

Partnerships in reverse logistics: OR-model building in view of practical developments

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1 Introduction

This paper deals with the use of mathematical optimisation (or: Operations Research) models in logistics, in view of new developments in reverse logistics on the one hand and chain logistics on the other hand. The paper builds on considerations and suggestions for further research of the Ph.D. thesis of the author [1]. We will start of with giving a brief explanation of the terms Operations Research, Reverse Logistics and Chain Logistics.

Operations Research is a discipline in Applied Mathematics dealing with quantitative optimisation or simulation of real world problems. Generally, an OR-model involves some objective function or a set of performance indicators -such as costs- that should be optimised within a number of constraints -such as production capacities or humans resources. The mathematical model can be programmed in a computer and after data are entered the computer optimises the problem and gives numerical results. Originally developed in the Military, Operations Research (OR) has developed into a full management discipline, with many applications. Most applications can be found in production planning, purchasing and logistics. However, OR is often criticised for occupying itself with 'non realistic' problems, preferring mathematical beauty over a sense of (business) reality.

Reverse logistics is a (re-)new(ed) area in logistics concerning the logistics of take back and recovery of discarded packages and products. *Renewed*, because recycling in itself is nothing new and has been applied for centuries. *New*, because the driving forces and responsibilities are different. In the old days economic motives were dominant and only valuable waste was recycled, while nowadays environmental concern is the driving force. Moreover, recycling was traditionally the domain of small scale specialised firms, where now Original Equipment Manufacturers (OEMs) are held responsible for proper take back- and recovery systems. This is often referred to as *extended producer responsibility*. In Europe, new political policies aim at the closure of material flows. To this end, laws or covenants are implemented which make OEMs formally responsible for recovery of their 'own' products after disposal. In the USA we see that not so much government policy, but consumer demand for recycling creates the same effect: OEMs are held responsible for closing material flows, with the ultimate goal to reduce emissions and minimise residual waste. One of the key problems OEMs have to deal with as a result of extended producer responsibility is the set-up of a *reverse logistic system* for their discarded products. A reverse logistic system can be described as the logistic system that takes care of collection, selection, transportation, recuperation (incl. disassembly), disposal and re-distribution of discarded products. The aim is to regain maximal economical and ecological value at minimal economic costs while maintaining an accurate customer service level. This may also involve changes in the forward logistic system, particularly regarding waste prevention.

Chain Logistics is characterised by the integration of logistic processes of different enterprises. It is process oriented and focuses at the integral optimisation of logistics in the production chain, disregarding the boundaries of organisations. This way, business may respond to increased customer demands, requiring higher flexibility and reliability, shorter lead times and lower costs at the same time. As part is of this development, many OEMs built partnerships: for example, they outsource activities, reduce the number of suppliers and strengthen supplier relations. Currently, the exchange information with other chain actors, inventory management and total quality management are top issues in Chain Logistics (also called ‘Supply Chain Management’). Planning, procedures and strategy are likely to follow [2].

Both developments -reverse logistics and chain logistics- are more or less autonomous, but both aim at the integration of logistic processes. They join in a so called *integral supply chain*, in which the (traditional) forward logistic chain is integrated with the reverse chain and material flows are overall optimised. This is reflected in Figure 1.

