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End of Life Management of Automation and IT Devices

P.Kopacek*. B.Kopacek**

* *Intelligent Handling and Robotics (IHRT) , Vienna University of Technology*
Favoritenstrasse 9-11, A – 1040 Wien, Austria ;e-mail : kopacek@ihrt.tuwien.ac.at
*** Austrian Society for Systems Engineering and Automation (SAT)*
Gurkgasse 43/2, A-1140 Wien; e-mail: bernd.kopacek@sat-research.at

Abstract: End of Life Management (EoL) will be more and more important not only for electr(on)ic, especially IT, devices but also for automation devices. Therefore the main goal of this contribution is to give an overview about the state of the art and further development trends in this field. In this paper, a first attempt for an evaluation model for finding optimal End-of-life strategies for specific devices is developed and presented. Based on this model, important devices within the modern automation technology are analyzed and ranked according to different criteria. The variety of the chosen factors shows, that it is very important to understand the products and the surrounding environment in detail.

Special emphasis will be on new approaches for EoL of process- and manufacturing devices like automated extraction of rare materials from scrap, using electronic scrap for education in automation, economical aspects of disassembly with special emphasis to SME`s and developing countries.

Keywords: End of Life Management, Recycling, Precious Metals, Reuse, Education.

1. INTRODUCTION

The European Directive "Waste from Electric and Electronic Equipment – WEEE" (European Commission, 2008) were responsible for 8,3 to 9,1 million tons of waste within the EU in 2005. This so called WEEE Directive was implemented by the EC in order to ensure an environmental friendly treatment of end-of-life electrical and electronic equipment. Waste from Electrical and Electronic Equipment (WEEE) is the fastest growing waste stream in Europe. Worldwide figures are ranging from 20-50 million cubic meters e-waste. About 5% of the total waste stream can be derived from End of Life of Electr(on)ics including Automation and IT devices. In the European Union alone more than 17 million tons of electrical and electronics will become obsolete this year. Predictions forecast a growth to 12,3 million tons till 2020, which means an expected growth rate of around 40-50% (European Union, 2003a, 2003b).

Rapid changes of consumer demands have affected that WEEE represents the fastest growing waste stream in the EU with between 3 and 5 % per year, which means that it doubles every 12-15 years. In average every three years the IT equipment is exchanged by rapid growing turnover rates. The life cycle of Automation and IT devices is decreasing continuously, products are exchanged faster and faster. Obsolete equipment ends up as e-waste which leads more and more to a global problem: With its complex composition of materials, components and hazardous substances, it constitutes a considerable threat to the environment. About 70% of the heavy metal in landfill is directly coming from e-waste.

Automation devices represent a large and still growing part of this waste from WEEE. To handle the devices in their "End of Life – EoL" in an economic and ecologic useful way, it is necessary to know about the possibilities and limitations. There exist a lot of different problems, but also a lot of chances to raise the standard of nowadays waste treating efficiency.

One dimension is the ecologic aspect. The handling of the devices should not affect the environment in any negative way. That means hazardous materials, like lead, should be prevented, but when it is necessary, then they have to be disposed in a way that as less as possible ecologic pollution occurs. Non-hazardous materials have to be reused or recycled as much as possible.

The goal of the economical dimension is valuable resources should not be wasted. Destroyed or worn out devices contains material which can be reused or recycled. These opportunities are nowadays not frequently taken into account. As the price for natural resources will increase in the future, it will be more important to put effort on a closed material loop.

Electr(on)ic products like automation and IT hardware consist of a high amount of diverse metals. According to several surveys e.g. mobile phones have a metal content of 25 % (accumulator and recharger not included), mainly copper (Cu), iron (Fe), nickel (Ni), silver (Ag) and zinc (Zn). Though the absolute amounts of each device regarding the most valuable elements are low (16 gCu, 0.35 g Ag, 0.0034 g Au, 0.015 g Pd, and 0.00034 g Pt) this adds up to e.g. 0.35 t of platinum based on estimated 1 billion of cell phones in 2010.

