INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003

ENGINEERING PARADIGMS FOR SUSTAINABLE DESIGN OF MOBILE TERMINALS

Pia Tanskanen, Roope Takala

ABSTRACT

End of life stage of the product can be divided into three different stages: take-back, separation and recycling. Each of these phases is of different nature and requires diverse actions. An economic model of EOL has been developed for finding out the bottlenecks in efficient recycling of obsolete products. Engineering process driven possibilities for enhancing efficiency in the EOL phase are discussed and paradigms arisen in the design for environment process are introduced. The main issue is that the time lag from design to recycling is typically several years. Another paradigm arises partly from the rapid development of recycling processes. These paradigms lead to the fact that in practice the use of traditional design-for-environment lists and guidelines will only result in compromises. With these compromises a product is designed to diverse end of life processes but it is not optimal in any of them

Keywords: design for disassembly and recycling (DDR), design for the environment, electronics recycling, end of life value

1. Introduction

Today’s successful product development requires a holistic approach, embracing the notion of the entire product life cycle. This life cycle of a product can be divided into different stages such as product conception, system and detail design and sourcing, production and delivery, active use and end of life (EOL). [1] In addition to these raw material extraction and component supplier activities can be included into the stages of a product's life cycle.

The end of life stage of a product begins when it is discarded by its user and becomes a waste. European union has defined electronics as one of the main waste streams and set the producer responsibility for this stream. The main focus of the legislation is to direct the waste flows from the landfill to recycling and increase the recycled material content of the product. [2]

Requirements in the forthcoming legislation include different topics, such as collection of the obsolete products from the consumers, increased information on the material content and design of the product in such a way that it helps in recycling the material content. These distinct requirements cannot be handled with the same approach as they focus on organizational, material and product structure/design related issues. Typically in a company different parts of the organization are contributing to these areas. For further understanding on how the complex environment of interactions between technical, environmental, socio-economic and legislative factors in take-back and end of life treatment can be affected, a structure is needed.

The challenge in including considerations related to the end of life stage in the product creation is in the long period of time between the design and the need for end of life features. Therefore the motivation for example for increasing the cost at the product creation for a feature, which will be used possibly in the future at the end of life stage, is low. The best practice to treat obsolete electronics products is not yet found, which makes it also difficult for today's engineers to design a product for these future processes.

A simplified economic and logistical model for an EOL process for mobile terminals is presented. This helps to identify the places for improvement and also the different players needed for each phase. The complex end of life system can be divided into three distinct stages with different characteristics and stakeholders. The first stage is the organization of the collection process. The second is identification, structural pretreatment and fragmentation of the product. The third stage is the recycling or disposal processes of the product material content. The target for the whole end of life system is closing the loop of the material circle.

The model is not static and it changes as each phase has an influence on another. Conflicts arise due to the constant changes in the different stages of the EOL process. New technologies and methods for tackling the EOL process are put forth almost daily. Many of these proposals are mutually exclusive causing problems in setting generic design guidelines for Design for Disassembly and Recycling (DDR). Examples of technical and engineering process driven possibilities in promoting economic implementation of the EOL processes are presented via examples. These examples include an automatic take-back machine and different active disassembly mechanisms for mobile terminals.

Currently both the electronics and the recycling industries are going through a fast development period. It will take time for the formation of a balance between the product design and EOL treatment stages of the product life cycle. In practice this can be seen so that Design for Environment (DfE) guidelines are changing dramatically. For example the "less screws" type of approach is not needed when the active disassembly type of technologies are taken into use. Another example is the combining of different kinds of plastics, which according to the traditional DfE rules is not accepted, but is not necessarily a problem when modern plastic separation processes are utilized. Building a knowledge and practice of sustainable design in the engineering processes is therefore not just one single effort but a continuous process. In building up the design culture of sustainable products, a modular approach for the end of life process can be exploited. In this way the changes and upgrades in different phases can effectively be taken into use.

2. EOL process

The end of life activity for mobile terminals can be modeled into a multi-step process, shown in figure1. This top-level process covers the route of activity from when the user of a mobile terminal decides to dispose a mobile terminal that has become obsolete to the final recycling of the product material content.

