A decision support model for the recovery and reuse of products and components.

A decision support model for the recovery and reuse of products and components

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Abstract
Recovery and reuse are becoming important issues for manufacturers. On the one hand legislation is introduced now or very soon that obliges manufacturers to be responsible for their products at the end of the life cycle, while on the other hand recovery and reuse may be profitable for the company.
It gives various possibilities to recover discarded or used goods. In view of recovering the added value, product and parts recovery are the most important options. In this paper a model is described that supports management in decisions concerning the recovery and reuse of goods at the end of their life cycle as well as the components or parts of these goods. The developed model has been divided into three submodels, resulting in: initial feasibility, technical feasibility and economical feasibility. This model has been used in practice for recovering parts for service ends. It is concluded that the model has shown to be useful in practice. However, further research has to be carried out in order to investigate the validity and reliability of the model.

Keywords: recovery; reuse; remanufacturing; management tool; feasibility; mathematical model.

1. Introduction

Because of society's increasing concern for the environment and resulting governmental legislation, companies are involved more and more with environmental aspects. Examples of such legislation are the Dutch rules with respect to product responsibility of manufacturers for their products at the end of the life cycle. This implies that a manufacturer is responsible for the environmental friendly processing of their discarded goods, while they have to fulfil some prescribed values for the mass fraction of the recovered materials and parts that will be reused. The Dutch are frontrunners in the world with respect to this legislation, but it will be introduced in more countries soon. The European Commission, for instance, is preparing such legislation now and it is expected that product responsibility will be introduced in all EU countries within a few years (European Commission, 1997).

Although companies may consider product responsibility to be a threat, it can be seen as an opportunity too. For instance, companies like IBM, Xerox and Oce have been engaged

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in recovery activities for several years and it has been shown that these are profitable activities. Not only purchasing costs are reduced because of remanufacturing of used components; such components and parts are also used for after sales services. Besides that, used goods are also reconditioned so that they fulfil 'as new' specifications. These products are put in the market again, although in some cases this might be a different market than for new products.

In this paper a model is described that supports management in decisions concerning the recovery and reuse of goods at the end of their life cycle as well as the components of these goods. Material reuse (recycling) is not considered as, on the one hand, the recovered added value is relatively low, while, on the other hand, this activity is not connected directly to the business processes of the manufacturer (e.g. manufacturing, services). With the developed model the economic feasibility of the recovery of used goods and components is estimated based upon data regarding the goods (e.g. design, information), the market and logistics.

As literature concerning reuse of products, components or materials is not consistent with respect to the nomenclature for the different recovery activities, in this paper the following definitions are used (Melissen and De Ron, 1998):
Recovery or asset recovery is used as a general expression for bringing back used or discarded goods and/or parts and materials from these goods in the economic process. This means that the added value of the good is recovered fully or partly. Returning a used (or discarded) good to a state which fulfils 'as new' specifications will be called reconditioning. If the good is renewed to a state that fulfils required specifications, not as rigorous as those for the same new product, the process is called refurbishing, while the process that returns a good to working order is called repair. The process that results in a part or component that fulfils 'as new' specifications is called remanufacturing, while a process resulting in parts or components with specifications lower than 'as new'; this is called revision. Cannibalization is the process that results in parts or components specified as working order. All these processes can be divided into subprocesses, including disassembly, cleaning, inspection, testing, repair, and reassembly.

1. Analysis of recovery influencing aspects

From an overview of the current state of the art with respect to recovery based upon literature (Flapper and De Ron, 1996, 1998) and interviews with several companies, the most important aspects that influence recovery activities can be summarized as follows, see figure 1.

Supply

The supply of used or discarded goods forms the input of the recovery chain. Information, which is needed with regard to the discarded goods, is the location of the goods supplied, the quantity and quality of the goods and the scale of goods supplied (world, European Union, country). The goods supplied can come from an internal or external market. The external market can be divided in consumer goods and business-to-business goods. Generally producers have more data about business-to-business products than consumer products with regard to the locations and quantities of the installed base.

