Logistique Inverse :
Etat de l'art
des problèmes de conception des réseaux logistiques
dans le contexte du développement durable.

Pierre DEJAX

Ecole des Mines de Nantes / IRCCyN,
pierre.Dejax@mines-nantes.fr

Journée GT2L

GDRMax

Saint-Etienne

10 octobre 2013

Acknowledgements

Sibel Alumur

Nathalie Bostel

Rommert Decker

Majid Eskandarpour

Olivier Péton

Diane Riopel

Reference

Majid Eskandarpour Pierre Dejax Olivier Peton, *Sustainable supply chain network design: an optimization-oriented review,*
Research Report 13/2/AUTO, August 2013, submitted for publication

Plan

1. Introduction to reverse logistics and sustainable development
2. General references, books and surveys
3. Design models for reverse logistics networks Example
4. Models integrating sustainable development-Example
5. Conclusions

Reverse Logistics

"Reverse 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 back to the point of origin, for the purpose of recapturing their value or proper disposal".
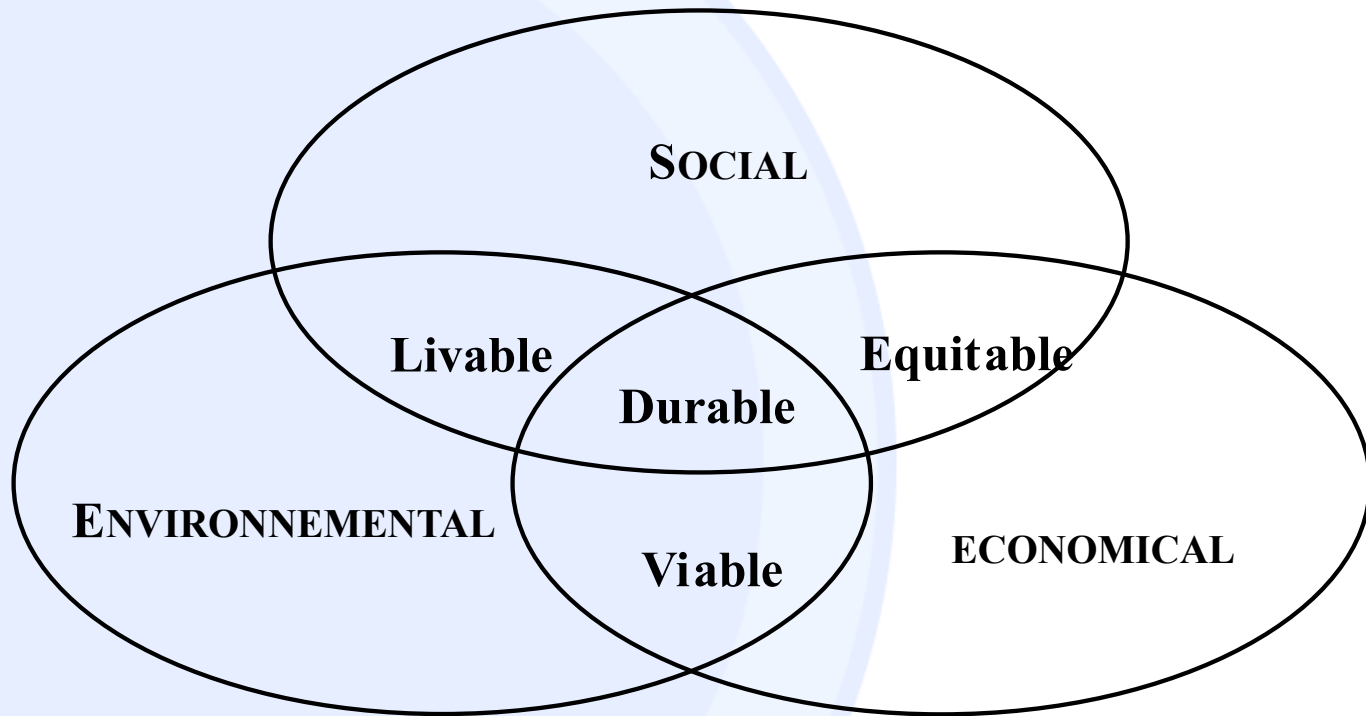
American Reverse Logistics Executive Council
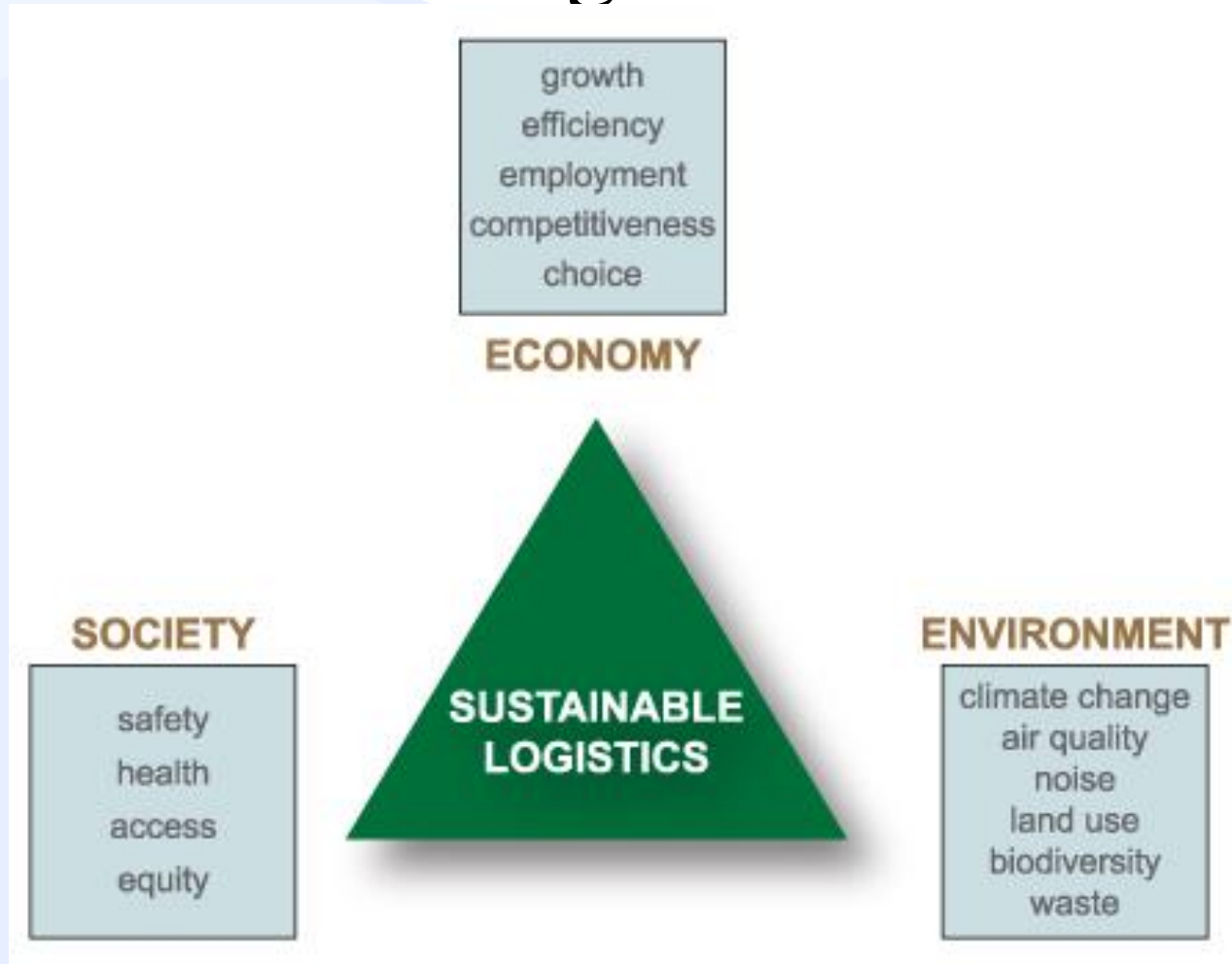
(Rogers and Tibben-Lembke, 1998)

