the willingness of the households to separate their waste. An implemented network design for the plastics waste can be theoretically sound, however positive moral motives can significantly lower the costs associated with the household recycling efforts.

5.4 Further research

This thesis on the reverse logistics of plastics waste management opens avenues for further research.

Within the reverse logistics area there is little literature pertaining to the pricing of the recovered products in relation to the quality. Plastics waste with a higher purity level has more and better options for re-use and will have higher economic value. Further research could involve quantitative modelling contributing to the systematic valorization of recovered plastics.

Besides, research with a stochastic nature and with inclusion of non-linearities should be broadened. By inclusion of uncertainty the theory will more realistically coincide with practice. There is a visible trend of including more stochastic elements since 2007; however, this can be extended to generalize to all waste or to develop a general framework for the area of reverse logistics.

Research could be executed concerning the ecological footprint of the entire cycle of re-using plastics and other products. Which system of options would be the most energy efficient? The challenge is to minimize the environmental burden in units of energy from a closed loop perspective. These kinds of questions strongly relate to the green supply chain management perspective.

The reverse logistics of plastics waste could be explored from a whole different perspective: from a transaction cost framework. What is the willingness of citizens to cooperate in separating their household waste? Perhaps different coordination mechanisms should be put in place if a too small share of all plastics waste is collected.

At last, some interesting references could be useful to validate and broaden this thesis. These references are supplemented in Appendix F.

REFERENCES

Akcali, E; Çetinkaya, S; Üster, H (2008), *Network Design for Reverse and Closed-Loop Supply Chains: An Annotated Bibliography of Models and Solution Approaches,* Wiley Periodicals, Inc; Published online 10 October 2008 in Wiley InterScience (www.interscience.wiley.com)

Alshamrani, A; Mathur, K; Ballou, RH (2007), *Reverse logistics: simultaneous design of delivery routes and returns strategies,* Computers & Operations Research 34 (2007) 595–619

Ambrose, CA; Hooper, R; Potter, AK; Singh, MM (2002), *Diversion from landfill: quality products from valuable plastics,* Resources, Conservation and Recycling 36 (2002) 309–318

Bautista, J; Pereira, J (2006), *Modeling the problem of locating collection areas for urban waste management. An application to the metropolitan area of Barcelona,* Omega 34 (2006) 617 – 629

Beamon, BM; Fernandes, C (2004), *Supply-chain network configuration for product recovery,* Production Planning & Control, Vol. 15, No. 3, April 2004, 270–281

Blackburn, JD; Guide, VDR; Souza, GC; van Wassenhove, LN (2004), *Reverse Supply Chains for Commercial Returns,* CALIFORNIA MANAGEMENT REVIEW VOL. 46, NO.2 WINTER 2004

Chouinard, M; D'Amoursa, S; Aït-Kadi, D (2008), *A stochastic programming approach for designing supply loops,* Int. J. Production Economics 113 (2008) 657–677

Coates, G; Rahimifard, S (2009), *Modelling of post-fragmentation waste stream processing within UK shredder facilities,* Waste Management 29 (2009) 44–53

Creswell, JW (2009), *Research Design; Qualitative, Quantitative, and Mixed Methods Approaches,* SAGE Publications Ltd, London, pp 3

DIRECTIVE 2004/12/EC OF THE EP (2004), *DIRECTIVE 2004/12/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste,* Official Journal of the European Union, L 47/26, pp 1 – 6.

Easwaran, G; Üster, H (2009), *Tabu Search and Benders Decomposition Approaches for a Capacitated Closed-Loop Supply Chain Network Design Problem,* Transportation Science, Vol. 43, No. 3, August 2009, pp. 301-320

Ellis, JR (1995), *Polymer recycling: Economic realities*, Plastics, Rubber and Paper Recycling – a pragmatic approach, Volume 609, pp 62-69

Fleischmann, M; Krikke, HR, Dekker, R; Flapper, SDP (2000), *A characterisation of logistics networks for product recovery,* Omega 28 (2000) 653-666

Fleischmann, M; Beullens, P; Bloemhof-Ruwaard, JM; van Wassenhove, LN (2001), *The impact of product recovery on logistics network design,* PRODUCTION AND OPERATIONS MANAGEMENT Vol. 10, No. 2, Summer 2001

Fleischmann, M; Bloemhof-Ruwaard, JM; Dekker, R; van der Laan, E; Nunen, JAEE; van Wassenhove, LN (1997), *Quantitative models for reverse logistics: A review,* European Journal of Operational Research 103 (1997) 1-17

French, ML; LaForge, RL (2006), *Closed-loop supply chains in process industries: An empirical study of producer re-use issues,* Journal of Operations Management 24 (2006) 271–286