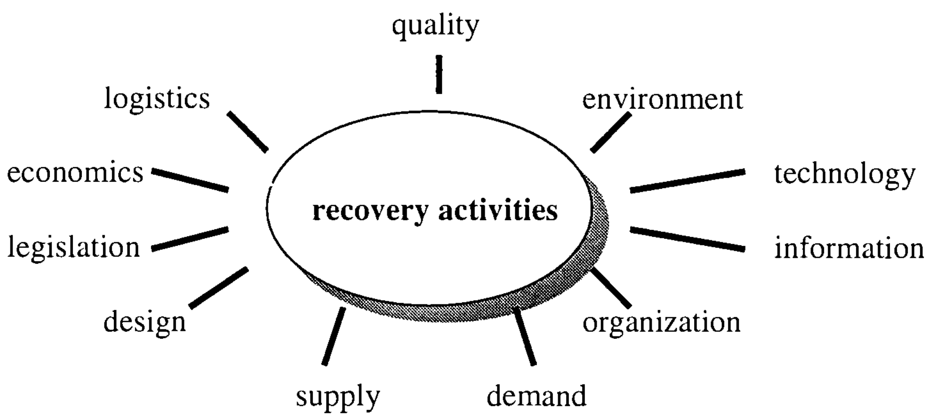

Fig.1: The most important aspects that influence recovery activities.

Demand

The demand for recovered products or parts is of essential importance. When there is no demand, it is no use to investigate the possibilities for recovery and reuse. The location of the demand, the required quantity and the expected quality need to be mapped. It is possible that sales organisations are interested in reconditioned or refurbished products for a special kind of reason. The demand for remanufactured parts can come from a production plant or a service organisation. Beside the possibilities within the organisation itself, an external market might be interested in reprocessed products or parts too.

Environment

The impact of recovery activities on the environment may be positive as savings are made when comparing to the current manufacturing process. When products or parts are recovered, the negative environmental impacts of the production of new products and parts are reduced. Examples are the savings of energy, materials, waste, land, and water and air pollution. There also are negative impacts like the transportation, energy used and waste created by the recovery process, and the land, water and air pollution as a result of the recovery processes. All this means, that the calculation of the exact impacts of recovery activities on the environment is very complicated.

Legislation

As has been described in the introduction, legislation is an important driver for companies to consider recovery. As producers will be responsible for their end-of-life products, they have to find a way to take back their products for free and make arrangements for the collection and environmental friendly processing of these goods. With regard to the recovery process, producers are obligated to recover a certain percentage of the total mass collected and to process hazardous parts and materials.

Logistics

The most important part of the aspect logistics is the transport of goods and parts for recovery ends. The total distance that needs to be covered in a recovery process can be divided in two main sections:

- the removal of discarded goods from the location where it is offered to the recovery process,

- the removal of reprocessed products or parts from the recovery process to the demand market.

To fulfil the demand, a collection strategy for the supply of discarded goods needs to be developed. An example of a collection strategy is offering fees to users for their used goods. The locations of the supply, the demand and the recovery process influence the total distance that needs to be covered. Depending on the characteristics of the product and the specification of transport (scale, speed, etc), a choice can be made between transport by plane, by ship, by train or by truck.

Quality/Reliability

Quality and reliability are important issues to inspect before recovering. To predict the quality and reliability of a good or part, information about for example failure rates, mean time between failures and circumstances, is needed. Statistics can be used and the prediction of quality and reliability can be based on a sample of the goods or parts (Kecedioglu, 1993).

Technology

Technology deals with the methods, the machines and tools needed for the recovery process. This process can be broken down into subprocesses, like: identification, inspection, disassembly, cleaning, assembly, testing, repairing, internal transport. For the reprocessing of products and parts, all or a combination of these subprocesses is needed (Penev, 1996; Melissen and De Ron, 1998).

Design

In the design process of a product, the end-of-life phase should be taken into account. The decisions about the issues influencing the recoverability of a product, are made during the design phase. Examples of these issues are the way parts are connected and whether the product is built up of modules. These issues lead to a product, which is easy to recover, resulting in short disassembly times and thereby less disassembly costs.