Motivations :

- Productivity and cost savings

- Customer service

- Environmental protection, product recycling

- Societal motivations

- Legal factors

The three dimensions of sustainable development
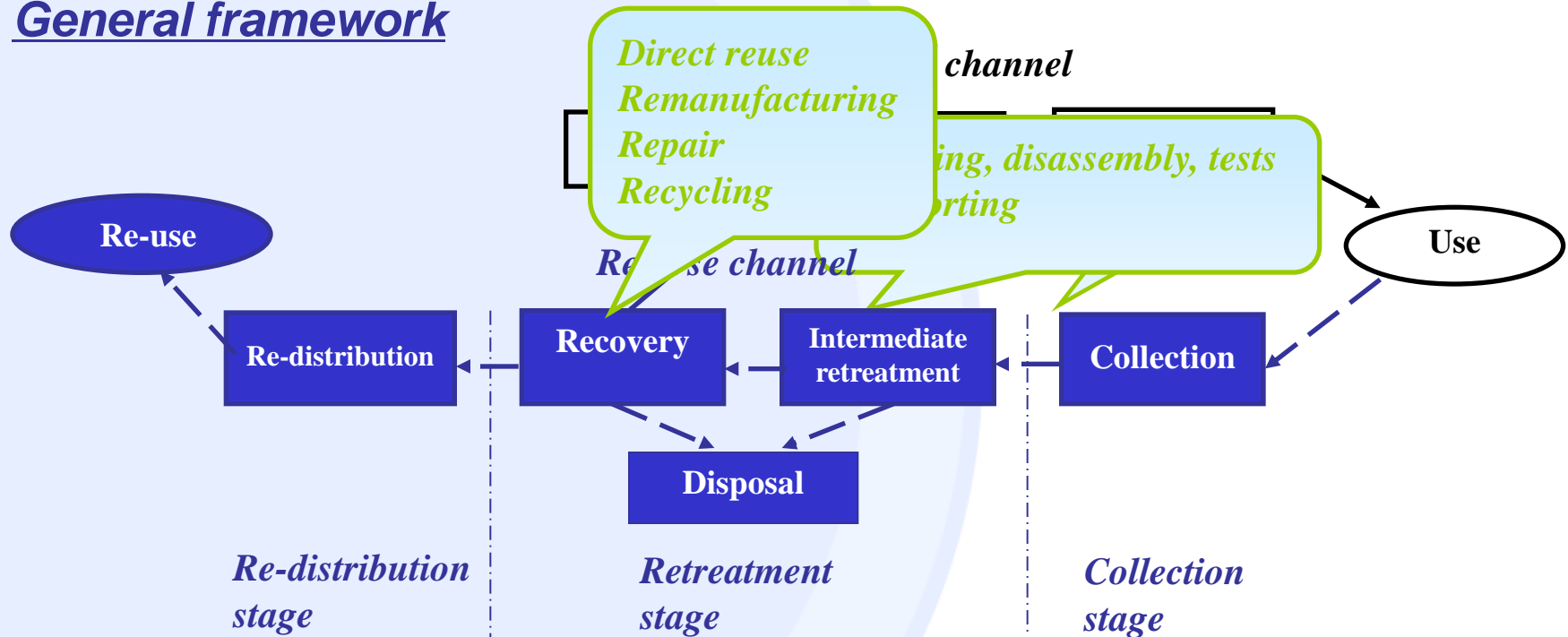
Sustainable logistics and green logistics