Frota Neto, JQ; Walther, G; Bloemhof, J; van Nunen, JAEE, Spengler, T (2009), *A methodology for assessing eco-efficiency in logistics networks,* European Journal of Operational Research 193 (2009) 670–682

Frota Neto, JQ; Bloemhof-Ruwaard, JM; van Nunen, JAEE; van Heck, E (2008), *Designing and evaluating sustainable logistics networks,* Int. J. Production Economics 111 (2008) 195–208

Ghiani, G; Laporte, G; Musmanno, R (2004), *Introduction to Logistics Systems Planning and Control,* John Wiley & Sons, Chicester, UK, pp 249

Gonzalez-Torre, PL; Adenso-Díaz, B (2002), *A model for the reallocation of recycling containers: application to the case of glass,* Waste Management Resource 2002: 20: 398–406

Guide, VDR, Van Wassenhove, LN (2006), *Closed-loop supply chains: An introduction to the feature issue (part 2),* Production and Operations management, Volume 15, Issue 4, pp 471-472

Heng, N; Ungul Laptaned, U; Mehrdadi, N (2008), *Recycling and Reuse of Household Plastics,* International Journal of Environmental Research, Vol. 2, No. 1, 2008, pp. 27-36

Howell, SG (1992), *A ten year review of plastics recycling,* Journal of Hazardous Materials, 29 (1992) 143-164

Hu, GP; Bidanda, B (2009), *Modeling sustainable product life cycle decision support systems,* Int. J. Production Economics 122 (2009) 366–375

Hu, TL; Sheu, JB, Huang, KH (2002), *A reverse logistics cost minimization model for the treatment of hazardous wastes,* Transportation Research Part E 38 (2002) 457–473

Kenniscentrum Nederland (KCN) (2009), *Businessplan Kenniscentrum Nascheiding,* Wageningen University and Research Center, Wageningen, pp 1-25

Krikke, HR; Kooi, EJ; Schuur, PC (1999), *Network design in reverse logistics: A quantitative model,* Management Report Series, New trends in distribution logistics (1999)

Kumar Pati, R; Vrat, P; Kumar, P (2008), *A goal programming model for paper recycling system,* Omega 36 (2008) 405 – 417

Lee, CKM; Chan, TM (2009), *Development of RFID-based Reverse Logistics System,* Expert Systems with Applications 36 (2009) 9299–9307

Lee, DH; Dong, M (2009), *Dynamic network design for reverse logistics operations under uncertainty,* Transportation Research Part E 45 (2009) 61–71

Lieckens, K; Vandaele, N (2007), *Reverse logistics network design with stochastic lead times,* Computers & Operations Research 34 (2007) 395–416

Lipsey, MW, Wilson, B (2001), *Practical Meta-analysis*, SAGE Publications Ltd, London, pp 1-2

Lunde, T (1995) *The impact of source separation, recycling and mechanical processing on MSW conversion to energy activity,* Biomass and Bioenergy, Vol. 9. Nos 1-5, pp. 387-398.1995

Mellor, W; Wright, E;Clift, R; Azapagic, A; Stevens, G (2002), *A mathematical model and decision-support framework for material recovery, recycling and cascaded use,* Chemical Engineering Science 57 (2002) 4697 – 4713

Menges, E (1996) *PVC recycling management,* Pure & Appl. Chem. Vol. 68, No. 9, pp. 1809-1822, 1996

Neiva de Figueiredo, J; Mayerle, SF (2008), *Designing minimum-cost recycling collection networks with required throughput,* Transportation Research Part E 44 (2008) 731–752

Plastic Heroes (2009a)**,** Stichting Nedvang, The Hague, retrieved on Internet on 19th January 2010: http://www.plasticheroes.nl/recyclen/contents/waar-maak-je-plastic-van%3f.php

Plastic Heroes (2009b)**,** Stichting Nedvang, The Hague, retrieved on Internet on 19th January 2010: http://www.plasticheroes.nl/recyclen/contents/wat-is-plastic%3f.php

Plastic Heroes (2009c)**,** Stichting Nedvang, The Hague, retrieved on Internet on 19th January 2010: http://www.plasticheroes.nl/recyclen/contents/campagne.php

Pokharel, S; Mutha, A (2009), *Perspectives in reverse logistics: A review,* Resources, Conservation and Recycling 53 (2009) 175–182

Repoussis, PP; Paraskevopoulos, DC; Zobolas, G;Tarantilis, CD; Ioannou, G (2009), *A web-based decision support system for waste lube oils collection and recycling,* European Journal of Operational Research 195 (2009) 676–700

Rubio, S; Chamorro, A; Miranda, FJ (2008), *Characteristics of the research on reverse logistics (1995-2005),* International Journal of Production Research, Vol. 46, No. 4, 15 February 2008, 1099–1120

Salema, MIG; Barbosa-Povoa, AP; Novais, AQ (2009), *A strategic and tactical model for closed-loop supply chains,* OR Spectrum (2009) 31:573–599

