Solutions For Industrial Reverse Logistics Systems

Track: Environmental Issues

Abstract

Based on voluntary pledges and legislative restrictions regarding the environmentally compatible management of end-of-life vehicles (ELV) automobile manufacturers are requested to install Reverse Logistics Systems. The paper describes a linear optimizing model taking the main aspects of industrial Reverse Logistics Systems into consideration, e.g. investments in recycling capacities, transport quantities, treatment of different types and quantities of residues etc.

The model components are integrated into the conceptions of offensive and defensive environmental management. Major determinants of the planning problem, based on simulations with different data constellations, are identified.

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Reverse Logistics As A Result Of "Environmental Changes"

Following the question, why an intensified and product-wide action is needed nowadays concerning the implementation of Reverse Logistics Systems, primarily three reasons – which are in interdependent relations and apply to many countries – can be stated:

- *A growing environmental awareness*, whereby from consumers' point of view the competence for the solution of environmental problems lies primarily at the producers. Non observance of this development will generally have the consequence that the consumers will make a shifting of demand towards products with less impact on the environment.
- *Environmental strategies of the competitors* who take advantage of the differentiation feature "environmental protection" and could get competition advantages in various market segments by recognizing valuable commercial opportunities in collecting, recycling, and reusing products and materials.
- *A more restrictive environmental legislation* which increasingly transfers the product responsibility to the manufacturers also after the use of goods in accordance with the causer-pays principle (e.g. packaging ordinance 1991 and end-of-life vehicle ordinance 1998 in Germany).

The subject of Reverse Logistics is integrated into the framework of Reverse Management which deals with planning and controlling the reintegration of used products (respectively residues) in consumer and production processes. In this context Reverse Logistics Systems can be characterised as the product, material and information flow system that contains the purposeful reintegration of used products in consumer and production processes.

Model To Support The Design And Implementation Of Reverse Logistics Systems

The planning model to support the design and implementation of Reverse Logistics Systems is set up firm-specifically and considers internal recycling (company owned system) and/or external recycling (contract with external recyclers) regarding the scope for the institutional form. Industry-wide co-operations, in which enterprises of the same production stage will take part, are not taken into consideration.

On the basis of a firm-specific data constellation, the model essentially helps to answer the question, which structure of a Reverse Logistics System corresponds to the objectives of the enterprise with respect to given restrictions.

Formulated as a model of linear optimization, the results were generated with the optimization program LINDO®.

The definition of the decision alternatives within the model was determined by the following simplified process of automobile recycling.

See Figure 1

On the basis of an car manufacturers obligation to retract automobiles, ELV are delivered by the consumers to return stations (e.g. car dealers). The quantity of ELV (in accordance with the valid legal regulation) is supposed to be known in the scheduling period. At these stations the decision is made whether the ELV will be supplied to external and/or internal recycling.

In the course of an external placing of the recycling tasks the car manufacturer can book the contractually guaranteed recycling quota for himself, by which he gets a planning security regarding the implemented recycling quotas and is able to give an account of this to the authorities. However, it is not possible for him to use this externally recycled material directly in his production process again.

With the transfer of the ELV from the return stations to the internal recyclers, according to the available and the co-ordinated capacities, this branch is exclusively competent for the following handling of the ELV. A material transport between internal recyclers is impossible due to the extra-emission resulting from it.
In the process of internal recycling the obligation of the car manufacturers consists to dismantle (incl. removing of operating fluids) the vehicles delivered to the internal recyclers in order to receive a most extensive sort purity of the materials for the following handling. With the disassembly the transformation takes place from "ELV" to "unit of weight/material". The material leaves the internal recyclers either towards the nearest dump – „voluntarily" due to planning or as "involuntary" residue from the recycling process – or it will be supplied to the production plants according to the realized recycling quota ($0 \leq$ proportion of recycling $\leq$ technically possible recycling quota). Therefore only the possibility of recovering material by changing the chemical-physical property will be considered as recycling in our model. A re-use of used parts in new cars as well as the sale of spare parts or recycled material is not regarded. On base of a determined production program for the scheduling period the material requirements are covered with the use of recycled material and bought-in materials (1 - technically possible recycling quota $\leq$ proportion of bought-in material ≤ 1).
The material requirements in the production plants are solely related to three materials: steel (70% of the cars weight with an average total weight of 1000 kg/car), plastics (15% weight percentage), and glass (15% weight percentage). Thereby an external supply of material does not only have an affect as a cost element but additionally represents an environmental impact due to the withdrawal of resources from the environment. Further premises are:

- The car manufacturer produces one type of car; resp. variants of it which do not have relevant effects on the costs and environmental impacts of the Reverse Logistics process.
- The planning horizon refers to one scheduling period of any length.
- Weightings of the materials with reference to their environmental impact (pollution units) are not made in the case of disposal, during the recycling process and transportation.

