Decision supporting model for the recovery of computer components

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Abstract: Legislation with respect to the recovery and environmentally friendly processing of discarded products may be an opportunity for companies to increase profits by creating components from the discarded products.

This research was directed to the profitability of the disassembly of some of the components of a product to use them in the assembly of new products or for service aims.

In order to get experience and knowledge, this research has been focused on computers. A mathematical model has been developed based upon the technical, operational and economic control of the recovery processes. With this model some preliminary simulation runs have been executed. The results obtained from the simulations were in accordance with the expectations.

Keywords: Recovery; decision supporting model.

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1 Introduction

Recycling of used materials is applied already for several years, e.g. glass, paper and some types of plastics. In most cases, specialised recycling companies carry out these operations. One of the main disadvantages of recycling is that the added value is lost with the destruction of the discarded product.

From experience it is known that about 20% of the components determine 80% of the material costs of a product. This means that the components of a product that can be reused are limited in number. The remainder of the product can be recycled after these components are disassembled (and the added value has been recovered).

However, it only makes sense to disassemble components if there is a market for them, if the volumes are large enough to fulfil the demand and if the quality and reliability of the components fulfil the requirements. After all, disassembly activities mean that capital is invested and costs are incurred.

If a company acts in an environmentally friendly way in the processing of its discarded products and takes the opportunity to utilise used components in the assembly of new products or for service aims, it has to decide whether to use the components or recycle them. The objective of this research is to help companies to decide whether it is more profitable to disassemble some of the components of a product and to use them in the assembly of new products or for service aims, or if there is greater financial advantage in recycling the complete product, and if so, to determine which components have to be disassembled

In this study these questions have been directed to a particular product: a computer. The reason is that the results obtained with this product may lead to more general knowledge and experience making it possible to answer the questions for a variety of products.

2 The structure of a computer

Physically, a computer can be divided into three main parts: the system unit, the keyboard and the monitor. In this project only the system unit is considered as it contains the removable components and parts that are of interest. Furthermore, the study has been focused on personal computers and especially on the regular desktop and tower types; these form the largest part of the volume of discarded computers. Therefore, in the remainder of this article the word ‘computer’ will be used to mean the system unit of an average personal computer.

Although the physical layout may vary from one computer to another, we assume that the logical organisation of the parts and components is more or less the same for all of them.

The main parts within a system unit are the following:

- the case, which is made from plastic
- the power supply, which transforms the main voltage into lower DC voltages; it contains a transformer with mainly copper wires
- the hard disc with disc driver
- the motherboard, which is a printed circuit board containing most of the main electronic parts, e.g. the processor and the memory
- interfaces which are situated at the front of the case like floppy disc driver and CD driver

- various printed circuit boards like the video card and the controller, which are connected to the motherboard by means of connectors (expansion slots); these connectors are situated on the motherboard
- cables which connect all parts and boards; although the cables are not real components, they should be treated as such, as they contain one main material (copper).

The parts that have a value on the market and therefore are worth consideration for disassembly are:

- motherboard, including internal memory (i=1)
- hard disc with disc driver (i=2)
- controller (i=3)
- video card (i=4)
- CD driver (i=5)
- floppy disc driver (i=6)
- processor (i=7)
- cables (i=8).

The numbering of the components will be used in the following sections to identify a particular component.

To remove parts from the system unit, the following sequential relationships between parts are supposed to hold true [1]:

- to disassemble the motherboard, it is necessary to first take off the video card, the controller and the cables attached to it
- the floppy disc driver and the CD driver can be disassembled only if all cards (video card and controller) and the cables have been taken off
- the disc driver can be disassembled only if the CD driver, the video card, the controller and the cables have been taken off.

Moreover a computer contains hazardous components or materials that have to be removed before any shredding operation can be executed. For instance, the power supply will have a capacitor, which contains a hazardous matter. Therefore, the capacitor has to be disassembled before shredding.