Salema, MIG; Barbosa-Povoa, AP; Novais, AQ (2007), *An optimization model for the design of a capacitated multi-product reverse logistics network with uncertainty,* European Journal of Operational Research 179 (2007) 1063–1077

Sbihi, A; Eglese, RW (2007), *Combinatorial optimization and green logistics,* Springer, 4OR (2007) 5:99–116

Schulze, R (2004), *Meta-analysis; a comparison of approaches*, Hogrefe & Huber Publishers, Göttingen, pp V

Sheu, JB (2008), *Green supply chain management, reverse logistics and nuclear power generation,* Transportation Research Part E 44 (2008) 19–46

Sheu, JB; Chou, YH; Hu, CC (2005), *An integrated logistics operational model for green-supply chain management,* Transportation Research Part E 41 (2005) 287–313

Srivastava, SK (2007), *Green supply-chain management: A state-of-the-art literature review,* International Journal of Management Reviews (2007) Volume 9 Issue 1 pp. 53–80

Srivastava, SK (2008), *Network design for reverse logistics,* Omega 36 (2008) 535 – 548

Üster, H; Easwaran, G; Akçali, E;Çetinkay, S (2007), *Benders Decomposition with Alternative Multiple Cuts for a Multi-Product Closed-Loop Supply Chain Network Design Model,* Wiley Periodicals, Inc; Published online 9 October 2007 in Wiley InterScience (www.interscience.wiley.com)

Vaus, D de (2001), *Research Design in Social Research*, Sage Publications Ltd, London

Verschuren, P, Doorewaard, H (2007), *Het ontwerpen van een onderzoek*, Lemma, Utrecht, pp 201-206

Wells, P; Seitz, M (2005), *Business models and closed-loop supply chains: a typology,* Supply Chain Management: An International Journal 10/4 (2005) 249–251

Yang, G; Wang, Z; Li, X (2009), *The optimization of the closed-loop supply chain network,* Transportation Research Part E 45 (2009) 16–28

APPENDICES

APPENDIX A OVERVIEW RELEVANT ARTICLES

Nr.	Author(s)	Year	Article	Journal
1	Akcali, E; Çetinkaya, S; Üster, H	2008	Network Design for Reverse and Closed-Loop Supply Chains: An Annotated Bibliography of Models and Solution Approaches	Wiley Periodicals, Inc; Published online 10 October 2008 in Wiley InterScience (www.interscience.wiley.com)
2	Alshamrani, A; Mathurb, K; Balloub, RH	2007	Reverse logistics: simultaneous design of delivery routes and returns strategies	Computers & Operations Research 34 (2007) 595–619
3	Ambrose, CA; Hooper, R; Potter, AK; Singh, MM	2002	Diversion from landfill: quality products from valuable plastics	Resources, Conservation and Recycling 36 (2002) 309–318
4	Bautista, J; Pereira, J	2006	Modeling the problem of locating collection areas for urban waste management. An application to the metropolitan area of Barcelona	Omega 34 (2006) 617 – 629
5	Beamon, BM; Fernandes, C	2004	Supply-chain network configuration for product recovery	Production Planning & Control, Vol. 15, No. 3, April 2004, 270–281
6	Blackburn, JD; Guide, VDR; Souza, GC; van Wassenhove LN	2004	Reverse Supply Chains for Commercial Returns	CALIFORNIA MANAGEMENT REVIEW VOL. 46, NO.2 WINTER 2004
7	Chouinard, M; D'Amoursa, S; Aït-Kadi, D	2008	A stochastic programming approach for designing supply loops	Int. J. Production Economics 113 (2008) 657–677
8	Coates, G; Rahimifard, S	2009	Modelling of post-fragmentation waste stream processing within UK shredder facilities	Waste Management 29 (2009) 44–53
9	Easwaran, G; Üster, H	2009	Tabu Search and Benders Decomposition Approaches for a Capacitated Closed-Loop Supply Chain Network Design Problem	Transportation Science, Vol. 43, No. 3, August 2009, pp. 301-320
10	Fleischmann, M; Krikke, HR, Dekker, R; Flapper, SDP	2000	A characterisation of logistics networks for product recovery	Omega 28 (2000) 653-666
11	Fleischmann, M; Beullens, P; Bloemhof-Ruwaard, JM; van Wassenhove, LN	2001	The impact of product recovery on logistics network design	PRODUCTION AND OPERATIONS MANAGEMENT Vol. 10, No. 2, Summer 2001
12	Fleischmann, M; Bloemhof-Ruwaard, JM; Dekker, R; van der Laan, E; Nunen, JAEE; van Wassenhove, LN	1997	Quantitative models for reverse logistics: A review	European Journal of Operational Rcsearch 103 (1997) 1-17
13	French, ML; LaForge, RL	2006	Closed-loop supply chains in process industries: An empirical study of producer re-use issues	Journal of Operations Management 24 (2006) 271–286