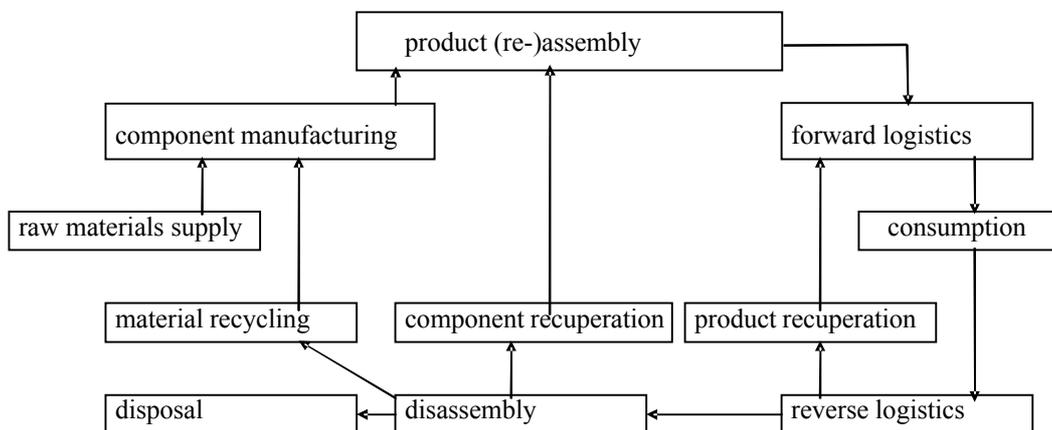


Figure 1: Reverse logistics and chain logistics leading to an integral supply chain

In this paper we review the impact of the above developments on logistic network optimisation and we go into the role of Operations Research model building. In particular, we focus on a specific class of logistic problems: *logistic network design*. This will be explained in the next section.

2 Logistic network design of supply chains

This paper focuses on the *network design* of integral supply chains. By network design we mean a *geographic blueprint* of the logistic system in terms of type, capacity and location of facilities as well as good flows through the system. This class of problems is also referred to as *location-allocation problems*. Figure 2 gives a virtual example of a logistic network design for the integral supply chain of two products.

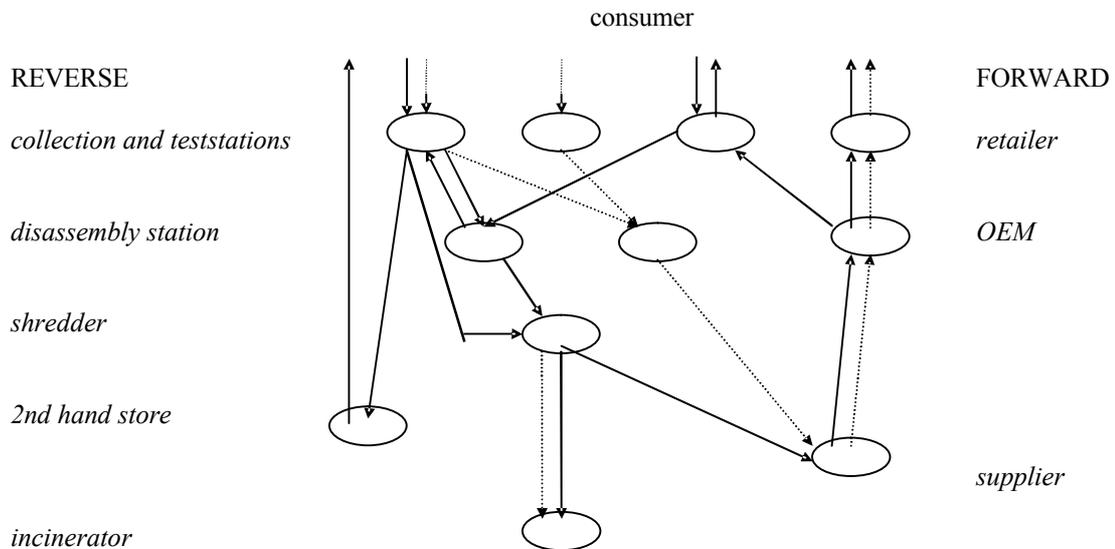


Figure 2: Virtual example of a reverse logistic network design for two products (1: \longrightarrow : $\cdots\longrightarrow$)