Framework of Reverse Logistics Systems

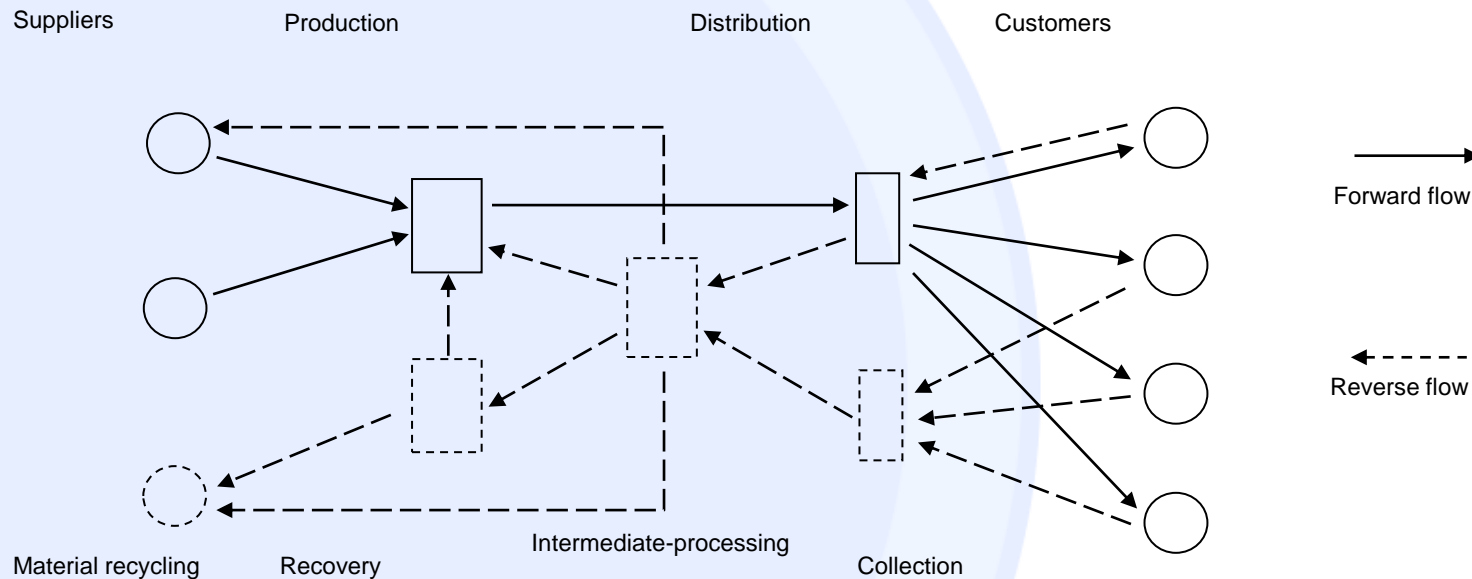*Reverse logistics activities*

[Beaulieu et al. (1999), Thierry et al. (1993), Dekker et al. (1999), Fleischmann et al. (2000a)]

General framework

Framework of an integrated logistics system
with forward and reverse flows

Suppliers Production Distribution Customers

Forward flow

Reverse flow

Material recycling Recovery Intermediate-processing Collection

A supply chain is said to

➤ *open loop* if the reverse circuit is independent of the initial forward flow.

➤ *closed loop* if forward and reverse flows are totally or partially integrated.

Classification

Two essential elements for classification:

- ❑ Product recovery options [Thierry et al. (1995)]

- ❑ Type of return objects [Fleischmann et al. (1997)]

4 basic types :

- ❑ **Direct reutilization network (closed loop)**
  - ✓ pallets, bottles, containers

- ❑ **Remanufacturing network (closed loop)**

  ✓Parts or products needing maintenance and recycled as new : copy machines, cartridges, refrigerators, airline engine parts, consumer products

- ❑ **Repair service network (open loop)**

  ✓Return and repair of parts in repair centers : durable products, electronic equipment

- ❑ **Material recycling network (open loop)**

  ✓ raw materials recycling by third parties : glass, paper, metal, plastics, used cars destruction

2. General References, books and surveys

• Dejax, P., Crainic, T.G., 1987. **A review of empty flows and fleet management models in fleet transportation**.

• Fleischmann, M., J. M. Bloemhof-Ruwaard, R. Dekker, E. Van Der Laan, J. A.E.E. Van Nunen, L. N. Van Wassenhove, 1997. **Quantitative models for reverse logistics: a review**.

• Gungor, A., S.M. Gupta, 1999. **Issues in Environmentally Conscious Manufacturing and Product Recovery: A Survey**.

• Fleischmann, M., 2001. **Quantitative models for reverse logistics.**

• Dekker R., Fleismann M., Interfuth K., van Wassenhove L edts., 2004, "**Reverse logistics. Quantitative models for closed loops supply chains",**436 p.

General References, books and surveys (2/3)

- Bostel N., P. Dejax, Z. Lu, 2005. "**The Design, Planning and Optimization of Reverse Logistic Networks**"

- CAOR, 2006. **Special issue on Reverse Logistics**, V.Verter & T. Boyaci, edts

- Rubio S., 2008, "**Characteristics of the research on reverse logistics (1995-2005)**"

- Stock J.R., 2008. "**Reverse Logistics, Green Logistics and Packaging**".

- Gehin et al (2008)

- Pokharel and Mutha, 2009

- Ferguson (2010)

- Ilgin and Gupta (2010)

- Nikolaou et al., 2011

Some observations

Reverse logistics is concerned with the return of products or equipments back from the nal customer, through the logistics system, for the purpose of reutilization, repair, remanufacturing or recycling.
Drivers for these activities may be legislative, environmental or commercial (Fleischmann et al., 2000a).

De Brito and Dekker (2003) distinguish different types of reverse logistics activities, for the purpose of recapturing the product value:

one may consider recuperating the products themselves, their components, raw materials or energy.

Reverse logistics systems may be classified into different categories depending on their characteristics, such as the types of returned products (Fleischmann et al., 1997), or the recuperation options (Thierry et al., 1995).

One distinguishes different types of networks, i.e. direct recuperation networks, repair or remanufacturing networks or component recycling network.

Logistics networks for product recovery

Fleischmann et al. (2000b) defined the main processes of reverse logistics: collection, inspection/separation, re-processing, disposal, and re-distribution.

Inspection / separation and reprocessing activities, (namely treatment activities), have a high influence in the configuration of reverse logistics network design.

The cost and environmental impact of products in reverse logistics network design highly depend on the configuration of the reverse logistics network : location of logistics and treatment activities (sorting, inspecting, disassembly, cleaning, etc.).

The configuration of the reverse logistics network and the problem of locating facilities for different types of reverse logistics operations have been thoroughly investigated in the literature.

Both generic and case-based models have been proposed. Fleischmann et al (1997) and Fleischmann (2001) published one of the earlier surveys of quantitative models for reverse logistics, including network design and inventory management systems.

Case studies of real applications

Fleischmann et al. (2000b) : case study based on the reverse logistics network design at IBM for the management of copy machines and their components.

De Brito et al. (2003) : comparative synthesis of more than 60 real cases published in different sectors and types of applications, among which the structure of networks.

The book by Dekker et al. (2004) is devoted to quantitative models for closed loop supply chains.

They propose a framework for reverse logistics and quantitative decision making models and address a number of problems, including for the economic and environmental optimization of supply chains.

Special issues of the Production and Operations Management (Guide and Van Wassenhove, 2006a,b) : *closed loop reverse logistics networks in the prospects of sustainable development.*

Special issue of Computers and Operations Research: *optimization models for reverse logistics* (Verter and Boyaci, 2007).

Gehin et al (2008) observe that recycling is currently the most common solution but it is far from meeting the goals of sustainable development.

They believe that constraints from end-of-life strategies should be better integrated into the early phases of design.

In their review on perspectives in reverse logistics (Pokharel and Mutha, 2009), find that research and practice in reverse logistics are focused on all aspects of reverse logistics : collection of used products, their processing and finally to the outputs of processing recycled materials, spare parts, remanufactured products and waste material disposal.

Research is mainly focussed on deterministic methods.

Few works consider stochastic demand for remanufactured products an dsupply of used products by the consumers.

Pricing models for acquiring used products are still developing.

The book by Ferguson (2010) is devoted to strategic and tactical aspects of closed loop supply chains.

It describes recent researches in this area, addresses the hypothesis and modeling frameworks proposed and suggests research directions.