14	Frota Neto, JQ; Walther, G; Bloemhof, J; van Nunen, JAEE, Spengler, T	2009	A methodology for assessing eco-efficiency in logistics networks	European Journal of Operational Research 193 (2009) 670–682
15	Frota Neto, JQ; Bloemhof-Ruwaard, JM; van Nunen, JAEE; van Heck, E	2008	Designing and evaluating sustainable logistics networks	Int. J. Production Economics 111 (2008) 195–208
16	Gonzalez-Torre, PL; Adenso-Díaz, B	2002	A model for the reallocation of recycling containers: application to the case of glass	Waste Management Resource 2002: 20: 398–406
17	Haas, DA; Murphy FH; Lancioni RA.	2003	Managing reverse logistics channels with data envelopment analysis	TRANSPORTATION JOURNAL, Volume 42, issue 3, 2003
18	Heng, N; Ungul Laptaned, U; Mehrdadi, N	2008	Recycling and Reuse of Household Plastics	International Journal of Environmental Research, Vol. 2, No. 1, 2008, pp. 27-36
19	Howell, SG	1992	A ten year review of plastics recycling	Journal of Hazardous Materials, 29 (1992) 143-164
20	Hu, GP; Bidanda, B	2009	Modeling sustainable product life cycle decision support systems	Int. J.ProductionEconomics122 (2009) 366–375
21	Hu, TL; Sheu, JB; Huang, KH	2002	A reverse logistics cost minimization model for the treatment of hazardous wastes	Transportation Research Part E 38 (2002) 457–473
22	Krikke, HR; Kooi, EJ; Schuur, PC	1999	Network design in reverse logistics: A quantitative model	Management Report Series, New trends in distribution logistics (1999)
23	Kumar Pati, R; Vrat, P; Kumar, P	2008	A goal programming model for paper recycling system	Omega 36 (2008) 405 – 417
24	Lee, CKM; Chan, TM	2009	Development of RFID-based Reverse Logistics System	Expert Systems with Applications 36 (2009) 9299–9307
25	Lee, DH; Dong, M	2009	Dynamic network design for reverse logistics operations under uncertainty	Transportation Research Part E 45 (2009) 61–71
26	Lieckens, K; Vandaele, N	2007	Reverse logistics network design with stochastic lead times	Computers & Operations Research 34 (2007) 395–416
27	Lunde, T	1995	The impact of source separation, recycling and mechanical processing on MSW conversion to energy activity	Biomass and Bioenergy, Vol. 9. Nos 1-5, pp. 387-398.1995
28	Mellor, W; Wright, E;Clift, R; Azapagic, A; Stevens, G	2002	A mathematical model and decision-support framework for material recovery, recycling and cascaded use	Chemical Engineering Science 57 (2002) 4697 – 4713
29	Menges, E	1996	PVC recycling management	Pure & Appl. Chem. Vol. 68, No. 9, pp. 1809-1822, 1996
30	Neiva de Figueiredo, J; Mayerle, SF	2008	Designing minimum-cost recycling collection networks with required throughput	Transportation Research Part E 44 (2008) 731–752
31	Pokharel, S; Mutha, A	2009	Perspectives in reverse logistics: A review	Resources, Conservation and Recycling 53 (2009) 175–182
32	Repoussis, PP; Paraskevopoulos, DC; Zobolas, G;Tarantilis, CD;	2009	A web-based decision support system for waste lube oils collection and recycling	European Journal of Operational Research 195 (2009) 676–700