Next to that a reproduction of electr(on)ics needs about 10 times the final weight on abiotic natural resources (especially crude oil). That means that a TV set of about 50 kilos consumed about 500 kilos of raw materials during the production phase. Hence it is clear that landfilling of e-waste is an environmental crime. Countries all over the world therefore reacted and developed a legislation which should lead to a "greening" of e-waste.

Until now Recycling was the most common method for EoL. Approximately 20 years ago the research in Reuse started with (semi- automatic) disassembly mostly for electr(on)ic devices (Duta, L.et.al; 2011; Puente, ST. et.al.; 2008), Automation devices were included 6 – 8 years ago.

The main goal of this paper is to give an overview about the state of the art and future-development trends of End of Life management and Resource Efficiency of Automation and IT equipment.

2. STATE OF THE ART

2.1 EoL Strategies

There are three basic strategies in End-of-Life Management (the "3-R" possibilities): Reduce, Reuse and Recycle (United Nations Environment Programme, 2009). Additionally, "Recover" can be added to enhance the method to a "4-R" theory: Reduce, Reuse, Recycle and Recover. Recover describes the energy recovery from the waste stream. This possibility should not be left out. As the fifth and last option, the strategy landfill is mentioned. This is not an EoL option in the narrow sense, but it is still very important in waste treatment nowadays (Fig.1).

On the top of the pyramid are the most preferable strategies, while the least preferred options are located on the basis of the pyramid. (European Union, 2008).

Fig. 1: End-of-Life pyramid (European Union, 2008)

2.2 An example

There exist several approaches in literature to support the decision for a special EoL strategy. The costs and benefits of different strategies for the products are calculated and the one with lowest costs (or highest benefits) is chosen. One approach is the Ecological and Economical (Eco^2) assessment methodology.
This method is based on the "Eco-indicator 99" methodology an approach to describe the economical and ecological impact of products during the whole life cycle (PRé Consultants B.V.,2001).

The aim of the Eco^2 assessment methodology is the evaluation and ranking of different EoL strategies of WEEE products. There are two major criteria; the economic factor on the one side and the ecologic factor on the other side.

One problem is that not all devices used in automation industry are within the scope of this directive. Many components that are important for the EoL of automation devices are not mentioned by this approach. Furthermore the result of the EoL-process is described by a monetary value. Without knowing the detailed circumstances, like the machinery of the recycling company, it is not possible to find exact cost-benefit relations. Therefore, it is just possible to find average results, which have to be detailed by the specific company.

Therefore in the following a simple and practicable method will be introduced (Haas, 2011).

3. THE NEW METHOD

To decide about the most profitable EoL strategy, it is necessary to evaluate the different devices regarding their profitability. For this analysis, eight important criteria are chosen to allow a quantitative rating.

3.1 Criteria

Amount of valuable material
This criterion is highly correlated to the size and weight of a device. Units with higher amounts of included raw materials, like metals, are more efficient to recycle than other units. Therefore, this is a criterion for a higher profit from the recycling alternative.

Expected amount of devices
This amount is an important point, where automated lines (especially for the disassembly phase) are getting more efficient than manual recycling or reusing.

Complexity of disassembling
This factor is especially for recycling important, as the disassembling process is responsible for the main part of the occurring costs. Additionally, units which require complex disassembly tasks are not as easy to summarize with other devices to disassembly families.

Here the time and costs of the disassembling process are included. Simple disassembling needs lower monetary costs (in form of machine costs, costs for workers and all side costs) and less time than a complex product.

Pureness of disassembling

For the efficiency of a recycling process it is vital to produce materials, which are as similar as possible to raw materials, which are used for new products. Materials, which cannot (or just after long processes) be used as inputs for production, are less valuable than other materials in general. This aspect will be called "pureness of disassembling".

Costs of a new device

This factor is not dependent on the old devices, but on the market situation for substitutes for these units. The costs of a new device are not necessarily the costs of the same unit, but can also represent the costs for a newer (and better) device, which can fulfill at least the tasks of the old device. These costs are important for the efficiency of the reuse option. Low costs tend to result in a reason against reusing and vice versa.

Evaluation marks

Five different categories are defined to rate and rank the influences of the above mentioned factors on the different devices. Very good, good, average, bad, very bad, no influence

3.2 The Method

Each product gets for each criterion an amount of points w_i during the following evaluation. All points together show the value of the product for the EoL stage.