According to the base conceptions of a Reverse Management, the model user can select between two objective functions which can be optimized:

- Cost minimization according to a defensive Reverse Management considering the legally prescribed recycling quotas *or*
- minimization of the environmental impacts in the context of an offensive Reverse Management, whereby for ensuring the economic efficiency a determined cost level may not be exceeded.

Those symbols used below have the following meaning:

See Table 1

In the model of the *defensive Reverse Management* the objective function generates the minimum of the sum of the following types of costs (Co):

- Costs of external recycling

$$Co = \sum_{h}\sum_{z} c^{e}{}_{hz} \cdot y^{e}{}_{hz} \qquad (1.1)$$

- Investment expenditure for the implementation of internal recycling branches

$$+\sum_{v} a_{v} \cdot A_{v} \qquad (1.2)$$

- Transportation and dismantling costs of ELV (internal recycling)

$$+\sum_h\sum_v\left(c_{hv}+c^d{}_v\right)\cdot y_{hv} \tag{1.3}$$

- Recycling costs (internal recycling)

$$+\sum_i\sum_v c^a{}_{iv}\cdot x^a{}_{iv} \tag{1.4}$$

- Depository costs (internal recycling)

$$+\sum_i\sum_v c^w{}_{iv}\cdot x^w{}_{iv} \tag{1.5}$$

- Transportation costs of the re-usable material (internal recycling)

$$+\sum_i\sum_v\sum_g c_{ivg}\cdot x^a{}_{ivg} \tag{1.6}$$

- Delivery costs of raw material

$$+\sum_i\sum_g q_{ig}\cdot x^f{}_{ig} \Rightarrow \min! \tag{1.7}$$

The model of the *offensive Reverse Management* calculates the minimum of the environmental impacts of the Reverse Logistics System (E) which compounds the total of the following environmental single-impacts:

- Deposition quantity from external recycling

$$E=\sum_i\sum_h\sum_z y^e{}_{hz}\cdot d_i\cdot\left(1-\beta_{iz}\right) \tag{2.1}$$

- Deposition quantity from internal recycling

$$+\sum_i\sum_v x^w{}_{iv} \tag{2.2}$$

- Emissions due to the recycling process

internal:

$$+\sum_i\sum_v x^a{}_{iv}\cdot\mu_{iv} \tag{2.3}$$

external:

$$+\sum_i\sum_h\sum_z y^e{}_{hz}\cdot d_i\cdot\beta_{iz}\cdot\mu_{iz} \tag{2.4}$$

- Transportation emissions referring to the following transportation distances:
  - from return stations to internal and/or external recyclers

internal:

$$+\sum_i\sum_h\sum_v y_{hv}\cdot d_i\cdot\varepsilon\cdot t_{hv} \tag{2.5}$$

external:

$$+\sum_i\sum_h\sum_z y^e{}_{hz}\cdot d_i\cdot\varepsilon\cdot t_{hz} \tag{2.6}$$

  - from internal and/or external recyclers to landfill

internal:

$$+\sum_i\sum_v\sum_l x^w{}_{iv}\cdot\varepsilon\cdot t_{vl} \tag{2.7}$$

external:

$$+\sum_i\sum_h\sum_z\sum_l y^e{}_{hz}\cdot d_i\cdot\left(1-\beta_{iz}\right)\cdot\varepsilon\cdot t_{zl} \tag{2.8}$$

  - from internal recyclers to production plants

$$+\sum_i\sum_v\sum_g x^a{}_{ivg}\cdot\varepsilon\cdot t_{vg} \tag{2.9}$$

- from suppliers to production plants

$$+\sum_i \sum_g \sum_s x^f{}_{ig} \cdot \varepsilon \cdot t_{sg} \qquad (2.10)$$