	Ioannou, G			
33	Rubio, S; Chamorro, A; Miranda, FJ	2008	Characteristics of the research on reverse logistics (1995-2005)	International Journal of Production Research, Vol. 46, No. 4, 15 February 2008, 1099–1120
34	Salema, MIG; Barbosa-Povoa, AP; Novais, AQ	2009	A strategic and tactical model for closed-loop supply chains	OR Spectrum (2009) 31:573–599
35	Salema, MIG; Barbosa-Povoa, AP; Novais, AQ	2007	An optimization model for the design of a capacitated multi-product reverse logistics network with uncertainty	European Journal of Operational Research 179 (2007) 1063–1077
36	Sbihi, A; Eglese, RW	2007	Combinatorial optimization and green logistics	Springer, 4OR (2007) 5:99–116
37	Sheu, JB	2008	Green supply chain management, reverse logistics and nuclear power generation	Transportation Research Part E 44 (2008) 19–46
38	Sheu, JB; Chou, YH; Hu, CC	2005	An integrated logistics operational model for green-supply chain management	Transportation Research Part E 41 (2005) 287–313
39	Sim, E; Jung, S; Kim, H; Park, J	2004	A generic network design for a closed-loop supply chain using genetic algorithm	Lecture Notes in Computer Science Vol. 3103 (2004), 1214-1225
40	Srivastava, SK	2007	Green supply-chain management: A state-of-the-art literature review	International Journal of Management Reviews (2007) Volume 9 Issue 1 pp. 53–80
41	Srivastava, SK	2008	Network design for reverse logistics	Omega 36 (2008) 535 – 548
42	Üster, H; Easwaran, G; Akçali, E; Çetinkay, S	2007	Benders Decomposition with Alternative Multiple Cuts for a Multi-Product Closed-Loop Supply Chain Network Design Model	Wiley Periodicals, Inc; Published online 9 October 2007 in Wiley InterScience (www.interscience.wiley.com)
43	Wells, P; Seitz, M	2005	Business models and closed-loop supply chains: a typology	Supply Chain Management: An International Journal 10/4 (2005) 249–251
44	Williams, V	1994	ADVANCES IN CHEMICAL RECYCLING FOR PLASTICS IN AUTOMOTIVE APPLICATIONS - SYNOPSIS	KAUTSCHUK GUMMI KUNSTSTOFFE 1994 (MAR)
45	Yang, G; Wang, Z; Li, X	2009	The optimization of the closed-loop supply chain network	Transportation Research Part E 45 (2009) 16–28

Legenda:
Not available in full text
(unless paying or membership or only abstract available)

APPENDIX B OVERVIEW RESEARCH OBJECTS, DRIVERS AND KEYWORDS

Nr.	Author(s)	Year	Object	Driver	Keywords									
					rl	*cl*	*nd*	*pr*	*re*	*se*	*wm*	*pl*	*pa*	*gl*
1	Akcali, E; Çetinkaya, S; Üster, H	2008	various	td	1	1	1	1	0	0	0	0	0	0
2	Alshamrani, A; Mathur, K; Ballou, RH	2007	blood containers	ec	1	0	0	0	0	0	0	0	0	0
3	Ambrose, CA; Hooper, R; Potter, AK; Singh, MM	2002	plastic waste	en	0	0	0	0	1	0	1	1	0	0
4	Bautista, J; Pereira, J	2006	municipal waste	l+en	1	0	0	0	1	0	1	0	0	0
5	Beamon, BM; Fernandes, C	2004	various	en+l+ec	0	1	0	1	0	0	0	0	0	0
6	Blackburn, JD; Guide, VDR; Souza, GC; van Wassenhove LN	2004	consumer electronics	ec	1	1	0	1	0	0	0	0	0	0
7	Chouinard, M; D'Amoursa, S; Aït-Kadi, D	2008	wheelchairs	ec	0	1	1	1	0	0	0	0	0	0
8	Coates, G; Rahimifard, S	2009	waste	td+ec+l	0	0	0	0	1	1	1	0	0	0
9	Easwaran, G; Üster, H	2009	ns	ec+en	0	1	1	0	0	0	0	0	0	0
10	Fleischmann, M; Krikke, HR, Dekker, R; Flapper, SDP	2000	used products	td	1	0	1	1	0	0	0	0	0	0
11	Fleischmann, M; Beullens, P; Bloemhof-Ruwaard, JM; van Wassenhove, LN	2001	copier and paper	td	1	1	1	1	0	0	0	0	1	0
12	Fleischmann, M; Bloemhof-Ruwaard, JM; Dekker, R; van der Laan, E; Nunen, JAEE; van Wassenhove, LN	1997	various	td	1	0	0	1	0	0	0	0	0	0
13	French, ML; LaForge, RL	2006	raw materials	td	1	1	0	0	0	0	0	0	0	0
14	Frota Neto, JQ; Walther, G; Bloemhof, J; van Nunen, JAEE, Spengler, T	2009	waste electrical and electronic equipment	ec+en	0	1	1	0	1	0	1	0	0	0
15	Frota Neto, JQ; Bloemhof-Ruwaard, JM; van Nunen, JAEE; van Heck, E	2008	pulp and paper	ec+en	0	0	1	0	1	0	0	0	1	0
16	Gonzalez-Torre, PL; Adenso-Díaz, B	2002	glass	ec	1	0	0	1	1	0	0	0	0	1
17	Haas, DA; Murphy FH; Lancioni RA	2003												
18	Heng, N; Ungul Laptaned, U; Mehrdadi, N	2008	plastics	en	1	0	0	0	1	0	1	1	0	0
19	Howell, SG	1992	plastics	en+l+ec	0	0	0	0	1	1	1	1	0	0
20	Hu, GP; Bidanda, B	2009	consumer electronics	en+l+ec	0	1	0	0	0	0	0	0	0	0
21	Hu, TL; Sheu, JB; Huang, KH	2002	hazardous waste	ec	1	0	0	0	0	0	1	0	0	0
22	Krikke, HR; Kooi, EJ; Schuur, PC	1999	automotive industry	en+l+ec	1	0	1	1	0	0	0	0	0	0
23	Kumar Pati, R; Vrat, P;	2008	paper	ec+en	1	0	0	1	1	1	1	0	1	0