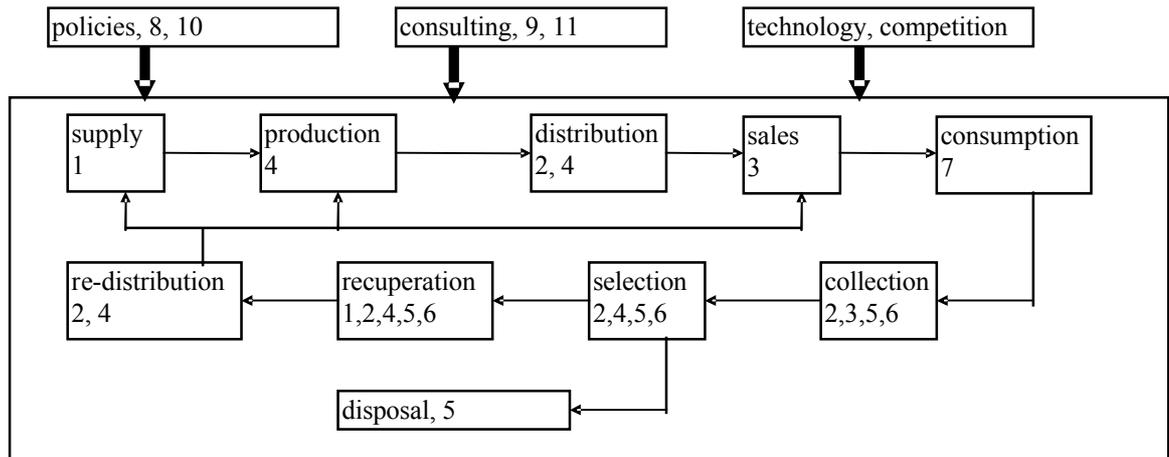
Due to the developments in chain logistics and reverse logistics described above, logistic optimisation shifts from (local) optimisation of sections of the forward logistic chain to integral optimisation of a full supply chain. Market demands are becoming higher and higher, resulting in a constant drive for cost minimisation and service level maximisation. Moreover, optimisation criteria shift from purely economical to both economical and ecological. In order to meet these high demands, co-operation of the *actors* in the supply chain is necessary. So far, OR location-allocation theory does not seem to pick up on these recent developments.

In the forward chain, traditionally five types of actors are distinguished: the supplier, the OEM, the retailer, the distributor and the consumer. In reverse chains, six chain member types are distinguished [3]: (i) municipalities, who usually perform the collection function, (ii) recovery plants that upgrade recyclable materials through value adding activities, (iii) brokers, who link buyers and sellers of recyclable material, (iv) intermediate processors, companies that purchase source separated recyclable materials, process them and resell them for remanufacturing, (v) end users, manufacturing companies using secondary material products and (vi) business joint ventures, e.g. between manufacturing companies, who co-operate in waste and recycling management (to reduce recycling cost). We add to this list (vii) policy makers, (viii) commercial collection firms and (ix) branch organisations. Many variations may be found in practice. For example, logistic service companies can perform both collection and processing.

In general, one can distinguish *internal actors* and *external actors*. Internal actors are the actual members of the supply chain, carrying out one or more logistic processes. For example the OEM and suppliers are internal actors. External actors do not participate in the supply chain, but are trying to influence it, for example the government and branch organisations. Internal actors may perform one or more key (logistic) processes. It can be distinguished for supply, production, distribution, consumption, collection, selection, recuperation, disposal and re-distribution.

Each actor has more or less power in the supply chain. Power bases can be economical/financial, commercial (marketing), legislation, information or know-how.

Depending on its power and the power of others, an actor may be able to enforce solutions that are optimal for him. Power bases may shift. For example, outsourcing developments give more power to logistic service companies. Figure 3 represents the different actors in the integral supply chain in a contingency oriented model. The figure represents the processes in the supply chain, where the numbers represent the actors listed underneath. Some processes may be performed by multiple actors.



Internal actors:

1. supplier
2. logistics service provider
3. retailer/agent
4. OEM
5. municipal waste company
6. commercial waste company

External actors:

7. consumer
8. policy makers
9. brokers
10. branch organisations
11. organisation consultancy

Figure 3: Actors and processes of integral supply chain, similar to [4]

In Subsection 2.1, we shall review economic conflicts of interest between internal actors. We also describe various types of partnerships that may exist in a reverse chain and the reasons of their existence. In Section 2.2, we give describe how economical and ecological targets may oppose, which form is potential source of conflicts between policy makers or consumers (external actor) and OEMs or other internal actors. Subsequently, it is described which instruments can be used to implement this integrally optimal solution such that the interests of all chain actors are satisfied and suboptimisation is avoided.