Cf chapter by Aras et al. (2010) on designing the reverse logistics network.

Review of literature on environmentally conscious manufacturing and product recovery : Ilgin and Gupta (2010) discuss the evolution in the last decade and discuss new areas that have emerged.

They classify the literature in four categories: environmentally conscious product design, reverse and closed-loop supply chains, remanufacturing, and disassembly.

According to (Nikolaou et al., 2011), the motivations of the business community for employing reverse logistics can be classified into two categories: proactive or reactive.

Cost saving or presenting better image to achieve competitive advantage and improve environmental performance can be accounted as proactive reasons.

Legislation laws would be the reactive reasons to adopt reverse logistics as a strategy.

The majority of available models of sustainable reverse logistics systems mainly focus on environmental and economic aspects, and have incorporated only a limited number of social aspects.

Therefore they propose an integrated model for introducing Corporate Social Responsibility (CSR) and sustainability issues in reverse logistics systems as a means of developing a complete performance framework.

Case studies based models (1/2)

• Thierry, M.C., M. Salomon, J. Van Nunen, L. Van Wassenhove, 1995. **Strategic issues in product recovery management.**

• De Brito, M. P., R. Dekker, S. D.P. Flapper, 2003. **Reverse Logistics – a review of case studies.**

• Kumar S. and P. Malegeant, 2006. **Strategic alliance in a closed-loop supply chain, a case of manufacturer and eco-non-profit organization.**

• Schultmann F., Zumkeller M. and O. Rentz, 2006.   **Modeling reverse logistic tasks within closed-loop supply chains: An example from the automotive industry.**

• Schultmann F., Engels B. and Rentz O., 2004. **Flowsheeting-based simulation of recycling concepts in the metal industry.**

• Seitz M., 2007, **A critical assessment of motives for product recovery: the case of engine remanufacturing.**

• Krikke H., le Blanc I., van Krieken M., Fleuren H., 2008. **Low-frequency collection of materials disassembled from end-of-life vehicles: On the value of on-line monitoring in optimizing route planning.**

http://www.fbk.eur.nl/OZ/REVLOG/

Different solution methods have been developed
for solving reverse logistics network
design models :

- commercial solvers,
- exact solution methods
- metaheuristics

multi-product closed-loop supply chain network design problem
(Ulster et al., 2007)

• locate collection centers and remanufacturing facilities

• coordinate the forward and reverse flows
in the network

• minimize the processing, transportation, and facility location costs.

The problem is motivated by the practice of an original equipment manufacturer in the automotive industry that provides service parts for vehicle maintenance and repair.

The problem formulation leads to efficient Benders reformulation and an exact solution approach.

integration of forward and reverse logistic. Wang and Hsu (2010)

A generalized closedloop model for the logistics planning is proposed by formulating a cyclic logistics network problem into an integer linear programming model and solving it for minimum cost.

A revised spanning-tree based genetic algorithm was also developed for solving this model.

remanufacturing end-of-life products Korchi and Millet (2011)

Design of economically and environmentally viable reverse logistics channels for supplying reusable used modules to the production chain.
• framework to allow generating and assessing different reverse logistics channel structures.
• application to a product remanufacturing case.
• analyzis of the current reverse logistics channel structure and proposition of alternative structures with less environmental impact and higher economic benefits.

location of treatment activities (Krikke et al.,2003)

• decision-making model concerning both the design structure of a product and that of the logistic network.

• environmental impacts are measured by linear-energy and waste functions.

• economic costs are modeled as linear functions of volumes with a set-up component for facilities.

Application to a closed-loop supply chain design problem for refrigerators using real life data of a Japanese consumer electronics company concerning its European operations.

facility procuring returned items from a set of collection sites for remanufacturing and sale (Tagaras and Zikopoulos, 2008)

Supply chain consisting of a central remanufacturing facility and a multiple collection sites.

The central units are suitable for remanufacturing before disassembly.

Stochastic optimization model aiming at the maximization of the expected annual profit function.

general closed loop supply chain network - Amin and Zhang (2012)

• supply chain network that includes manufacturer, disassembly, refurbishing, and disposal sites.

• two-phase integrated model including a multi objective mixed-integer linear programming model to determine

    - which suppliers and refurbishing sites should be selected (strategic decisions)

    - and find out the optimal number of parts and products in the network (tactical decisions).

General comprehensive model for strategic closed-loop supply chain network design under data uncertainty - Hasani et al. (2012)

Various assumptions :

• multiple periods, multiple products with bills of materials, and multiple supply chain echelons

• uncertain demand and purchasing cost.

The model assumptions are well matched with decision making environments of food and high-tech electronics manufacturing industries.

Experiments are conducted using LINGO 8 to demonstrate its efficiency.

Multilevel multiperiodic model for reverse logistics network design.
Alumur et al. (2012)

Framework is justified by a case study in the context of reverse logistics network design for washing machines and tumble dryers in Germany.

The MIP model is solved using a commercial solver. Extensive parametric and scenario analysis are conducted to illustrate the potential benefits of using a dynamic model and to derive a number of managerial insights.

Table 1: Characteristics of reviewed papers in reverse logistics network design

	Activity			Types of layers						
Article	Product Recovery	Material Recovery	Waste management	Collection	Inspection	Refurbish	Repair	Disassembly	Recycling	Disposal
Eskandarpour et al. (2013)	*	*	*	*			*			*
Amin and Zhang (2012)	*	*	*			*		*		*
Amin and Zhang (2012)	*	*	*	*			*	*	*	*
Lieckens and Vandaele (2012)	*	*	*	*	*		*			
Das (2012)	*	*					*			
Pishvaee and Torabi (2010)	*	*		*			*		*	
Alumur et al. (2012)	*	*		*	*		*			
Ramezani et al. (2013)	*		*	*						*
Lee et al. (2010)	*			*						
Pishvaee et al. (2011)	*			*			*			
Vidovic et al. (2011)	*			*					*	
Zarandi et al. (2011)	*			*						
Kannan et al. (2012)	*			*			*			*
Hasani et al. (2012)	*			*						
Nenes and Nikolaidis (2012)	*						*			
Piplani and Saraswat (2012)	*			*			*			
Kannan et al. (2010)		*	*	*					*	*
Wang and Hsu (2010)		*						*		
Zarei et al. (2010)		*		*				*		
Ye et al. (2011)		*		*					*	
Dat et al. (2012)			*	*			*	*	*	*

(1) Although reverse logistics can be a significant tool of sustainable development, there may also be some conflicts between economic, environmental and social issues.

For example, activities such as product recovery could lead to higher greenhouse gas emissions which is in contradiction with the environmental
goal of sustainable development (Chaabane et al., 2012).