	Kumar, P													
24	Lee, CKM; Chan, TM	2009	printers/photocopier	ec+en	1	1	0	1	1	0	0	0	0	0
25	Lee, DH; Dong, M	2009	ns	ec+en	1	0	1	1	0	0	0	0	0	0
26	Lieckens, K; Vandaele, N	2007	ns	ec	1	0	1	1	0	0	0	0	0	0
27	Lunde, T	1995	waste	en+l+ec	0	0	0	0	1	1	1	0	0	0
28	Mellor, W; Wright, E;Clift, R; Azapagic, A; Stevens, G	2002	polymers (plastic waste bottles)	ec+en	0	0	0	1	1	0	1	1	0	0
29	Menges, E	1996	pvc	td	0	0	0	0	1	1	1	1	0	0
30	Neiva de Figueiredo, J; Mayerle, SF	2008	tires	en+l+ec	1	0	1	0	1	0	1	0	0	0
31	Pokharel, S; Mutha, A	2009	various	td	1	0	0	1	1	0	1	0	0	0
32	Repoussis, PP; Paraskevopoulos, DC; Zobolas, G;Tarantilis, CD; Ioannou, G	2009	waste lube oils	ec+en	1	0	0	0	1	0	1	0	0	0
33	Rubio, S; Chamorro, A; Miranda, FJ	2008	ns	td	1	0	0	1	0	0	0	0	0	0
34	Salema, MIG; Barbosa-Povoa, AP; Novais, AQ	2009	ns	ec	0	1	1	0	0	0	0	0	0	0
35	Salema, MIG; Barbosa-Povoa, AP; Novais, AQ	2007	office documents	td	1	0	1	1	0	0	0	0	0	0
36	Sbihi, A; Eglese, RW	2007	ns	td+en+ ec	1	0	0	0	0	0	1	0	0	0
37	Sheu, JB	2008	nuclear power and radioactive waste	en+l+ec	1	0	0	0	0	0	1	0	0	0
38	Sheu, JB; Chou, YH; Hu, CC	2005	notebooks	en+l+ec	1	0	0	0	0	0	0	0	0	0
39	Sim, E; Jung, S; Kim, H; Park, J	2004												
40	Srivastava, SK	2007	ns	td (en+ec)	1	0	1	1	1	0	0	0	0	0
41	Srivastava, SK	2008	various	ec	1	0	1	1	0	0	0	0	0	0
42	Üster, H; Easwaran, G; Akçali, E;Çetinkay, S	2007	automotive industry	ec	0	1	1	0	0	0	0	0	0	0
43	Wells, P; Seitz, M	2005	automotive industry	td	0	1	0	0	0	0	0	0	0	0
44	Williams, V	1994												
45	Yang, GF; Wang, Z; Li, X	2009	ns	en+ec	0	1	1	0	0	0	0	0	0	0

Legenda:

rl	= Reverse logistics	en	= environmental
cl	= Closed loop supply chain	ec	= economical
nd	= Network design	l	= legislative
pr	= Product recovery	td	= theoretical development
re	= Recycling		
se	= Separation		
wm	= Waste (management)		
pl	= Plastics		
pa	= Paper		
gl	= Glass		