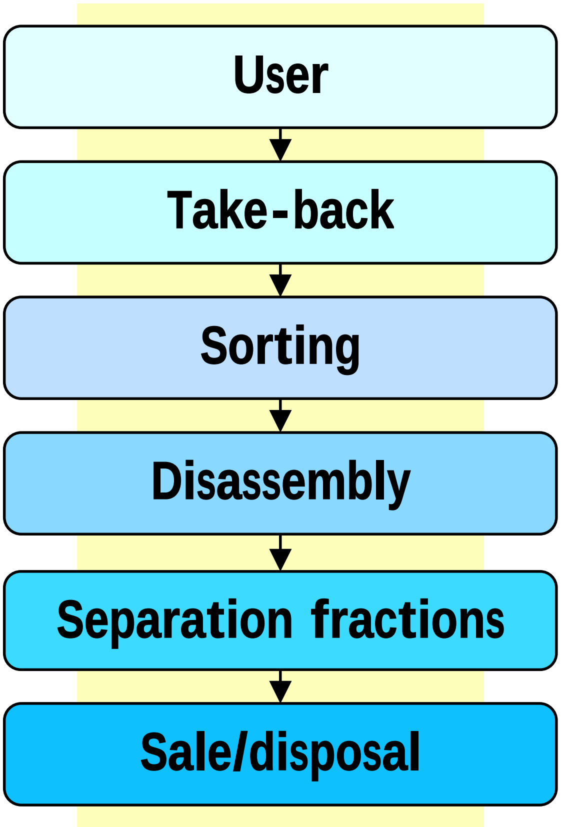

Figure 1. EOL process

The user initiates the EOL process by returning his mobile terminal to a take-back operator. There are a number of possible take-back routes and operators for mobile terminals. [3] The take-back operator can be the mobile terminal vendor, who takes the old terminal back as a part of the purchase of a new one. Alternately a dedicated take-back operator model is also feasible or the producer may also collect the products. Currently most terminals are returned through the vendors as the old products still have a certain value.

After the user has deposited the mobile terminal into the EOL process through the take-back scheme, terminals move into sorting. Products are sorted according to the economic value they possess or by the recycling process they require. For example the shredding process may cause terminals with large magnesium parts to ignite, and thus such products need to be separated for an alternative process.

In the disassembly phase the mobile terminal is opened to allow for key components to be separated. The components are separated according to their economic value and the disposal process. For example the printed wiring board, which contains precious metals is separated and sold to precious metal recovery. Batteries are separated according to their chemistries and sent to corresponding recycling facilities. Legislation and health & safety issues also play a role here, as toxic substances need to be removed for appropriate treatment.

The final step of the process is reuse of the different material fractions. This includes the logistics and businesses for trading of various fractions. Some of the fractions, such as resin and fiberglass, need to be sent for appropriate disposal whereas others, like plastics and metals, have a clear economic resale value. In the recycling, the material has commercial value when it is not more expensive than a virgin material and possesses as good material properties as virgin material does.

Each of the process steps described above is of different nature. Take-back and collection requires a logistics structure and education of the end users. In the sorting phase the information of the material content and treatment profile of the product must be available. In the disassembly phase the structure of the product, ease of disassembly, is crucial and in recycling the material content and the additives in different materials define the reuse potential of the material.

3. Economic and logistical model of EOL

Based on the process described previously, an economic model for the EOL process of mobile terminals is presented. The model, shown in figure 2, describes the cash flows during the process. The economic model is important for determining how the EOL treatment market can be separated vertically among different players in this business field. The model also helps in identifying the points where negative cash flows can be minimized and positive maximized. As such it is an effective tool for targeting design improvements and the planning of EOL activities for new products.

Currently the main issues in setting up the EOL treatment businesses is the formation of organizations that have enough vertical dimension to include the cash consuming activities and cover the costs with the profits from the ones that have a positive cash flow. The difficulty is in the economics of the first steps in the EOL process: take-back, disassembly and component separation offer little economic benefit as such. These steps require significant financial input into take-back and pretreatment logistics and dedicated disassembly and component separation facilities. The economic benefits are only available downstream in the purification and sale of the raw materials of the terminals. The treatment of hazardous waste and disposal of the non-reusable components in a landfill incur additional cost to recyclers. The positive cash flow comes from the sale of recovered raw materials and from the direct reuse of product components. Incineration of components as fuel for power and heat production is generally regarded to be an economically zero sum activity.