3 A decision support model

The goal of the mathematical model that will be derived is to support companies in their decision to reuse components. These decisions are difficult to take as there are many uncertainties are expected. For instance, the quality and reliability of the components may be unknown or only partly known, the delivery of discarded products in quantity and/or time may be uncertain, and so on (see also [2]). The model uses expected values for the input variables and the parameters, while the computers are assumed to be of an average type. It will determine which processing activities for a supplied batch of computers will result in maximum revenues.

A computer can be considered to be built up of a set of parts as has been described in the previous section about the product structure. Three decisions have to be taken:

1 disassemble one or more parts or components for reuse applications

2 disassemble one or more parts or components to shredder them to obtain more pure material flows

3 shred the complete computer (apart from obligatory operations to remove hazardous parts or materials).

As these decisions determine the revenues and costs that are created by the particular operations, the model should choose those decisions that maximise the net result.

The stock of supplied computers is not considered in the model. This is not caused by difficulties in modelling, but the decisions to be made are not influenced by this stock.

The control of the recovery activities for products can be divided into three main parts:

1 technical control which determines the order of activities enforced by the product structure

2 operational control to avoid undesired operational situations

3 economic control in order to obtain the maximum financial result.

3.1 Technical control

By defining binary variables, the three processing activities of the decision process can be described by mathematical expressions. If an activity is executed, the variable will have the value 1, while the value 0 indicates that the activity is not executed. During the operations, the decision to be taken may change as variables change. Therefore the decision is time dependent. Then, the decision to disassemble a component or part i can be expressed as: $D_{d,i}(k)=1$, where k is the k-th time interval. If this disassembled component or part is reused, it means that: $D_{r,i}(k)=1$. Then, the three decisions to be taken can be expressed mathematically as follows:

1 disassemble one or more parts or components for reuse applications:

$D_{d,i}(k).D_{r,i}(k) =1;$ $(D_{shr,i}(k)=0;\ D_{shr}(k)=0)$

2 disassemble one or more components or parts for shredding them:

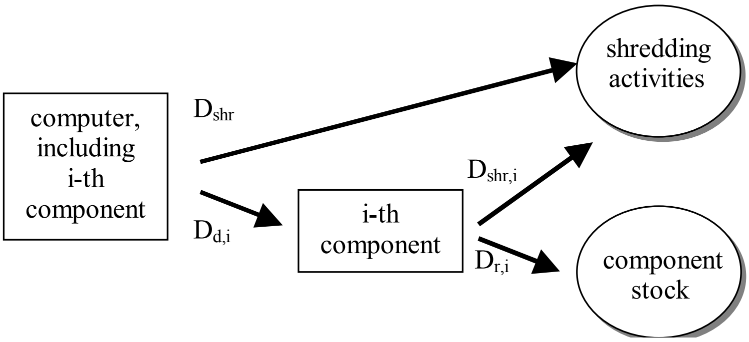
$D_{d,i}(k).D_{shr,i}(k)=1;$ $(D_{r,i}(k)=0;\ D_{shr}(k)=0)$

3 shredder the complete computer:

$D_{shr}(k)=1;$ $(D_{d,i}(k)=0;\ D_{r,i}(k)=0;\ D_{shr,i}(k)=0)$

where $D_{shr}(k)$ represents the decision at time interval k to shredder the complete computer, while $D_{shr,i}$ represents the decision at time interval k to shredder part or component i . Figure 1 shows the different decisions that have to be taken.

Figure 1 The various decisions to be taken



As a part can be processed only by one activity, the binary variables have to fulfil the following equations:

$$Dd,i(k) + Dshr(k) = 1 \quad (1)$$

$$Dd,i(k) = 1 : Dr,i(k) + Dshr,i(k) = 1 \quad (2)$$

The components of the computer are fixed to each other. They can be released by disassembly. However, for some components individual activities may be limited, as they can be disassembled only after other components have been disassembled too. This has been described in the previous section.