APPENDIX C OVERVIEW PROBLEM, METHOD AND SOLUTION TECHNIQUE

Nr.	Author(s)	Year	Problem	Research method	Solution technique
1	Akcali, E; Çetinkaya, S; Üster, H	2008	nd	lr	various milp + minlp
2	Alshamrani, A; Mathurb, K; Balloub, RH	2007	vr	cs	he (alg)
3	Ambrose, CA; Hooper, R; Potter, AK; Singh, MM	2002	dm	er	none
4	Bautista, J; Pereira, J	2006	la	mm +cs	he (alg)
5	Beamon, BM; Fernandes, C	2004	la	mm	milp
6	Blackburn, JD; Guide, VDR; Souza, GC; van Wassenhove LN	2004	dm	cs (fictitious)	none (only economical)
7	Chouinard, M; D'Amoursa, S; Aït-Kadi, D	2008	nd	mm + cs	milp + he (alg) *(SAA)*
8	Coates, G; Rahimifard, S	2009	dm	mm	stats
9	Easwaran, G; Üster, H	2009	nd/ la	mm	milp + he (ts) + bd
10	Fleischmann, M; Krikke, HR, Dekker, R; Flapper, SDP	2000	dm	lr	ns
11	Fleischmann, M; Beullens, P; Bloemhof-Ruwaard, JM; van Wassenhove, LN	2001	nd	mm + cs	milp
12	Fleischmann, M; Bloemhof-Ruwaard, JM; Dekker, R; van der Laan, E; Nunen, JAEE; van Wassenhove, LN	1997	dm	lr	ns
13	French, ML; LaForge, RL	2006	dm	er	none
14	Frota Neto, JQ; Walther, G; Bloemhof, J; van Nunen, JAEE, Spengler, T	2009	nd	cs	he (alg)
15	Frota Neto, JQ; Bloemhof-Ruwaard, JM; van Nunen, JAEE; van Heck, E	2008	nd	cs	molp
16	Gonzalez-Torre, PL; Adenso-Díaz, B	2002	la	mm + cs	gp
17	Haas, DA; Murphy FH; Lancioni RA	2003			
18	Heng, N; Ungul Laptaned, U; Mehrdadi, N	2008	dm	lr + cs	stats
19	Howell, SG	1992	dm	lr	none
20	Hu, GP; Bidanda, B	2009	dm	mm	mdp + alg
21	Hu, TL; Sheu, JB; Huang, KH	2002	vr + dm	mm	lp
22	Krikke, HR; Kooi, EJ; Schuur, PC	1999	nd/ la	mm + cs	milp
23	Kumar Pati, R; Vrat, P; Kumar, P	2008	nd/ la	mm + cs	migp
24	Lee, CKM; Chan, TM	2009	nd	mm	he (alg)
25	Lee, DH; Dong, M	2009	nd/ la	mm	minlp + he (alg/ sa)
26	Lieckens, K; Vandaele, N	2007	nd/ la	mm	minlp + he (alg)
27	Lunde, T	1995	dm	er	none
28	Mellor, W; Wright, E;Clift, R; Azapagic, A; Stevens, G	2002	dm	mm	lp *(CHAMP-model)*
29	Menges, E	1996	dm	er	none
30	Neiva de Figueiredo, J; Mayerle,	2008	nd	cs	he (alg)

	SF				
31	Pokharel, S; Mutha, A	2009	dm	lr	ns
32	Repoussis, PP; Paraskevopoulos, DC; Zobolas, G;Tarantilis, CD; Ioannou, G	2009	vr + dm	cs	he (alg)
33	Rubio, S; Chamorro, A; Miranda, FJ	2008	dm	lr	ns
34	Salema, MIG; Barbosa-Povoa, AP; Novais, AQ	2009	nd/ la	mm + cs	milp
35	Salema, MIG; Barbosa-Povoa, AP; Novais, AQ	2007	nd	mm	milp
36	Sbihi, A; Eglese, RW	2007	vr + dm	lr	various he
37	Sheu, JB	2008	dm	mm	molp
38	Sheu, JB; Chou, YH; Hu, CC	2005	dm	mm + cs	molp
39	Sim, E; Jung, S; Kim, H; Park, J	2004			
40	Srivastava, SK	2007	dm	lr	ns
41	Srivastava, SK	2008	nd/ la	mm	milp
42	Üster, H; Easwaran, G; Akçali, E; Çetinkay, S	2007	nd/ la	mm + cs	milp + bd
43	Wells, P; Seitz, M	2005	dm	lr	none
44	Williams, V	1994			
45	Yang, G; Wang, Z; Li, X	2009	dm/ nd	mm	he (alg)

Legenda:

OR-problem	Research method	OR solution technique	
la = location	lr = literature	lp = linear programming	he = heuristics
allocation	review		alg = (genetic) algorithm
		milp = mixed integer	sa = simulated annealing
nd = network	cs = case study	linear programming	ts = tabu search
design			
	mm = mathematical	minlp = mixed integer	bd = benders
vr = vehicle	model	non linear programming	decomposition
routing			
	er = empirical	molp = multi objective	mdp = Markov decision
dm = decision	research	linear programming	process
making			
		migp = mixed integer	stats = statistical
		goal programming	techniques
		gp = goal programming	ns = not specified

APPENDIX D OVERVIEW JOURNALS

Journals	Number of articles
Biomass and Bioenergy	1
CALIFORNIA MANAGEMENT REVIEW	1
Chemical Engineering Science	1
Computers & Operations Research	2
European Journal of Operational Research	4
Expert Systems with Applications	1
Int. J. Production Economics	3
International Journal of Environmental Research	1
International Journal of Management Reviews	1
International Journal of Production Research	1
Journal of Hazardous Materials	1
Journal of Operations Management	1
Management Report Series	1
Omega	4
OR Spectrum	1
PRODUCTION AND OPERATIONS MANAGEMENT	1
Production Planning & Control	1
Pure & Appl. Chem.	1
Resources, Conservation and Recycling	2
Springer	1
Supply Chain Management: An International Journal	1
Transportation Research Part E	6
Transportation Science	1
Waste Management	1
Waste Management Resource	1
Wiley Periodicals, Inc;	2