- Withdrawal of resources from the environment

$$+\sum_i \sum_g x^f{}_{ig} \Rightarrow \min! \qquad (2.11)$$

These objective functions are limited by *constraints* that refer to the following contents:

- quantity continuities involving all process levels;
  - return station – (internal/external) recycler:

$$Y_h = \sum_v y_{hv} + \sum_z y^e{}_{hz} \quad \forall\, h \qquad (3)$$

- ELV – material: $$\sum_h y_{hv} \cdot d_i = x_{iv} \quad \forall\, i,v \qquad (4)$$

- material – (non) re-usable material:

$$x_{iv} = x^a{}_{iv} + x^w{}_{iv} \quad \forall\, i,v \qquad (5)$$

- internal recycler – production plant:

$$x^a{}_{iv} = \sum_g x^a{}_{ivg} \quad \forall\, i,v \qquad (6)$$

- capacity conditions concerning the necessary resp. the available capacities for disassembly and recycling;
  - disassembly: $$\sum_h y_{hv} \le a_v \cdot C^d{}_v \quad \forall\, v \qquad (7)$$
  - recycling: $$x^a{}_{iv} \le a_v \cdot C^a{}_{iv} \quad \forall\, i,v \qquad (8)$$
- production conditions to ensure that the production program of the scheduling period is fulfilled;

$$\sum_v x^a{}_{ivg} + x^f{}_{ig} = X_{ig} \quad \forall\, i,g \qquad (9)$$

- recycling and deposition restrictions according to the legally determined recycling ratios.
  - recycling: $$x^a{}_{iv} \le \alpha_i \cdot x_{iv} \quad \forall\, i,v \qquad (10)$$
  - deposition: $$x^w{}_{iv} \ge (1-\alpha_i) \cdot x_{iv} \quad \forall\, i,v \qquad (11)$$

These constraints are identical for *both* objective functions.
In the model minimizing the environmental impacts, however, we need an additional constraint that determines the maximum cost level of the system to ensure its economical efficiency. This constraint corresponds to the objective function of the cost minimization model.

The model calculations emanated from an internal structure which consists of three potential recycling institutions and two production plants as well as an existing network of return stations, external recyclers, landfills, and suppliers.

In different calculations the data constellations were modified in particular regarding the parameters external recycling costs (the difference to the costs of the internal recycling is crucial), technically realizable recycling quotas, quantity of ELV per scheduling period, transportation cost unit rates, delivery costs for raw material and investment expenditure.

On base of the results of the simulation the following model-supported core determinants concerning the question, whether an internal and/or external recycling of ELV should be implemented could be identified:

(1) Economic efficiency of the Reverse Logistics System:
The spatial expansion of the system strongly influences the solution of the decision problem by the distance-dependent transportation costs. With increasing spatial concentration of the system the model tendentious recommends an internal recycling.
Beyond that the relation of the process costs of the internal recycling to the appropriate proportionate costs of the external recycling affects substantially the institutional form. If it is not possible for the regarded enterprise to undercut these (external/market-) prices within his internal recycling (in particular due to missing technology and process control), the model tends to an external recycling solution.
Furthermore the aspect of the economic efficiency refers to the possibility of integrating recovered material into the own production process. If this should not be given or only to a small proportion, then external recycling will be suggested by the model.

(2) Ecological efficiency of the Reverse Logistics System:
In this connection a comparison of the realizable recycling quotas of the internal recycling with those of the external recycling is decisive. With enterprises whose expected recycling quotas are situated either below the business aims and/or the legal minimum quotas, a foreign assignment of the recycling activities is generally recommended.
If therefore the realizable recycling quotas of the internal recycling differ from those of the external recycling, an ecological control by these quotas will be possible.
In addition to that the ecological efficiency of the system depends on the quantity of bought-in material which is in direct connection with the internally realized recycling quota. Thus a consideration of the outside supply rate as environmental impact (in terms of withdrawal of resources) leads tendentious to an internal recycling.
With an increasing expansion of the catchment area of an internal recycling network the transportation emissions are of consequences. Therefore different proceedings of the Reverse Logistics depending on the region may be provided. Those can contain both internal and external recycling. Thereby an orientation at the enterprises sales figures appears necessary.