These limitations concern the following activities:

- if the motherboard (i=1) has to be disassembled, the controller (i=3), the video card (i=4) and the cables (i=8) have to be disassembled too:

$$Dd,1(k) = 1 : Dd,3(k) = Dd,4(k) = Dd,8(k) = 1 \quad (3)$$

- if the floppy disc driver (i=6) has to be disassembled, the controller (i=3), the video card (i=4) and the cables (i=8) have to be disassembled too:

$$Dd,6(k) = 1 : Dd,3(k) = Dd,4(k) = Dd,8(k) = 1 \quad (4)$$

- if the CD driver (i=5) has to be disassembled, the controller (i=3), the video card (i=4) and the cables (i=8) have to be disassembled too:

$$Dd,5(k) = 1 : D,3(k) = Dd,4(k) = Dd,8(k) = 1 \quad (5)$$

- if the disc driver (i=2) has to be disassembled, the controller (i=3), the video card (i=4) , the CD driver (i=5) and the cables (i=8) have to be disassembled too:

$$Dd,2(k) = 1 : Dd,3(k) = Dd,4(k) = Dd,5(k) = Dd,8(k) = 1 \quad (6)$$

3.2 Operational control

The stock volume of components of type i ($V_{st,i}$) depends upon the number of products that are processed to recover components i (F_s) and the demand flow of these components ($F_{d,i}$). After m time intervals, the stock volume is the accumulated difference between the number of component i disassembled to reuse them and the number of components i distributed to be reused:

$$V_{st,i}(m) = \sum_{k=1}^{m} [D_{d,i}(k).D_{r,i}(k).F_s(k) - F_{d,i}(k)] + V_{st,i}(0) \qquad (7)$$

where $V_{st,i}(0)$ is the stock volume at the beginning of this batch of products.

If the stock volume is too small to fulfil the demand at any time interval, no parts will be supplied:

$$Vst,i(m) \prec Fd,i(m) : Fd(m+1) = 0 \qquad (8)$$

If the stock volume of component i is crossing an upper limit value ($V_{ul,i}$), this component will not be disassembled to be reused anymore until the stock volume has become lower than this upper limit value:

$$Vst,i(m) \geq Vul,i : Dr,i(m+1) = 0 \qquad (9)$$

If the demand for component i is larger than the flow of disassembled components to stock, the stock volume will decrease. If a lower limit value of the stock volume ($V_{ll,i}$) is reached, in order to prevent unexpected deficits, the flow of components i that are distributed to be reused will be zero for the next time interval:

$$Vst,i(m) \leq Vll,i : Fd,i(m+1) = 0 \qquad (10)$$

If a component i is in stock too long, the technology may be changed so that this component type has lost value or even does not have any value anymore. Therefore, the time a component of type i is kept in stock may not exceed a limited value ($T_{sl,i}$). If this time period is exceeded, components of this type are not disassembled to be reused anymore:

$$k.\Delta T \geq Tsl,i : Dr,i(k) = 0 \qquad (11)$$

where ΔT is a basic time interval.

3.3 Economic control

The processor (i=7) is an essential component of a computer which is located on the motherboard (i=1). This means that if the processor is disassembled from the motherboard, the latter decreases in value. This can be expressed as follows:

$$Dd,7(k) = 1 : EV1(k) = EV1l(k) \qquad (12)$$

where $EV_1(k)$ is the economic value of the complete motherboard and $EV_{1l}(k)$ is the economic value of the motherboard without processor.