2.1 Economic conflicts of interest: internal actors

Internal actors may have conflicts of interest e.g. regarding inventories. For example, OEMs may force suppliers to keep stock for them and deliver Just in Time. Although this reduces costs for the OEM, it increases costs for the supplier and hence may be suboptimal from a chain perspective. Other conflicts of interest may involve the location of facilities; an OEM moving to Asia may demand suppliers to do the same, which can be very costly. However, if a supplier does not move to Asia, he may lose all business. In general, increasing customer demands will lead to increased pressure on logistic costs all over the logistic chain. Also recycling can be very costly. To deal with this, the following partnerships may be encountered. In order to reduce recycling cost, strategic alliances can be formed between chain actors. Co-operation can be realised within or across product chains, in information exchange, product re-design and joint recovery operations. For instance, a joint venture between waste management companies and energy firms might create benefits for both: guaranteed supply for the energy firm and capital for investments for the waste management companies. Also, companies operating in the same markets might set up joint programs. Outsourcing to logistic service companies may lead to economies of scale and increased quality. Co-makership may lead to improved product designs and better quality, but also to more efficient inventory management.

2.2 Economical and ecological conflicts of interest: internal and external actors

External and internal actors may have conflicts of interest e.g. in finding the balance between ecology and economy, leading to conflicts between OEMs and policy makers. For example, transportation restrictions in environmental laws may prohibit efficient distribution of recyclables. High recycling costs may make it more interesting for OEMs to incinerate, although the government prefers recycling. Policy makers and branch organisations can make a difference in solving these conflicts of interest. One of the most common instruments used to enforce recycling in the supply chain include prescription of recovery targets and increasing incineration tariffs. OR-methods may help rationalise policy choices, for example by linking life cycle assessment to logistical optimisation. Sometimes, transportation restrictions should be eased and alternative recycling options (such as energy recovery) should be allowed for in order to realise an economically and ecologically sound supply chain.

A different type of conflict concerns consumers: on the one hand they like OEMs to recycle, but on the other hand they often do not accept lower quality of products. To deal with this OEMs may set-up quality and marketing programs, together with e.g. retailers.

Resuming, the above list is not complete, but indicates potential conflicts of interest among actors in the integral supply chain and potential ways to solve them. In OR optimisation tools, these aspects are only scarcely built in so far. Examples of integrating environmental aspects of logistic systems can be found in [5] and in [6] environmental problems are optimised with OR-methods. However, these are still exceptions to the rule and do not concern location-allocation problems.

This brings us back to the subjects of this paper: (i) what are the changes in logistic network optimisation due to developments in reverse logistics and chain logistics and (ii) what are the consequences for OR *location-allocation* modelling in order to give proper decision support in integral supply chains. In Section 3, we shall analyse aspects concerning (ii) deeper.

3 OR-models for network re-design of supply chains

Recall that logistic network design concerns the geographic lay-out of the logistic network. For this, many optimisation models have been developed by Operation Research scientists. Often, these models focus on *economic* optimisation of a section of the logistic chain, where there is assumed to be one decision maker. Subsequently we discuss the traditional way of modelling logistic network design in 3.1 and in 3.2. we discuss adaptations necessary in the view of the author in order to deal with network design for integral supply chains, incorporating chain logistics and reverse logistics developments.