Hence, idealistic models should consider simultaneously all of the sustainable development aspects.

Reverse logistics contributes to sustainble development even if SD factors are not explicitely included into the model :
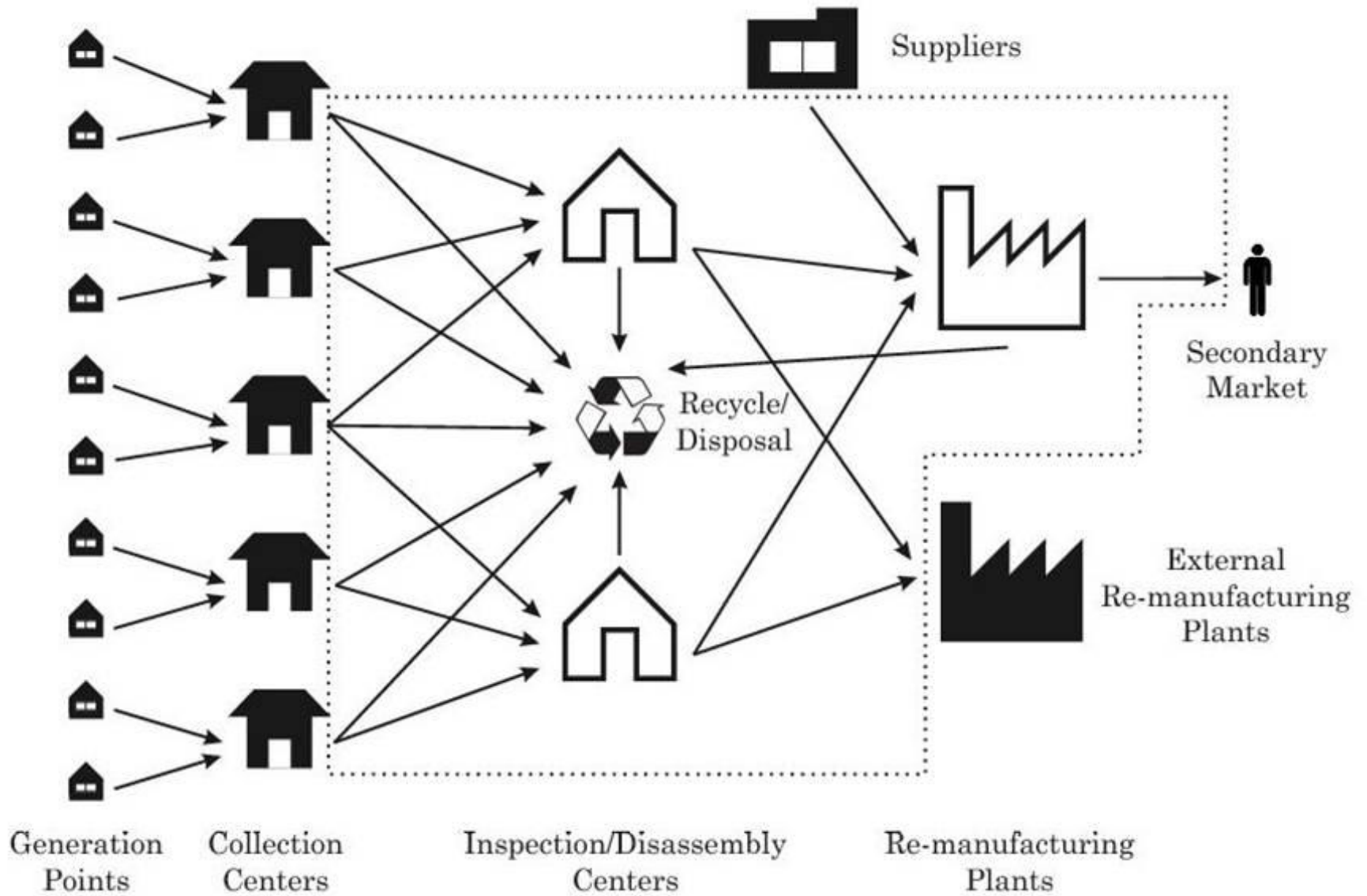
• cost reduction

• materials savings

•Energy saving and pollution reduction (?)

•Social factors : quality of life

Example

Multi-period reverse logistics network design

Sibel A. Alumur, Stefan Nickel,
Francisco Saldanha-da-Gama, Vedat Verter

Generation Points | Collection Centers | Inspection/Disassembly Centers | Re-manufacturing Plants

Suppliers

Recycle/Disposal

Secondary Market

External Re-manufacturing Plants

Configuration of the reverse logistics network :
• determination of the optimal sites and capacities of collection centers, inspection centers, remanufacturing facilities, and/ or recycling plants.
• profit maximization modeling framework for reverse logistics network design problems. We present a
• mixed-integer linear programming formulation that is flexible to incorporate most of the reverse network structures plausible in practice.
• multi-period setting in order to consider the possibility of making future adjustments in the network configuration to allow gradual changes in the network structure and in the capacities of the facilities.

- multi-commodity formulation
- reverse bill of materials in order to capture component commonality
among different products and to have the flexibility to incorporate all plausible means in tackling
product returns.

- framework justified by a case study in the context of reverse logistics network design for washing machines and tumble dryers in Germany.
- extensive parametric and scenario analysis to illustrate the potential benefits of using a dynamic model and also to derive a number of managerial insights.

P	set of products (disposals)
C	set of components
C_p	set of components for product $p \in P$ $(C_p \subset C)$
T	set of periods in the planning horizon
I^G	set of generation points or collection centers
I^I	set of potential locations for inspection centers
I^R	set of potential locations for remanufacturing plants
R^G	recycling node for collection centers
R^I	recycling node for inspection centers
R^R	recycling node for remanufacturing plants
ER	external remanufacturing plants
SM	secondary market
Q^I	set of capacities of the modules available for inspection centers
Q^R	set of capacities of the modules available for remanufacturing plants

Revenues

PRG_p^t — unit revenue from product $p \in P$ recycled from a collection center in period $t \in T$

PRI_c^t — unit revenue from component $c \in C$ recycled from an inspection center in period $t \in T$

PRR_c^t — unit revenue from component $c \in C$ recycled from a remanufacturing plant in period $t \in T$

PER_{ip}^t — unit revenue from product $p \in P$ sold to an external remanufacturing plant at $i \in ER$ in period $t \in T$

PSM_p^t — unit revenue from product $p \in P$ sold to the secondary market in period $t \in T$