By disassembling the processor, the mass of the motherboard will reduce too:

$$Dd,7(k) = 1 : M1(k) = M1(k) - M7(k) \tag{13}$$

The total revenues (TR) that are obtained after the processing of products during N time intervals is determined by the revenues from the reused components (R_s) and the revenues (or savings) from shredding components or parts (R_{shrc}) and from shredding the remaining computers (R_{shr}):

$$TR(N) = Rs(N) + Rshrc(N) + Rshr(N) \tag{14}$$

After N time intervals, the revenues from the reused components or parts can be expressed by:

$$Rs(N) = \sum_{k=1}^{N} [\sum_{i=1}^{8} Fd,i(k).EVi(k)] \tag{15}$$

where $EV_i(k)$ is the economic value of component type i at time interval k. Although it is not necessary from a modelling point of view, it is supposed that the same components or parts from different computers have the same economic value. $F_{d,i}(k)$ is the flow of demanded components of type i during time interval k.

The revenues after N time intervals from the shredded components or parts that are disassembled, is determined by the mass of these components:

$$Rshrc(N) = \sum_{k=1}^{N} Fs(k).\{\sum_{i=1}^{8} Dshr,i(k).Mi(k).Pshrc,i(k)\} \tag{16}$$

where $P_{shrc,i}(k)$ is the price that is obtained for the shredded materials of component or part i and M_i is the mass of a component of type i.

The revenues after N time intervals from the remaining products that are shredded can be expressed by:

$$Rshr(N) = \sum_{k=1}^{N} Fs(k).\{[Mcomp - \sum_{i=1}^{8} Dd,i(k).Mi].Pshr(k)\} \tag{17}$$

where $M_{comp,j}$ is the total mass of a computer and P_{shr} is the selling price obtained for shredded computer materials.

The total costs after N time intervals consist of costs for disassembly, costs for shredding and separation, stock costs and miscellaneous costs:

$$TC(N) = TCdis(N) + TCshr(N) + TCst(N) + TCmis(N) \tag{18}$$

The total disassembly costs are determined by the activities for the components that are disassembled:

$$TCdis(N) = \sum_{k=1}^{N} Fs(k).\left[Cdis,o(k) + \sum_{i=1}^{8} \{Dd,i(k).Tdis,i(k).Cdis(k)\}\right] \tag{19}$$

where $C_{dis,o}(k)$ are the disassembly costs for the components which have to be removed compulsorily from the computers, $T_{dis,i}(k)$ is the time to disassemble components of type i and $C_{dis}(k)$ are the disassembly costs per time unit.

The total shredding costs are determined by the remaining mass of the computer after the components are disassembled:

$$TCshr(N) = \sum_{k=1}^{N} Fs(k).[(Mcomp - \sum_{i=1}^{8}\{Dd,i(k).Mi\}).Cshr(k)] \quad (20)$$

where $C_{shr}(k)$ are the costs to shredder per mass unit.

The total stock costs are determined by the space that is allocated for the stock (A_{st}) and the missed interest income of the capital that represents the economic value in stock.

The miscellaneous costs consist of various costs that have an impact on the final result. Some of these costs are:

- administration costs
- building costs
- energy costs
- financial costs

The total revenues and the total costs that result from processing the products determine the net revenues:

$$NR(N) = TR(N) - TC(N) \quad (21)$$

Equation (21) is optimised, so with respect to $D_{d,i}$, $D_{r,i}$, $D_{shr,i}$ and D_{shr}, the net revenues will be maximum.

4 Simulations

With the derived mathematical model some preliminary simulations have been executed by using the optimisation program AIMMS (Advanced Interactive Multidimensional Modelling Software) in order to see that the model generates values that are expected. AIMMS is an algebraic modelling software tool that contains a data driven user-interface builder.

In a first run, fixed input data were used, independent from time. Furthermore it is supposed that all components or parts that are disassembled have a demand and the structure of the computer is fixed. The values of the data are given in Table 1.

The result of the optimisation process indicates that disassembly of all components is the most profitable. The revenues obtained with the calculated scenario show that these are extremely high, see Table 2, which is caused by the assumptions made.