Information

Information about the products and parts to be processed is needed for the recovery process. This information should be registered very carefully. Furthermore, information is needed about the location of the products, from where they have to be collected and how many products are available at one location. Before deciding whether to recover products and parts or not, it is important to have information about the quality and reliability of the goods. When the quality and reliability of the goods do not meet the required standards, reuse of products and parts might not be possible.

Organisation

The aspect organisation deals with all subjects within the recovery chain. Examples are the management of the chain, but also arrangements about warranty periods for recovered products or parts. Another subject is the marketing of reconditioned items. With certain marketing tools awareness can be created by the customers leading to stimulation for buying these items. A possible consequence is a better company image regarding to the environment, a so-called 'green image'.

Economics

It will be clear that all aspects mentioned above have a relationship with economy. The supply of goods will have an effect on the revenues. It also leads to costs for the collection and transportation. The demand of products and parts determine the revenues.

The law has its influence on the reverse logistics. As producers are obliged to take back the goods that are discarded, this will result in extra costs.
The economic feasibility of recovery and reuse is based on the financial result of the above mentioned revenues and costs.

3. The design of the model

Before the model was designed, first the goals, the function, the requirements and the characteristics of the model have been defined (Cross, 1994). Based on these results a model has been developed. The outcome of the model is a prediction of the economic feasibility of the recovery of products or parts in order to be reused. The total model can be divided in three submodels, see figure 2.

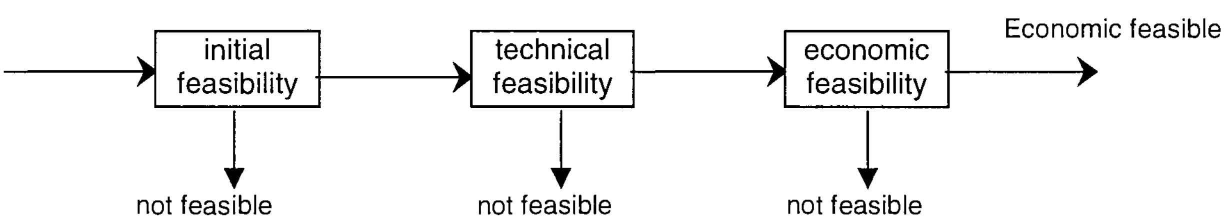

Fig.2: The three submodels

The initial feasibility is based upon the demand for recovered products or parts and components and the supply of discarded goods. If the demand can not be fulfilled for a specific part because of a lack of supply, it makes no sense to continue the feasibility study. Therefore, recovery is initial feasible, if:

$$TSG \geq \{\gamma_p.TDP + \max_c(\gamma_{co,c}.TDC_c / n_c)\} \quad (1)$$

As equation (1) indicates, recovery is initially possible only if the supply of goods can cover a certain percentage of the total demand for recovered products and parts. The value of the fraction (γ_p and $\gamma_{co,c}$) is determined by the client and the supplier. It is supposed that the demand for recovered products has to be fulfilled over the demand for recovered parts.

The technical feasibility deals with the quality and reliability of the goods (and their parts) supplied and the required quality and reliability of product and parts or components demanded.
Recovery is technically feasible if:

$$\left.\begin{aligned} & q_p.TSG \geq TSP \geq \gamma_p.TDP \\ & q_c.(TSG - TSP).n_c \geq TSC_c \geq \gamma_{co,c}.TDC_c \text{, for } \forall c \end{aligned}\right\} \quad (2)$$

If eq. (2) is not fulfilled, the recovery may not be feasible for product recovery (the first equation), but might be feasible for component recovery (the second equation). In that case TDP=0 and q_p=0 in the first part of eq.(2) and all the following equations.