3.1 (Reverse) logistic network design according to traditional OR-approach

In the Ph.D. project of the author, a number of Operations Research models was developed to design a reverse logistic network in the traditional way. In other words: it focused on a re-design situation where an reverse logistic network has to be designed given a forward logistic network, which remains unchanged. Briefly summarised, these models cover the following steps [1]:

1. Determination of recovery strategies. It is determined how return flows should be processed. For durable assembly products this means determining an optimal *degree of disassembly* and assigning *optimal recovery and disposal options* for the product or its released components. A recovery strategy is determined to secure economically and ecologically feasible recovery of return flows.
2. Logistic network design. This concerns the actual physical set-up of the network. It has to be determined (a) where install which facilities at what capacity level (location) and (b) how should good flows run between the established facilities (allocation). In this model, the sum of annualised investment costs, constant and variable processing costs and transportation costs is minimised, given constraints set by legislation, consumer demand and recovery technology. In particular, constraints defined by the predetermined recovery strategy need to be met.

The basic idea of this approach is first to determine what to do (1) and subsequently where to do it (2). Prior to these steps, one has to do some forecasting (0). Here, we assess quality, quantity, composition and timing of return flows delivered at the collection stations. Analogously, we forecast volumes/capacity of secondary/disposal markets at demand locations. Also, potential recovery and disposal options and their cost and revenue functions must be determined as well as assessments of cost functions and capacities for (potential) facilities and transportation. The three steps (0) forecasting, (1) recovery strategies and (2) logistic network design represent the full *decision procedure* for optimising a (reverse) logistic network. Let us

now concentrate on the last step: logistic network design. We give an example to illustrate the working of the model in the Ph.D. project (quoted from [1]):

Example

An OEM takes back two types of cars: a high volume middle class car A and a low volume luxurious car B. In the recovery strategies for this case three processes can occur, namely disassembly (p_1), repair (p_2) and shredding (p_3), for which we have to find efficient locations. The cars are collected (p_0) in various quantities at three regional distribution centres in Bergen op Zoom (s_1), Den Helder (s_2) and Zwolle (s_3). The recovery strategies are as follows:

- Car A is disassembled, after which a toxic fraction of 5 mass% is delivered at a specialised dump (p_{m2}) in Lemmer (d_2). The remaining 95 mass% is shredded after which the fluff (consisting of commingled materials) is delivered to a big material recycler in Hoek van Holland (d_1) for material recovery (p_{m1}).
- Car B is also disassembled, after which a toxic fraction of 3 mass% is disposed of at the dump in Lemmer. In addition, 48.5 mass% of the car is reused at the part level in the car repair business (p_{m3}) throughout the Benelux. To this end, these parts are repaired and subsequently delivered at the Benelux Main Distribution Centre in Roermond (d_3). The remaining parts, another 48.5 mass%, are shredded and transported to Hoek van Holland for material recovery.

For car B, tests are installed at the disassembly facility to assess the feasibility of parts for reuse. The processing graphs and transportation graph are omitted here for brevity. Instead, we give the network graph straight away. Here, the regional distribution centres serve as supply points and the demand points are the secondary markets at various locations. The three processes, disassembly, repair and shredding, can each be installed in three of the following seven cities, Enschede (f_1), Groningen (f_2), Haarlem (f_3), Maastricht (f_4), Tilburg (f_5), Utrecht (f_6) and Middelburg (f_7). These assignments constitute the intermediary nodes. All facilities have to be newly established, except for a shredder in Tilburg that already exists.

The network graph is visualised in Figure 4, where the bold lines represent the joint processing steps of both products and the thin lines the separate repair steps of product B.

The supply (collection) and demand (reuse) locations are fixed. The decision variables concern (i) at which location and capacity level which process should be installed and (ii) how good flows should run between installed facilities. For each process (disassembly, repair, shredding) are potentially three locations available and each process can be installed at three levels (0=closed, 1=small capacity and 2=large capacity). Each capacity level has different cost functions.