APPENDIX E OVERVIEW CITATIONS

Nr.	Author(s)	Year	Cited within set of 42 articles	Cited in Web of Science
12	Fleischmann, M; Bloemhof-Ruwaard, JM; Dekker, R; van der Laan, E; Nunen, JAEE; van Wassenhove, LN	1997	18	307
10	Fleischmann, M; Krikke, HR, Dekker, R; Flapper, SDP	2000	16	110
11	Fleischmann, M; Beullens, P; Bloemhof-Ruwaard, JM; van Wassenhove, LN	2001	12	72
6	Blackburn, JD; Guide, VDR; Souza, GC; van Wassenhove LN	2004	1	32
38	Sheu, JB; Chou, YH; Hu, CC	2005	6	30
21	Hu, TL; Sheu, JB; Huang, KH	2002	5	24
5	Beamon, BM; Fernandes, C	2004	4	23
35	Salema, MIG; Barbosa-Povoa, AP; Novais, AQ	2007	2	20
40	Srivastava, SK	2007	1	20
26	Lieckens, K; Vandaele, N	2007	3	17
41	Srivastava, SK	2008	1	17
3	Ambrose, CA; Hooper, R; Potter, AK; Singh, MM	2002	0	11
4	Bautista, J; Pereira, J	2006	1	11
28	Mellor, W; Wright, E;Clift, R; Azapagic, A; Stevens, G	2002	0	11
19	Howell, SG	1992	0	10
23	Kumar Pati, R; Vrat, P; Kumar, P	2008	1	9
22	Krikke, HR; Kooi, EJ; Schuur, PC	1999	0	7
33	Rubio, S; Chamorro, A; Miranda, FJ	2008	1	6
42	Üster, H; Easwaran, G; Akçali, E;Çetinkay, S	2007	1	6
2	Alshamrani, A; Mathur, K; Ballou, RH	2007	1	5
29	Menges, E	1996	0	5
13	French, ML; LaForge, RL	2006	1	4
37	Sheu, JB	2008	0	4
43	Wells, P; Seitz, M	2005	0	4
32	Repoussis, PP; Paraskevopoulos, DC; Zobolas, G;Tarantilis, CD; Ioannou, G	2009	0	3
7	Chouinard, M; D'Amoursa, S; Aït-Kadi, D	2008	1	1
15	Frota Neto, JQ; Bloemhof-Ruwaard, JM; van Nunen, JAEE; van Heck, E	2008	2 (1 *in print*)	1
16	Gonzalez-Torre, PL; Adenso-Díaz, B	2002	0	1
18	Heng, N; Ungul Laptaned, U; Mehrdadi, N	2008	0	1
20	Hu, GP; Bidanda, B	2009	0	1
24	Lee, CKM; Chan, TM	2009	0	1
27	Lunde, T	1995	0	1
30	Neiva de Figueiredo, J; Mayerle, SF	2008	0	1
31	Pokharel, S; Mutha, A	2009	0	1
34	Salema, MIG; Barbosa-Povoa, AP; Novais, AQ	2009	0	1
36	Sbihi, A; Eglese, RW	2007	0	1
45	Yang, GF; Wang, Z; Li, X	2009	0	1

1	Akcali, E; Çetinkaya, S; Üster, H	2008	0	0
8	Coates, G; Rahimifard, S	2009	0	0
9	Easwaran, G; Üster, H	2009	0	0
14	Frota Neto, JQ; Walther, G; Bloemhof, J; van Nunen, JAEE, Spengler, T	2009	0	0
25	Lee, DH; Dong, M	2009	0	0
39	Sim, E; Jung, S; Kim, H; Park, J	2004	3	6

APPENDIX F OVERVIEW INTERESTING REFERENCES

- ✓ **Caruso, C; Calorni, A; Paruccinni, M** (1993), *The regional urban solid waste management system: A modelling approach,* European Journal of Operational Research 70, 16–30.
- ✓ **Guide, VDR, Van Wassenhove, LN** (2006), *Closed-loop supply chains: An introduction to the feature issue (part 2),* Production and Operations management, Volume 15, Issue 4, pp 471-472
- ✓ **Jayaraman, V; Guide, VDRJr; Srivastava** (1999), *A closed-loop logistics model for remanufacturing.* J Oper Res Soc 50:497–508
- ✓ **Krikke, H; Bloemhof-Ruwaard, J; Van Wassenhove, LN** (2003), *Concurrent product and closed loop supply chain design with an application to refrigerators,* International Journal of Production Research, 41: 16, 3689-3719
- ✓ **Listes, O; Dekker, R** (2005), *A stochastic approach to a case study for product recovery network design,* European Journal of Operational Research 160 (1), 268–287