To determine the economic feasibility, the revenues and costs resulting from the recovery processes, need to be calculated. Recovery is economic feasible if the financial result fulfils the financial requirements made by the company or the chain actors. The different revenues and costs can be expressed as follows:

- financial result:

$$FR = TR - TC \tag{3}$$

- total revenues:

$$TR = R_p.TSP + \sum_c (R_{co,\,c}.TSC_c) \tag{4}$$

- total costs:

$$TC = C_{col} + C_{pro} + C_{dis} + C_{\log} \tag{5}$$

-
- collection costs:

$$C_{col} = P_g.TSG \tag{6}$$

- processing costs:

$$C_{pro} = TSP.C_{pr} + (\min\{q_p.TSG, TSD\} - TSP).C_{insp} + \sum_c (TSC_c.C_{cr,\,c}) \tag{7}$$

- disposal costs:

$$C_{dis} = \{(TSG - TSP).W_g - \sum_c (W_{co,\,c}.TSC_c)\}.C_{lf} \tag{8}$$

- logistic costs:

$$\begin{aligned} C_{\log} = {} & TSG.W_g.D_{sp}.(\delta_a.C_a + \delta_r.C_r + \delta_s C_s + \delta_t.C_t) + \\ & + TSP.W_g.D_{pc}.(\delta_a.C_a + \delta_r.C_r + \delta_s.C_s + \delta_t.C_t) + \\ & + \sum_c (TSC_c.W_{co,\,c}.D_{pc,\,c}).(\delta_a.C_a + \delta_r.C_r + \delta_s.C_s + \delta_t.C_t) \end{aligned} \tag{9}$$

The decision to recover goods and parts or components is made by the company. This decision can depend on the economic feasibility, but it is also possible that a company does not decide to execute recovery activities although the financial result is positive or because of some other reason.

4. Application of the model

To test the designed model, a pilot project has been executed at a company that had supply problems with parts for service ends. Some of the suppliers of parts do not deliver anymore the parts needed for service although the company is obliged to deliver service for their systems until at least the year 2001. One of the possibilities to solve this problem is reusing the parts of the systems in the field. To investigate the possibility of recovery and reuse of parts, this pilot project has been started.

4.1 Analysis of the demand

The starting point of mapping the demand, is a total parts list of the particular system. Based on this list, two categories of demanded parts are created: critical parts and interesting parts. The first category contains parts, which can not be delivered anymore in the nearby future. The problem earlier described refers to these parts. These parts should always be recovered (remanufacturing). The second category consists of parts, which are interesting to recover from an economic point of view. When a system will be processed to recover the critical parts, it is worthwhile to investigate if perhaps other parts are also interesting to recover. Making a Pareto analysis has created this category first. Although 20% of the total parts list is representing 80% of the total costs for a system, it would not be wise to spend time and money to a number of these parts because the yearly consumption is very low.
To solve the service problem, the quantity of systems that should be collected, has to be calculated. The critical part with the largest year consumption, determines the initial required quantity of systems ($Q_{i,r}$) to be collected. Because some service parts are repairable, an extra flow of service parts is created. These parts are sent back to the company when they are replaced by an operating part. The parts are repaired and can be used again as service parts. But not all the parts can be repaired. So when a critical part is repairable, still a fraction f of the total demand should be collected by recovering them from systems. The minimum quantity of systems to be collected is ($f.Q_{i,r}$) systems.
The location of the demand is important for the logistics process. As in the current situation the service department is demanding the parts, there are two possibilities for the location: the current warehouse for service parts or a new warehouse elsewhere, based on the optimization of the financial result.

4.2 Analysis of the supply

To map the possible current supply, it is important to know the quantity and the locations of the systems in the field. On a regular base the company gets information from the field about the installed base. From this information Table 1 has been created, where the quantities of the different countries are combined to continents.

	Percentage of the total
Europe	43,5%
North-America	43,1%
Asia	7,4%
South-America	4,2%
Africa	1,7%
Total	100,0%

Table 1: The distribution of systems over the world.

Note that the company will be responsible within a few years for almost half of the total systems after they have been discarded as a result of future EU legislation.

4.3 Determination of the collection strategy

A strategy has to be determined to get at least (f.$Q_{i,r}$) systems back from the field. The systems need to be collected to fulfil the demand for service parts. Several strategies are possible to be applied, e.g.:

- start a special action to stimulate the return of systems. To discuss the best way to start an action, contact with the field is necessary.
- exchange systems by 'old' for 'new'. Let sales people of new systems know that there is an interest in the particular systems.