Costs

Costs

FI_i^t	set-up cost for installing an inspection center at $i \in I^I$ in the beginning of period $t \in T$
FR_i^t	set-up cost for installing a remanufacturing plant at $i \in I^R$ in the beginning of period $t \in T$
FKI_{iq}^t	set-up cost for a module of type $q \in Q^I$ to be added to an inspection center located at $i \in I^I$ in period $t \in T$
FKR_{iq}^t	set-up cost for a module of type $q \in Q^R$ to be added to a remanufacturing plant located at $i \in I^R$ in period $t \in T$
OI_{ip}^t	cost for operating one unit of product $p \in P$ in an inspection center $i \in I^I$ in period $t \in T$
OR_{ip}^t	cost for producing one unit of product $p \in P$ in a remanufacturing plant $i \in I^R$ in period $t \in T$
T_{ijp}^t	unit transportation cost of product $p \in P$ (component $p \in C$) from $i \in I^G$ to $j \in I^I$, or $i \in I^I$ to $j \in I^R$ in period $t \in T$
IC_{ic}^t	unit inventory holding cost for component $c \in C$ in a remenufacturing plant $i \in I^R$ in period $t \in T$
BC_{ic}^t	cost of purchasing one unit of component $c \in C$ for remanufacturing plant $i \in I^R$ in period $t \in T$

Decision variables

x_{ijp}^t amount of product $p \in P$ (component $p \in C$) shipped from site i to site j, $(i,j) \in A$, in period $t \in T$

I_{ic}^t amount of component $c \in C$ hold in inventory in remanu-facturing plant $i \in I^R$ in the end of period $t \in T$

b_{ic}^t amount of component $c \in C$ purchased for remanufactur-ing plant $i \in I^R$ in the beginning of period $t \in T$

$$y_i^t = \begin{cases} 1 & \text{If an inspection center } i \in I^I \text{ is operating in period } t \in T, \\ 0 & \text{otherwise,} \end{cases}$$
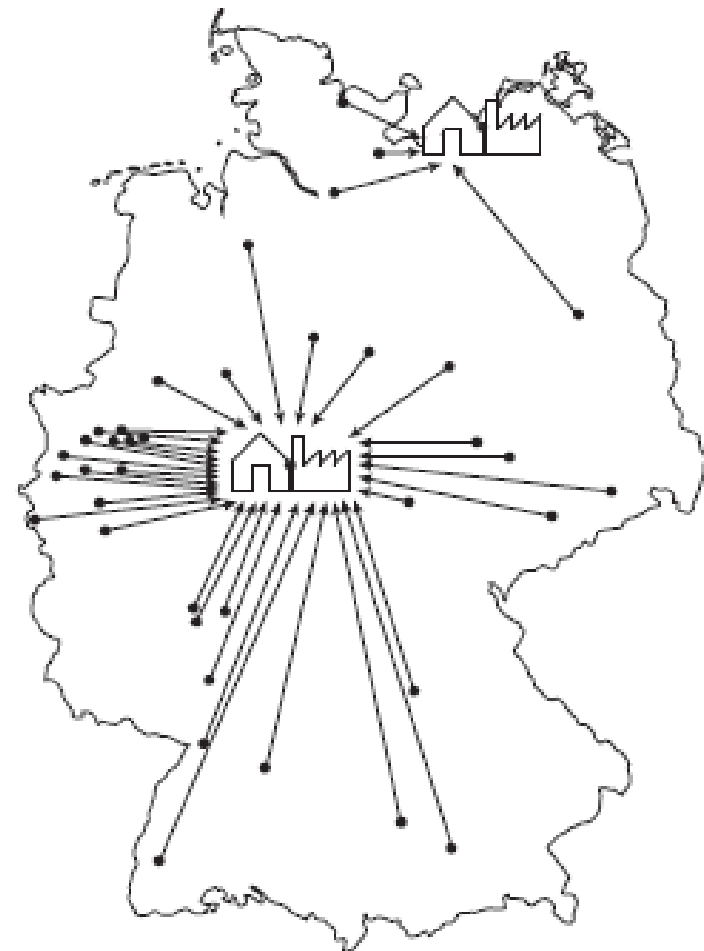
$$z_i^t = \begin{cases} 1 & \text{If a remanufacturing plant } i \in I^R \text{ is operating in period } t \in T, \\ 0 & \text{otherwise.} \end{cases}$$

$$u_{iq}^t = \begin{cases} 1 & \text{If a module of type } q \in Q^I \text{ is added to an inspection center} \\ & i \in I^I, \text{ in the beginning of period } t \in T, \\ 0 & \text{otherwise,} \end{cases}$$