Table 1 The values of the input data used in the first simulation run

quantity	*component*							
	mother-board i=1	*hard disc driver i=2*	*controller i=3*	*video card i=4*	*CD drive r i=5*	*floppy disc driver i=6*	*processor i=7*	*cables i=8*
P_i (€)	5.68	5.68	2.25	5.68	14.77	2.25	3.40	0.00
M_i (kg)	0.50	0.60	0.15	0.15	0.65	0.01	0.07	0.15
$T_{dis,i}$(h.)	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02
M_{comp} (kg)	6.0							
P_{shr} (€/kg)	0.10							
C_{dis} (€/h.)	13.50							
$C_{dis,o}$ (€)	0.90							
C_{shr} (€/kg)	0.09							
C_{mis} (€)	0.35							

Table 2 The individual costs and revenues

costs and revenues	*value (€)*
total sales revenues (R_s)	39.77
total shredding revenues (R_{shr})	0.36
total revenues (TR)	40.13
total disassembly costs (TC_{dis})	4.32
total shredding costs (TC_{shr})	0.36
total miscellaneous costs (TC_{mis})	0.35
total costs (TC)	5.03
net revenues (NR)	35.10

The conclusion from this simulation run is very clear: some of the assumptions are not realistic because of the extremely high revenues. As it gives a direct relation between the sales price of each component and the total revenues from disassembly and selling, it is obvious that the selling prices of the components are too high. Moreover, the assumption that every component that is disassembled can be sold is also unrealistic and supports the outcome of the simulation, namely disassemble as many components as possible. Nevertheless, the obtained values agree with the values that were expected.

A second simulation run has been executed with the aim to calculate the minimum price for which components can be sold in order to obtain a prescribed net result. Three possible options have been simulated:

- all components are disassembled to be reused
- the motherboard, the hard disc driver and the floppy disc driver are disassembled to be reused
- the complete computer is shredded.

To be able to run these simulations, a relation between the prices of the individual components has to be given. Therefore the prices are related to the price of the floppy disc driver, see Table 3. In this run all other input data are equal to those given in the first run. The required net result per computer is € 27.27.

Table 3 The values of the input data used in the second simulation run

quantity	*component*							
	mother board i=1	*hard disc driver i=2*	*controller i=3*	*video card i=4*	*CD drive i=5*	*floppy disc driver i=6*	*processor i=7*	*cables i=8*
price weighting	2.5	2.5	2.0	2.5	6.5	1.0	1.5	0.00
M_i (kg)	0.50	0.60	0.15	0.15	0.65	0.01	0.07	0.15
$T_{dis,i}$(h.)	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02
M_{comp} (kg)	6.0							
P_{shr} (€/kg)	0.10							
C_{dis} (€/h.)	13.50							
$C_{dis,o}$ (€)	0.91							
C_{shr} (€/kg)	0.09							
C_{mis} (€)	0.35							

The results for the first and second option are given in Table 4. The third option, shredding the complete computer, will never result in the prescribed net revenues, as the given input values do not allow it.

Table 4 The minimal prices for two options: all components are disassembled to be reused and some components are disassembled to be reused

	all components disassembled	*some components disassembled*
component	*minimal price (€)*	*minimal price (€)*
motherboard	6.27	12.50
hard disc driver	6.27	12.50
controller	2.50	-
video card	6.27	-
CD driver	2.50	-
floppy disc driver	2.50	5.00
processor	2.50	-
cables	2.50	-

From the simulations it may be concluded that the results are in accordance with values that were expected.

5 Conclusions

In order to be able to develop a decision support model for the recovery options for the components of various goods, a mathematical model for the recovery of computer components has been considered.

By means of various simulation runs with this model, it was observed that the obtained results were equal to the results that were expected.

This study will be continued with further simulation runs that will have more realistic parameter values in order to get more insight into the model. Furthermore, the model will be extended in such a way that decisions concerning components of other products can be supported as well.

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