On the other hand emissions in the course of the recycling process do not prove as decision relevant due to the legal regulations and a supposed technological minimum level.

(3) Financial resources in the enterprise:
If financial restrictions exist which make eventually planned investments impossible the model inevitably will suggest an external recycling or a reduced internal recycling according to the financial possibilities of the enterprise.

(4) Uncertainty:
The aspect of uncertainty refers in particular to the quantity of ELV (critical quantity) and its temporal distribution in the planning period. To both areas of uncertainty applies: A reduction of planning reliability tendentiously leads to an external recycling to avoid problems of resp. fluctuations in the capacity load.

Since the model in its presented structure indicates a strong simplification regarding the real life problem of ELV Reverse Logistics the informational content can be described as concrete but not sufficient. To improve the quality of the decision support two alternatives can be used:

- upgrading the model complexity and/or
- additional consideration of qualitative aspects

Under perpetuation of the general model structure the following aspects can additionally be integrated into the model, whereby the model complexity and the programming effort rise, e.g.:
Several products (variants of cars), several periods (dynamic modelling), other forms of recycling (re-use in the same function, re-use in an other function, use of the recovered material in an other function), different environmental impacts per kg material (pollution units), direct use of recovered material from the external recycler, revenues by the sales of parts, recovered material etc., facets of uncertainty.

Nevertheless, the methodology as a basis for the model calculation almost excludes a consideration of qualitative aspects of the planning problem which result from the enterprise strategy and/or market conditions. Therefore it is advisable to complete the analysis with a firm specific evaluation of this planning problem with consideration of qualitative aspects, e.g. by means of a Scoring Model or the use of a multi-factorial portfolio analysis.
Consequently in supplement of the model-supported core determinants qualitative arguments have to be integrated into the decision process of the design and implementation of a Reverse Logistics System.

Decisions in favour of the institutional form of a *company owned system* can be positively influenced by following aspects:

- Homogeneity of the product range, as the dismantling and the recycling could be automated. In this case potentials of rationalisation and scale-effects can be realized.
- The possibility of realizing high prestige and image-effects by the own system, whereby a positive effect on the market shares can be achieved if the consumers actually change their consumer behaviour towards environmental-compatible products because of the "green image" of the company.
  The image effect can also have an impact on the employees of the company and on the company's success, as far as a "green image" contributes to satisfy the existing employees, may lead to a higher identification with the company and/or rises the attractiveness of the company on the labour market.
- Availability of the recycling technology and the know-how.
- Endeavour of the company to get a material loop control:
  This explains the attempts of the producers, who want to control the recycling costs and possible profits as they give the subsidies for the Reverse Logistics.
- Institutional attachment of dismantling and assembling to reach scale effects especially in the area of process-arrangement.
- Secrecy reasons concerning the materials and the assembly process.
- Possibility to realize revenues on markets for second-hand parts and secondary raw material. If a company decides to take such a possibility into account, a building of such markets by the external recyclers can be counteracted and also a control of these markets may occur.
- Possibility of diversification in Reverse Logistics by what a new business can develop that helps to achieve profits and lies relatively close to the core business of the company.
- Diffusion of new property-forms for cars (leasing, "usage rights" trade), so that used parts can be installed into "new" products.
  By means of such property forms the amount of old cars in the scheduling period can be controlled in a better way with the help of recall-actions or in the course of servicing. Moreover an evenly capacity utilisation can be achieved.

In contrast to that the design and implementation of the institutional form *“contract with external recyclers (market)“* can be supported by the following qualitative arguments:

- High diversity of the product range, because thereby the necessary processes receive a complexity, which possibly reduces the realization of economies of scale.
- According to the principle that enterprises should limit their business activities to their core competence, Reverse Logistics could be classified as non-core competence from the beginning due to the newness of the problem.
- Existence of competent partners who can function as strategic partners of the examined company providing their infrastructure and know-how in this partnership.
- Uncertain political-legal situation especially regarding aspects which relate to regulations of the freight traffic, of landfilling and of sanctions in case of non-observance with recycling quotas. A more restrictive legislation concerning these points, in particular in the sense of increased costs, could entail a delegation of Reverse Logistics to third parties. Beyond that, an extension of the catchment area of ELV due to a political motivated extension of the geographical scope of the end-of-life directive (east expansion of the European Union) will have impact on the results of the planning process.