$$v_{iq}^t = \begin{cases} 1 & \text{If a module of type } q \in Q^R \text{ is added to a remanufacturing center} \\ & i \in I^R, \text{ in the beginning of period } t \in T, \\ 0 & \text{otherwise.} \end{cases}$$
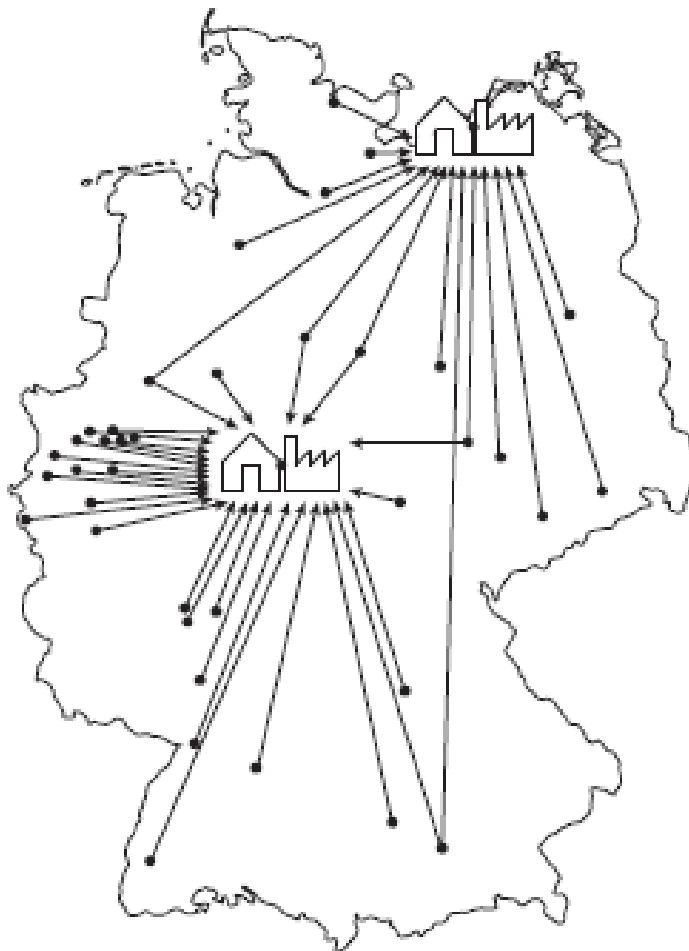
(a): End of period 1
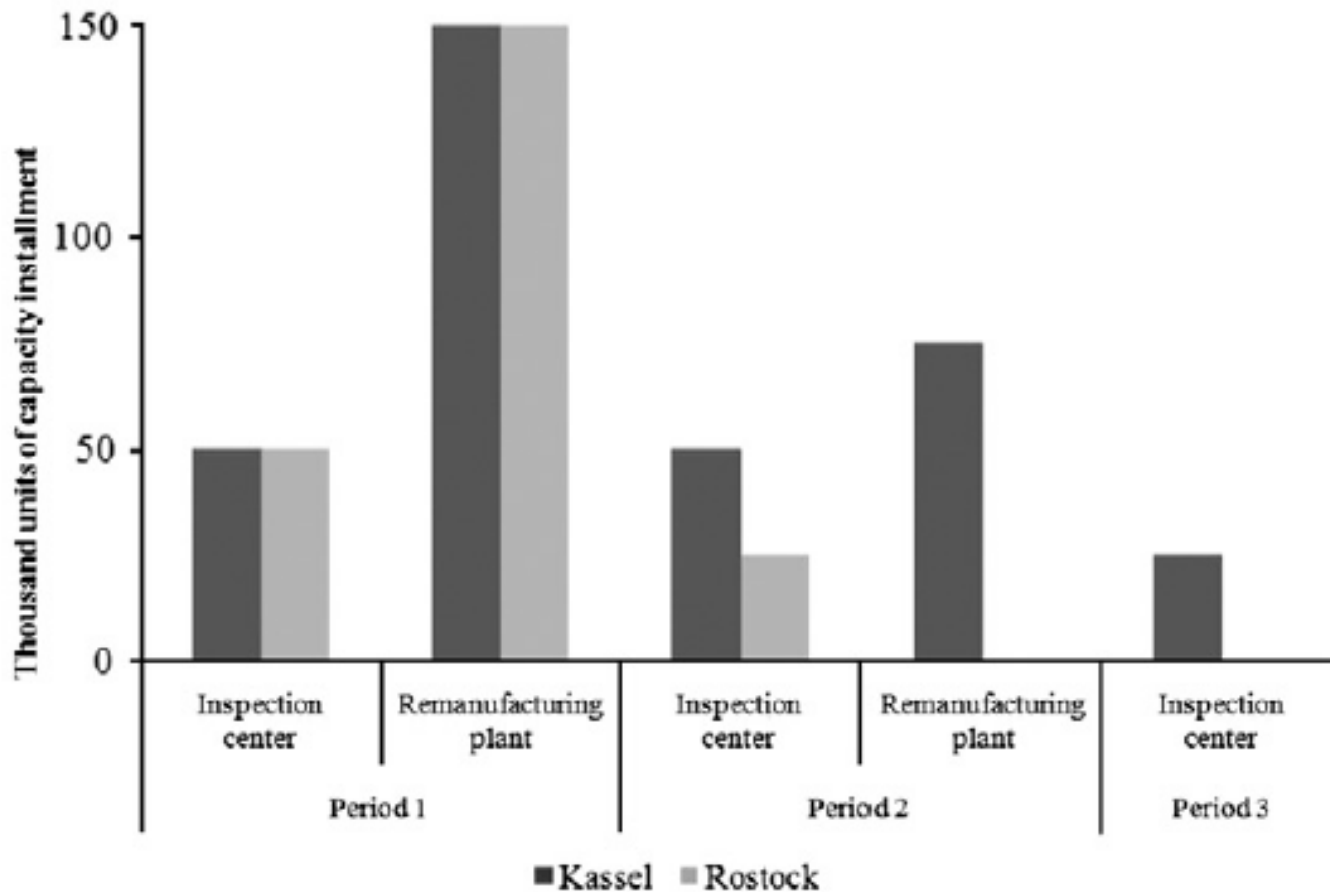
(b): End of period 5

Fig. 2. A solution of the problem.

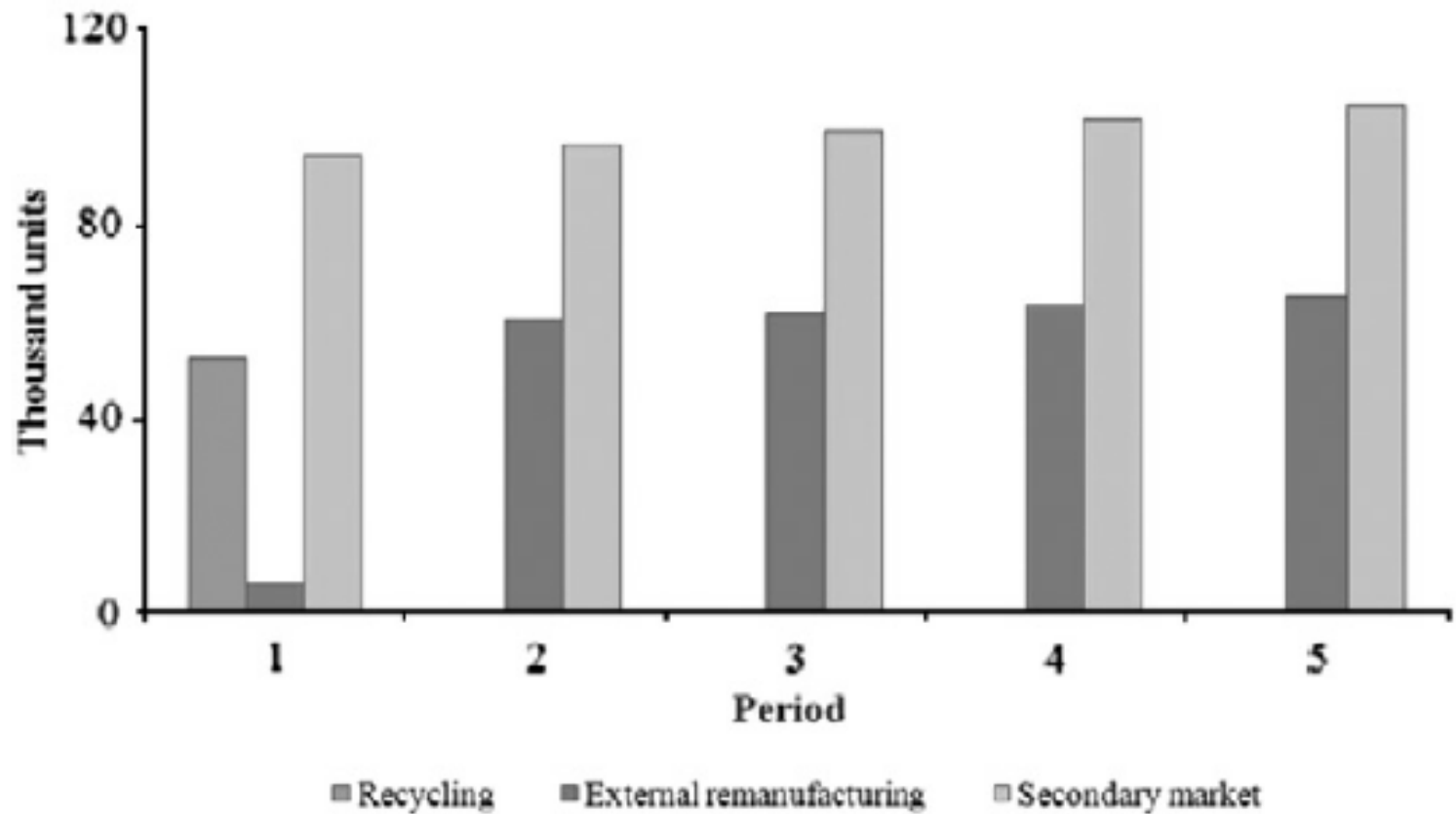**Fig. 3.** Capacity installment decisions in the solution.