To get the best result, a combination of the above mentioned strategies is possible. Actually it is possible to choose for an active or passive way for collection. For the systems it is possible to collect actively in Europe. When systems are collected passively, no extra actions are done and the systems will be offered randomly all over the world.

4.4 Determination of the technical feasibility

To determine the technical feasibility, more information about the parts is necessary. This information should contain data about the possibility to disassemble systems in order to obtain parts and data about the quality of the parts. After checking both types of parts, the critical and the interesting parts, all parts seemed to be technical feasible to be recovered for reuse ends.

4.5 Design of the recovery process

The total recovery process can be divided in several subprocesses, e.g.:

- Identification and inspection of the systems
- Disassembling the total system for the demanded parts
- Testing of the parts based on quality norms
- Packaging and labelling of the demanded parts

When the total recovery process is known, the costs for this process can be calculated. Afterwards one should consider the revenues and the costs for recovery, to make a definite list of parts to be disassembled when reusing parts is implemented in practice. The costs for the total recovery process is determined by multiplying the time needed for the execution of the subprocess by the hourly rate of labour.

After calculating the costs for the total recovery process per part, the revenues gained by saving purchase costs per part were higher than the costs made for the several subprocesses. An extra investment needs to be made for a test system to check the functionality of the parts.

The costs for the recovery process will increase per year as more parts will become critical each year and so the demand for parts will increase. This results in more time needed for the execution of the processes which increases the costs. On the other hand, the revenues will increase too.

4.6 Design of the logistics process

To map the logistic process, the location of the supply, the demand and the recovery process are essential. The total transport can be divided, in a supply and a delivery channel, as shown in figure 3.

Supply **Supply channel** → *Recovery Process* **Delivery channel** → *Demand*

Fig. 3: The logistics process

In the supply channel collected discarded systems are transported to the location of the recovery process. Depending on the chosen collection strategy, it is possible to calculate the costs for transport.
From an organisational point of view the company would like to have the recovery process close to the demand location. This means that the transport costs to the demand location can be neglected in this study.
It is possible to use several kinds of transport, for example by air, by rail, by sea or by road. From a cost minimisation point of view, in this project a choice has been made for transport by sea for systems returning from out of Europe and transport by road within Europe. In Table 2 the transport rates per system are shown.

supply location	Transport costs
North-America	950,-
Europe	475,- (average)
Germany	300,-
Italy	650,-
France	490,-
Benelux	220,-
United Kingdom	450,-
Spain	750,-
Asia	850,-
South-America	1150,-
Africa	1150,-

Table 2: Transport rates per system (guilders).

Based on these figures the total costs for transport can be calculated. The variant of active collection (by paying a fee) will be concentrated on Europe. The passive way of collection means that the current installed base is taken back after discarding by the user. The costs for transport are much higher for a passive collection because systems are coming from all over the world.

4.7 Calculation of the economic feasibility

The revenues that can be made are based on the savings of purchase costs. The total demand for a particular part is multiplied by the factory-selling price. Because the total number of parts disassembled, is varying within the considered years, the revenues are varying too, see Table 3 (For reasons of confidentiality, no real data are given).

	f.Qi,r systems/ year
Year 1	366.500
Year 2	436.400
Year 3	476.600
Year 4	486.900
Year 5	492.500

Table 3: Revenues from reprocessed parts (guilders).

The total costs are divided into costs for collection, recovery, disposal and logistics.
The costs for collection need to be determined by a market research, as there is no experience with such collection strategies.
The costs for disposal can be neglected as the waste has a certain value, which means that no costs are paid to an external specialised waste company for waste collection and disposal.
The costs for the recovery process and the costs for logistics have been calculated for five years, see Table 4 and 5.

Year 1	18.560
Year 2	19.650
Year 3	20.860
Year 4	21.310
Year 5	21.630

Table 4: Costs for the recovery process (guilders).

Variant 1: active collection	6.650
Variant 2: passive collection	10.550

Table 5: Costs for logistics (guilders).