Conclusion

In this paper it is shown that the design and implementation of industrial Reverse Logistics Systems can methodically be supported by a quantitative model in principle.
On the basis of the (simulated) results, core determinants of this decision problem have been worked out. The model supplies concrete decision support and proves capable of being extended on the one hand regarding the model structure and elements and on the other hand also for other practical applications (other industries).

Since the planning problem generally refers to durable consumer goods a transfer of the model structure on other industries e.g. computer, electrical appliances ("white goods") appears possible and reasonable.

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Figures and Tables

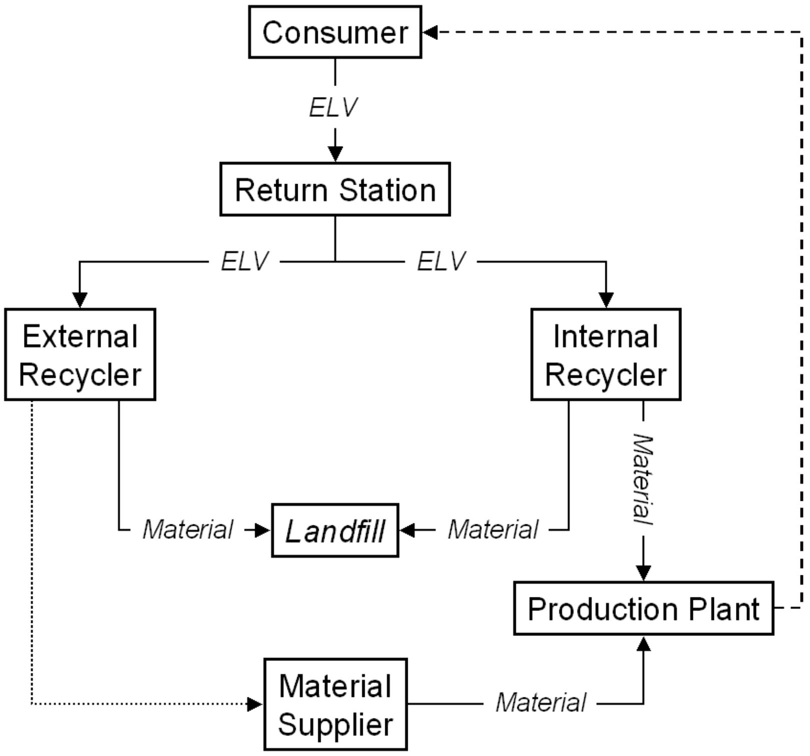

Figure 1: Simplified Automobile Recycling Process

Indices:

g :	production plant (g = 1, …, G)
h :	return station (h = 1, …, H)
i :	material (i = 1, …, I)
l :	landfill (l = 1, ..., L)
s :	supplier (s = 1, …, S)
v :	internal recycler (v = 1, …, V)
z :	external recycler (z = 1, …, Z)

Variables:

a_v :	investment variable for internal recycling capacity (integer variables)
x :	quantity of material (kg)
x^a :	quantity of re-usable material (kg)
x^f :	quantity of bought-in materials (kg)
x^w :	quantity of non re-usable material (kg)
y :	quantity of ELV (EA)
y^e :	quantity of ELV given to external recyclers (EA)

EA = each
MU = monetary unit

Data:

A :	investment expenditure (MU)
C^a :	recycling-capacity (kg)
C^d :	dismantling-capacity (EA)
c :	costs of transport (MU/ELV or kg)
c^a :	preparation costs (MU/kg)
c^d :	dismantling costs (MU/ELV)
c^e :	costs of external recycling (MU/EA)
c^w :	costs of transport and deposition(MU/kg)
d_i :	amount of material i per ELV (kg/EA)
q :	material cost price (MU/kg)
t :	distance
X :	material requirement (kg)
Y_h :	quantity of ELV (EA)
α :	internal recycling quota (%)
β :	external recycling quota (%)
ε :	transportation-emissions coefficient (kg per ton-kilometre)
μ :	recycling-emissions coefficient (%)

Table 1: List Of Symbols