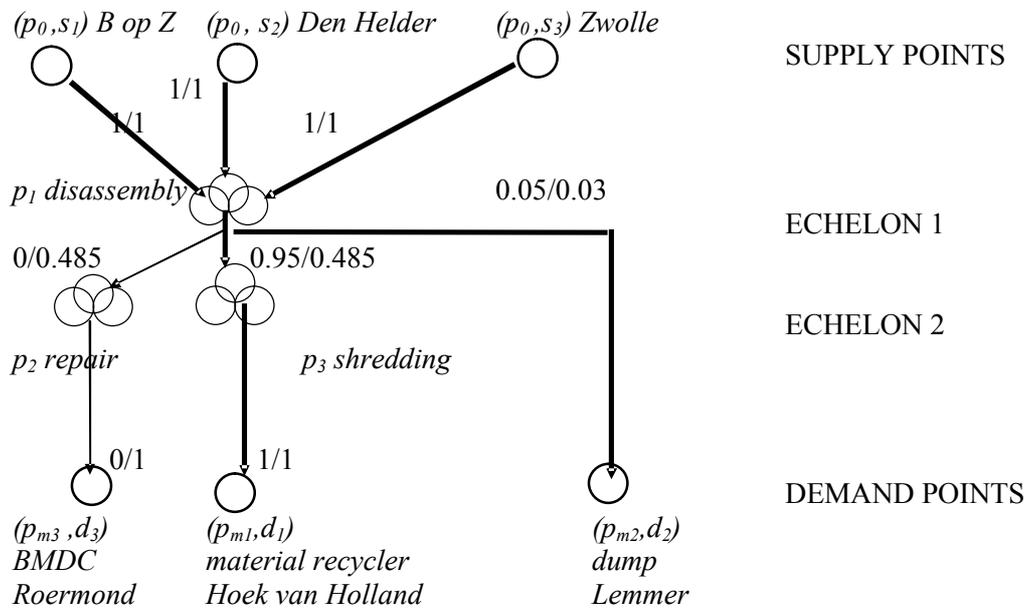


Figure 4: network graph of the case problem

The outcome of an optimisation is a reverse logistic network design. The problem was optimised using commercial software LINDO. An outcome for one situation is given in Figure 5.

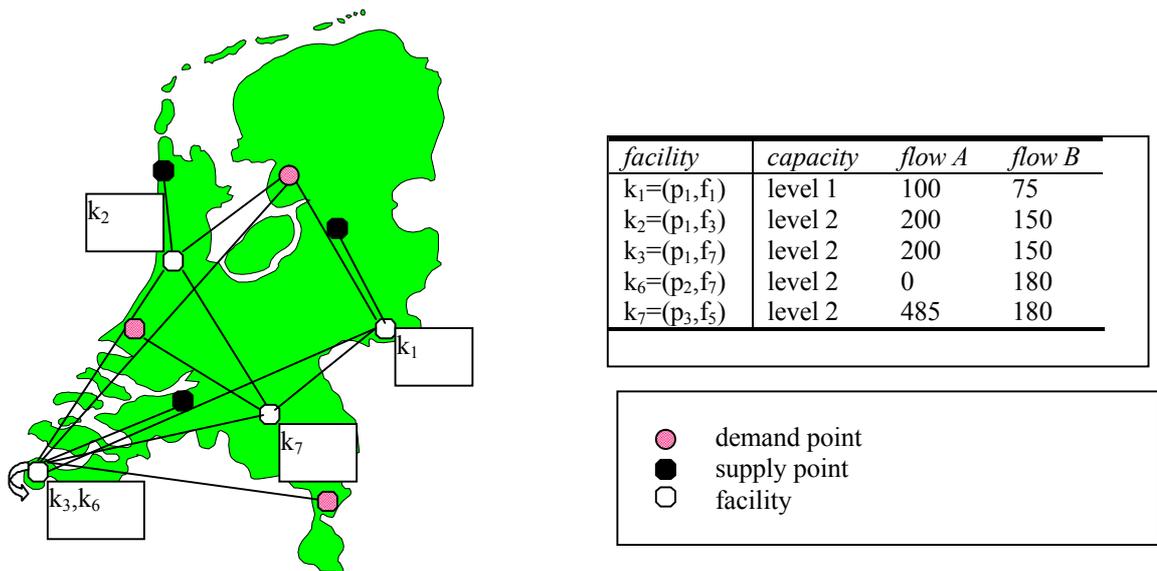


Figure 5: A network design for case example

end of example

We can see the following shortcomings in the model building:

- The reverse chain is optimised separately from the forward chain. The collection points are seen as the sources of the network and the demand points as the sinks. Now, intermediary activities, such as disassembly, repair, cleaning etc., have to be assigned to optimal locations and also good flows are optimised. This may lead to overall sub-optimality.
- The neglect of multiple actors in the supply chain. Although this is principally in line with the concept of chain management, the total ignorance of conflicts of interest and power bases of actors may obstruct successful implementation of an ‘optimal’ network . Sometimes a ‘second best’ solution close to the overall optimum may be more acceptable to all actors inside and outside the chain.
- Optimisation occurs on economic costs, where environmental goals are defined as constraints. As a result, only minimal environmental improvements will be strived for. Also, customer service is missing.

Shortcomings seem to be representative for current ‘generation’ of OR location-allocation models. Thus, we need to reconsider the way we model logistic network design. This is discussed in 3.2.

3.2 OR location-allocation models for (green) integral supply chains

Looking at the subjects discussed above, OR location-allocation models should be able to tackle the following questions in order to provide proper decision support in logistic network design for integral supply chains.

- What are overall supply chain goals?
- Who are the actors and what are their tasks, roles and liabilities?
- What is their position of power and what are their individual goals?
- How can individual goals be fit in overall goals by ‘smart’ optimisation with OR-based tools?
- How can synergy between ecological and economical goals be realised by ‘smart’ optimisation with OR-based tools?
- How can partnerships enhance integral optimisation?
- How can policy makers and branch organisation contribute to overall network design optimisation?

If we look at the problem from a methodological point of view, we can see a clear difference in the ‘traditional’ approach and our proposed approach. This is summarised in Table 1.

Table 1: Methodological differences in traditional and proposed approach for OR location-allocation models

	<i>traditional OR</i>	<i>proposed</i>
logistic goals	economic and sometimes customer service	economic, environmental and customer service
scope	local (per company)	integral (process oriented)
objects	section of the chain	all processes and actors
research questions	location-allocation	location-allocation + individual actors goals

Our point is that one should not aim for the overall cost-optimal solution, but find an optimal balance between customer service, economic costs and ecological costs, where no actor in the chain should be substantially prejudiced or privileged. This avoids sub-optimal (local) solutions on the one hand and too dominant positions of power of some actors on the other hand.

In order to link OR location-allocation models to new developments in reverse logistics and chain logistics, the following steps may be made:

- connect the logistic chain to the environmental chain by combining logistic optimisation with life cycle assessment,
- define sub-systems per actor and define constraints regarding individual actors goals,
- formulate models that optimise forward and reverse logistics in an integral way.

These are just some examples of modelling consequences. In the authors view, we need to develop general frameworks for integral supply chain management, which can serve as a basis for improved OR modelling.

4 Conclusions

In this paper we have sketched recent developments in chain logistics and reverse logistics and indicated the consequences for OR location-allocation modelling. These models provide decision support in the logistic network design of (integral) supply chains. This concerns the choice of type, location and capacity of facilities as well as optimisation of good flows through the system. We have found that OR location-allocation models need adaptation with respect to the following aspects:

- optimisation goals are no longer merely economic, but a balance should be found in economical, ecological and customer service targets
- optimisation can no longer be limited to a section of the forward chain, but the scope should be extended to an integral optimisation of forward and reverse network.
- overall chain objectives and individual actors objectives should be integrated.

In future research, we have to link OR to other management disciplines, such as quality management, product design, law, social sciences, politicology and environmental studies. Interesting issue is whether this only affects OR-models or whether a mutual impact will occur. For example, ‘smart’ OR-based tools may reveal that some perceived conflicts of

interest between ecological and economical goals are in fact no conflicts at all if products are designed recycling friendly.

Mathematical complexity of integral supply chain optimisations will form a serious burden. However, the design of integrally optimal logistic systems is of crucial interest to realise economically and ecologically viable supply chains and is thus a contribution to a sustainable future. Therefore, the directions pointed out in this paper are the way to go!

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