The total financial result, being the difference between the revenues and the total costs, is shown in Table 6.

year	Active	Passive
1	341.300	337.400
2	410.100	416.200
3	449.000	445.100
4	458.900	455.000
5	464.200	460.300

Table 6: Financial result (guilders).

From Table 6 it can be concluded that recovering and reusing parts is economic feasible, because the financial result is positive.

From this project, the following conclusions can be drawn:

- The current service problems can be solved by recovering and reusing parts from discarded systems,
- The total recovery and reuse process will be a lucrative business when implemented in practice,
- The difference in the financial result between active and passive collection has turned out to be minimal. Active collection is recommended because this situation can be controlled better.
- The collection strategy may have an important influence as the calculated results are based on the actual returning of the systems.

5. Conclusions

After investigating the state of the art it became clear that the main reason for companies to be interested in recovery and reuse is that they can make money with it. Reuse could also have a positive impact on the environment, but for companies this is not the main reason.
After analysing the aspects that are important when starting with recovery and reuse, the conclusion can be drawn that not all the aspects have the same importance. (Re) design, information, organisation, environmental impacts are issues that can be investigated after the company has decided to set up recovery and reuse activities. Redesign can result in an easier recovery process, but is not an issue that influences considerably the prediction of the economic feasibility. The same can be concluded for the registration of information and the needed information system. The organisation of the recovery and reuse activities is extremely important but effectuated after the company has decided to recover and reuse. Most companies will start with recovery and reuse, when a business process needs it and the costs are reasonable; environmental impact does not play an important role on forehand.

The model has shown to be usable in practice. The project has shown that the model indeed supports decisions concerning recovery and reuse. However, this model is just a first step. The different parts of the model will be studied further so that a more accurate prediction can be made and extended with not foreseen aspects.

No conclusions can be made about the validity and reliability of the model. The model is not used in more cases and it also is not used more than once in the same case. Therefore, this will be a subject for further research too.

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List of Symbols

c	type of part or component
C_a	transport rate by air (money value/tonkilometer)
C_{col}	collection costs (money value)
C_{cr}	recovery costs of part or component type c (money value/kilogram)
C_{dis}	disposal costs (money value)
C_{insp}	inspection costs (money value/good)
C_{log}	logistic costs (money value)
C_{pr}	recovery costs of a good (money value/good)
C_r	transport rate by rail (money value/tonkilometer)
C_s	transport rate by sea (money value/tonkilometer)
C_t	transport rate by road (money value/tonkilometer)
D_{pc}	distance between the location of the recovery process and the client for reprocessed products (kilometer)
$D_{pc,c}$	distance between the location of the recovery process and the client for remanufactured parts or components of type c (kilometer)
D_{sp}	distance between the location of the supplied goods and the recovery process (kilometer)
f	fraction of broken parts that can not be repaired
FR	financial result (money value)
n_c	number of parts or components of type c in a good

P_g	price of a discarded good (money value)
q_c	fraction of parts or components from a good that fulfil the quality standards
q_p	fraction of goods that fulfil the quality standards
$Q_{i,r}$	number of goods to be supplied that fulfil initially the required demand for reprocessed products and remanufactured parts or components
$R_{co,c}$	revenues from a part or component of the type c (money value)
R_p	revenues from a reprocessed product (money value)
TDC_c	total demand for parts or components of type c (#/time period)
TDP	total demand for reprocessed products (#/time period)
TR	total revenues (money value)
TSC_c	total number of parts or components of type c that has been supplied to the client (#/time period)
TSG	total supplied goods (#/time period)
TSP	total number of products that has been supplied to the client (#/time period)
$W_{co,c}$	weight of a part or component of type c (kilogram)
W_g	weight of a good (kilogram)
$\gamma_{co,c}$	covering factor for the total demand for parts or components of type c
γ_p	covering factor for the total demand for reprocessed products
δ_a	decision factor air transport (0,1)
δ_r	decision factor rail transport (0,1)
δ_s	decision factor sea transport (0,1)
δ_t	decision factor road transport (0,1)