Fig. 4. Flows.

4. models for RL network design integrating sustainable development.

Factors generally considered :

➢Economic factors : costs, revenue

➢Environmental factors :
  • GRG emissions
  • Wastes generated
  • Energy use
  • Material recovery

➢ Social Factors
  • Labor

Modelling approaches :

➤ single objective models :
- Linear, non linear, mltiproduct, period, mode
- deterministic / stochastic models

➤ Multiobjective models :
- deterministic, stochastic
➤ Social Factors
- Labor

Solution methods :

➢ single objective models
- heuristic, metaheuristics
- Lagrangian reaxation

➢ Multi-objective models
- weighted sum of objectives
- Epsilon – constraint
- Goal programming
- Meta heuristics (genetic, memetic, VNS)

Applications :

➢ waste management
➢ steel and aluminum
➢ tires
➢ medical items
➢ white goods
➢ plastics
➢ electronic devices
➢ paper

Domestic wastes treatment
Berger et al. (1999)

•Comprehensive multiperiodic MIP model for the strategic design and tactical planning of an integrated regional solid waste management planning.

• several types of treatment technologies and sites for treatment and landfilling,

• possibility of recycling wastes on markets.

• several environmental parameters and indicators may be
used.

The model has been solved using a commercial solver and applied to the Montreal area and two french departments.

Published models (1)

T. Abdallah, A. Diabat, and D. Simchi-Levi. *Sustainable supply chain design: a closed-loop formulation*, 2012.

S. H. Amin and G. Zhang. *A multi-objective facility location model for closed-loop supply chain network under uncertain demand and return*, 2013.

N. Aras, T. Boyaci, and V. Verter. *Designing the reverse logistics network,* 2010.

C. Berger, G. Savard, and A. Wizere. *EUGENE: an optimization model for integrated regional solid waste management planning*, 1999.

X. Bing, J. Bloemhof-Ruwaard, and J. van der Vorst. *Sustainable reverse logistics network design for household plastic waste*, 2012.

P. Costi, R. Minciardi, M. Robba, M. Rovatti, and R. Sacile. *An environmentally sustainable decision model for urban solid waste management*, 2004.

J. Duque, A. Barbosa-Povoa, and A. Novais. *Design and planning of sustainable industrial networks: application to a recovery network of residual products*, 2010.

M. Eskandarpour, S. Zegordi, and E. Nikbakhsh. *A parallel variable neighborhood search for the multiobjective sustainable post-sales network design problem*, 2012.

M. Fonseca, A. Garcia-Sanchez, M. Ortega-Mier, and F. Saldanha-da Gama. *A stochastic bi-objective location model for strategic reverse logistics*, 2010.

N. A. Harraz and N. M. Galal. *Design of sustainable end-of-life vehicle recovery network in Egypt*, 2011.

M. Ilgin and S. Gupta. *Environmentally conscious manufacturing and product recovery (ecmpro): A review of the state of the art,* 2010.

D. Kannan, A. Diabat, M. Alrefaei, K. Govindan, and G. Yong. *A carbon footprint based reverse logistics network design model,* 2012

.

H. Krikke. *Impact of closed-loop network congurations on carbon footprints: A case study in copiers*, 2011.

H. Krikke, J. Bloemhof-Ruwaard, and L. N. Van Wassenhove. *Concurrent product and closed-loop supply chain design with an application to refrigerators*, 2003.

I. Nikolaou, K. Evangelinos, and S. Allan. *A reverse logistics social responsibility evaluation framework based on the triple bottom line approach*, 2011.

T. Paksoy, E. Ozceylan, and G. Weber. *A multi-objective model for optimization of a green supply chain network*, 2010.

R. Pati, P. Vrat, and P. Kumar. *A goal programming model for paper recycling system*, 2008.

M. Pishvaee, R. Zanjirani Farahani, and W. Dullaert. *A memetic algorithm for bi-objective integrated forward/reverse logistics network design,* 2010.

K. Pochampally, S. Nukala, and S. M. Gupta. *Strategic Planning Models for Reverse and Closed-Loop Supply Chains*, 2008.

S. Pokharel and A. Mutha. *Perspectives in reverse logistics: A review*, 2009.

H.   Pourmohammadi, M. Rahimi, and M. Dessouky. *Sustainable reverse logistics for distribution ofindustrial waste/byproducts: A joint optimization of operation and environmental costs*, 2008.

M. I. G. Salema, A. P. Barbosa-Povoa, and A. Q. Novais. *Simultaneous design and planning of supply chains with reverse ows: A generic modelling framework, 2010.*

G. Tuzkaya, B. Gulsun, and S. Onsel. *A methodology for the strategic design of reverse logistics networks and its application in the Turkish white goods industry*, 2011.

5. Conclusions and perspectives

- **increasing concern for reverse logistics** in a variety of contexts, many recent works.

- a **lot of scientific works** already produced for open and closed loops logistics at all levels of planning.

- Integration of **sustainable development** factors is growing

- need for **generic models** as well as **specialized models**

- need to **develop models** focussed on **real applications**

- need to develop **very efficient techniques** especially for models integrating forward and reverse flows.

- need to study **sustainable complex supply chains…**

Logistique Inverse :
Etat de l'art
des problèmes de conception des réseaux logistiques
dans le contexte du développement durable.

Thanks, Merci !

Questions ?