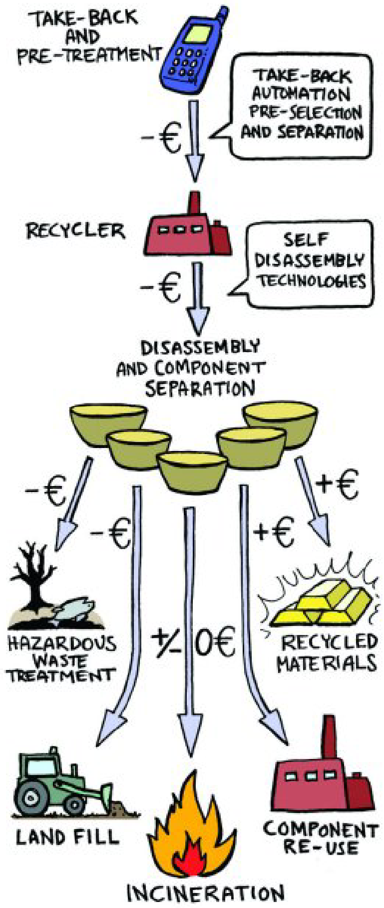

Figure 2. Economic model of EOL

The model also describes the top-level logistics of the mobile terminal EOL process. The delivery of mobile terminals to a large number of customers is efficiently done through stores but take-back and reverse vending is rather problematic. Products incorporate a wide range of materials and components that may require different disassembly and recycling processes. Getting mobile terminals into the recycling process is a major task. The logistics of refining the obsolete products into usable materials is reasonably well specified but the model does offer some suggestions for streamlining the logistics process. Currently logistical costs can easily exceed the revenues in the recycling process, if the chain is not optimized. There is some indication on where a vertical business structure would be more beneficial than the currently highly segmented field.

4. Technologies

To promote an economically feasible EOL process several steps can be taken in product development. Three levels of engineering and design applications of the economic model of EOL have been identified:

1. Take-back automation technology.
2. Recycling processes.
3. Self-disassembly and component separation technologies.

To demonstrate an application of take-back automation, a reverse vending machine for mobile phones, was developed by Nokia Research Center, Tomrasystems and Helsinki University of Technology. The prototype device, shown in figure 3, demonstrated how take-back can be facilitated while simultaneously attending to the need to sort the returned phones. The parameters for sorting can be configured remotely to allow for rapid changes in the sorting based on factors such as the disassembly processes available or the manufacturer of the phone. This increases the value of the fractions and reduces the cost of manual work at the disassembly and recycling plants. The device also generates an information flow on the phones returned to facilitate reporting to legislators.

The prototype machine demonstrates the basic functionality of a take-back machine with identification and separation of the collected mobile terminals and batteries. The identification of the mobile terminals is done with a dual system of automatic and user identification. Automatic identification of terminal model is done by comparing its weight to a database of mobile terminal weights. The person depositing the terminal does the final confirmation of the identification. This makes the returning process slower than that of bottles or aluminum cans, but as only one phone is generally returned at a time this was not seen as a problem. Additionally, by having the user engaged in discourse with the reverse vending machine, it is possible to provide him with information on the recycling process or ask for his phone number for sending a SMS voucher as a thank you for the transaction.

Figure 3. Prototype of automated takeback machine

Currently two lines for gaining efficiency in mobile terminal disassembly are pursued. The first is that of generating more sophisticated disassembly processes. The second is designing parts of the disassembly processes into the products themselves.

Several cases of improved disassembly processes have been demonstrated. An example of these is the EcoElectronics Oy company's disassembly process based on inductive heating. In this process the metal screws in a mobile terminal are heated inductively to reduce the structural strength of the plastic screw boss. A small shock after heating disassembles the phone effectively. After the covers are disassembled from the electronics, these two fractions can be routed in different processes. [4] In the figure 4 different automated disassembly processes for mobile phones are described.

A built in disassembly system is a feature or component that can be triggered by a simple outside force to open the phone structure. In previous work several designs that accomplish this task have been presented. [5, 6, 7, 8] Common triggering forces for self-disassembly are a magnetic field and heat. Even chemical or biological agents can be considered

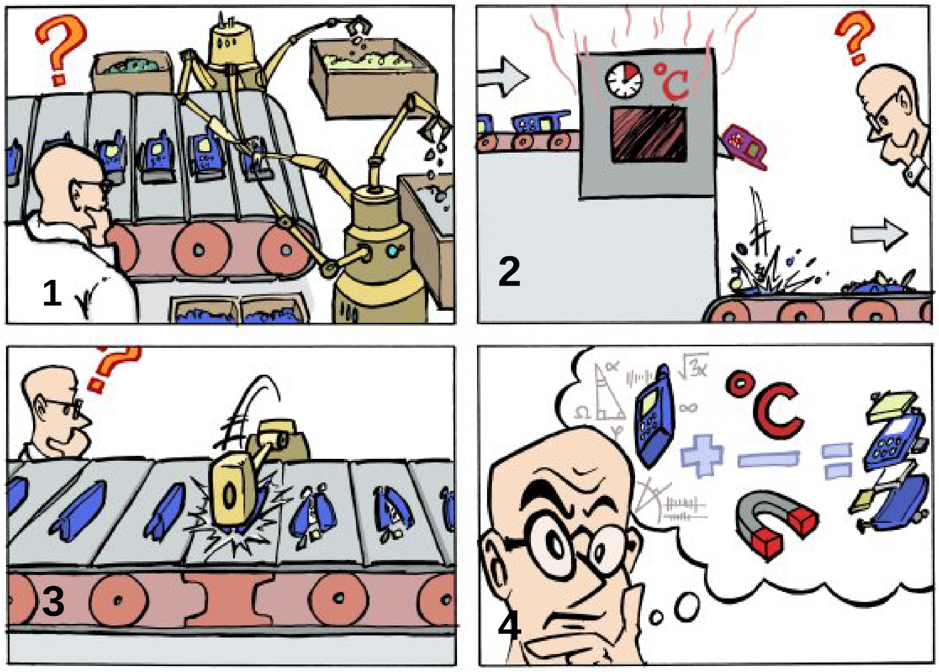

Figure 4: Automated disassembly possibilities for a mobile terminal. 1) Robotic disassembly 2) induction heating disassembly 3) mechanical impact disassembly 4) build-in disassembly system

5. Design Paradigms

End of life treatment of electronics is a rapidly changing and developing area where new technologies and practices are constantly being created. For this reason the feedback information from the end of the life processes to the product design is not up to date. The delay between the design of a product and its recycling is several years which also brings uncertainty for the compatibility of these two ends of the products' life cycle.

Recycling can be approached from two directions: how to design a product, which can be easily recycled, and how to build a recycling process that works in an efficient way. The challenge is to approach the same solution from two directions and this is a cause of a major design paradigm. The products' design has to be optimized for example to facilitate a manual sorting process. However, if the product will be sorted automatically with the automatic take-back machine, it is bound to be sub-optimal.

The next paradigm is related to general design guidelines. Gradually DfE has been implemented in the design guidelines within the electronics industry. In practice at the beginning this means the use of lists and guidelines, e.g. stating use only one type of screws, minimize the amount of screws, not combining metal and plastic material. These instructions are good for manual disassembly but not for automated processes. But as we have shown here, the end of life processes for disassembly and material separation are developing very fast. The future in the recycling industry cannot rely on manual work. For this reason the use of general guidelines result in "good compromises". In these compromises a product is designed to have some favorable characteristics for diverse processes but is not optimized for any processes. The difficulty at the moment is to design for something for the industry, which is not yet settled. This uncertainty prevents the introduction of rethinking in the end of life design and companies are adhered to minor amendments.

6. Obstacles for electronics recycling

Based on the analysis of the EOL field with the EOL process and economic model in mind several bottlenecks or obstacles for efficient EOL activity have been identified.

- Recycling of engineering plastics

The need for recycled plastic has not been growing. Impurities in the material prevent using it for high value applications, which is the target in recycling. This obstacle causes another paradigm in design for recycling. Disassembly as such for mobile terminals is not needed if the plastic material from the cover parts is not recycled. The plastics can be used as fuel in the precious metal recovery, for which purpose the product needs not be disassembled.

- Efficient take back

The environmental efforts described before are necessary, but it is all in vain if the consumer is not informed about the take back processes available. In practice this means that people are either not returning their products at all but keep them in museums at home, or in the worst case are disposing them with the household waste. In the latter case the products would end up to be landfilled and precious raw materials would be lost. Efficient, large-scale collection of handsets remains the biggest obstacle to effective recycling.

The processes after collection, sorting and disassembly, are labour-intensive and expensive. Sorting is needed in all of the recycling scenarios as different products need different treatment routes and also the cost for the treatment in many cases is dependent on the treated goods.

- No prevalent process technologies for disassembly / material separation to design for.

Designing a product for a specified recycling process is a typical chicken and egg situation. The recycling industry will not invest in special process lines if constant product flow cannot be guaranteed. From the OEM industry point of view design for a certain process is risky, if there are not global and reliable treatment facilities for these products. The best and commonly accepted technology needs to be defined so decisions at both ends can be made.

7. Conclusions

Splitting EOL into stages helps define bottlenecks in the process but also brings up some problematic paradigms in designing for recycling. The main issue is that the time lag from design to recycling is typically several years. This time lag compromises the feedback of design guidelines and restrictions from the EOL stage to product development. The engineering knowledge of a product has dissipated and is often lost by the time the feedback from the EOL process is available. The products in the recycling process today have not been in production for years and the design understanding that once existed for them has been lost. Vice versa designers today cannot anticipate the restrictions and design guidelines that should be available for designing their products to be recyclable in the future.

Another paradigm arises partly from the rapid development of recycling processes. The different processes have conflicting design restrictions and guidelines. The recycling process needs to be selected at design stage, but with the rapid changes in the industry the selection of a recycling process is difficult. The recycling process for which a product is designed for today may not exist as such when the product is actually recycled in a few years.

These paradigms lead to the fact that in practice the use of DfE lists and guidelines, stating for example to use only one type of screws, to minimize the amount of screws, and not to combine metal and plastic material will only result in compromises. With these compromises a product is designed to diverse processes but it is not optimal in any of them. The difficulty at the moment is to design for recycling processes, which is in constant change. This uncertainty prevents the introduction of rethinking in the end of life design and companies are adhered to minor amendments.

By understanding the components of the EOL phase in a product’s lifespan it is possible to identify and focus on the engineering possibilities in enhancing the efficiency of EOL activity. Breaking the EOL process up into different activities it is easier to find areas for the development of the EOL processes. This view also helps identify common engineering guidelines for different steps and ways of tackling the EOL process steps. The analysis of the activities and opportunities for EOL highlights the need for planning, and the criticality of some engineering decisions on the efficiency of the EOL treatment of mobile terminals and other similar products.

References

[1] Ulrich K., and Eppinger S., Product Design and Development, McGraw-Hill, Singapore, 1995.

[2] Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE)

[3] Lonn S., Stuart J. and Losada A., How Collection Methods and E-commerce Impact Product Arrival Rates to Electronics Return, Reuse and Recycling Centres, Proceedings of 2002 IEEE International Symposium on Electronics & the Environment, San Francisco, CA, USA, May 6-9, 2002 pp.228-241

[4] Leskinen, K., Tanskanen, P., Takala, R., Ahonen, H., Disassembly of mobile terminals with induction heating, Proceedings of International Electronics Recycling Congress, Basel, 2003

[5] Tanskanen P. and Takala R., Integrierte Demontgemechanismen für Tragbare Elektrogeräte, Submitted to Z. Konstruktion, Dec03

[6] Tanskanen P., Takala R., Concept of a mobile terminal with an active disassembly mechanism, Proceedings of International Electronics Recycling Congress, Davos, Switzerland, January 2002.

[7] Arnaiz, S., Bodenhoefer, K., Constantin, H., Hussein, H., Irasarri, L., Schnecke, D., Tanskanen, P., Active Disassembly Using Smart Materials (ADSM), a status report of the ongoing EU project, Proceedings of Care Innovation, Vienna, 2002

[8] Takala, R., Tanskanen, P., Outlining Opportunities of Engineering Processes and Technology on Environmental Impacts of the End of Life Treatment of Mobile Terminals, Proceedings of IMAPS Nordic Annual Conference, Stockholm, September, 2002

Pia Tanskanen
Nokia Research Center
PO BOX 407
00045 NOKIA GROUP
Finland
Phone: +358 7180 37628
Fax: + 358 7180 37128
Email: pia.tanskanen@nokia.com