The criteria are weighted by a factor q_i, because the various criteria might not be equally important. The sum of the weight factors is 1. Finally, the points are normalized to a scale from 0 to 1, to have a better comparability between the different devices. Formally, the EoL value (EoLV) of a single device k resulting from eight criteria and 5 evaluation marks can be written as:

$$EoLV_k = \frac{1}{5}\sum_{i=1}^{8} q_i \cdot w_i \tag{1}$$

q_i...Weight of the criterion i
w_i...Evaluation points of the criterion i

$$EoLV_M = \sum_{k=1}^{n} EoLV_k \tag{2}$$

From (1) and (2) follows

$$EoLV_M = \frac{1}{5}\sum_{k=1}^{n}\sum_{i=1}^{8} q_i \cdot w_i \tag{3}$$

The value $EoLV_M$ represents the value of an automation or IT device after use. This value is normalized for comparability .

Currently, no reliable statistical data are available for weighting the importance of the various criteria. Therefore, in the following evaluation, the weight factors q_i are the same for each criterion, which represents an equal distribution of importance. Formally written, the weight criteria for this case are:

$$q_1 = q_2 \; ... = q_8 = \frac{1}{8} = 0{,}125 \tag{4}$$

3.3 An example: Selected Automation devices

The evaluated devices are widely used in the automation industry (Kopacek, P. and B. Kopacek, 2012a):
Sensors (thermocouples, Hall sensors); analogue controllers, PCs and PLCs, actuators (electric motors, cylinders, valves), printers, keyboards, screens, cameras, racks, cables.
The results are shown in Table 1.

Devices with an $EoLV_M$ of 650 and more points can be used efficiently with the current available recycling and disassembly technologies. These devices are: PCs and PLCs, electric motors, printers, racks and control cabinets.

Table 1 EoLV of Automation components

Ranking	Device	$EoLV_M$
1	Racks and Control cabinets	775
2	PCs and PLCs	700
3	Printers	650
4	Electric Motors	650
5	Cables	625
6	Cylinders	625
7	Valves	600
8	Analog controllers	525
9	Screens	500
10	Thermocouples	450
11	Hall Sensors	450
12	Keyboards	425
13	Cameras	325

Devices with an $EoLV_M$ between 500 and 625 points are in between, so the decision has to be made dependent on the product. These devices are: Analogue controllers, valves, cylinders, screens, cables.

Devices with an $EoLV_M$ of less than 500 points are currently not cost-effective to use in the EoL strategies. These devices are: Sensors (Thermocouples and Hall sensors), keyboards, cameras….

4. EoL OF INDUSTRIAL ROBOTS

An industrial robot as a mechatronic system consists of the mechanical part, the axes including the gears, the gripper and the gripping devices; the electrical part (drives and control unit hardware) the encoders and sensors as electromechanical devices and the software of the control unit as the IT part. Control Engineering is included in the position controller.

Nowadays there are worldwide approximately 1.2 millions of industrial robots in use. There is no statistic about the age of these. According to our experience the average age is approximately 12 years.

As an example for EoL of industrial robots a Sony SRX-611 SCARA robot (selective compliance assembly robot arm), manufactured in 1990, was chosen. It consists of 3 rotation axes and one linear vertical axis. Two of the rotation axes are moving the robot gripper. The third rotation axis can move more than 360°, so it is possible to assemble screws or other parts. The vertical axis moves the gripper in the z direction. The high speed robot is developed mostly assembly of small parts, inspection and handling tasks. The drives are AC servo motors equipped with absolute encoders. The maximal payload is 5kg (Kopacek, 2012b).

The robot consists of 7 main units, the base, the arm 1, the arm 2, the gripper, the control unit and racks, other parts as well as cables. In detail: Body (mechanical construction), drives (electric, hydraulic), gears, gripping devices, control computer (rack, cables, PC, printer), teach panel, sensors, peripheral devices (clamping, fences, cables).

Currently it`s not economic to recycle electrical drives, teach panels and racks and cables from the control computer. All others are efficient recyclable with the currently available recycling and disassembly technologies.

5. A NEW APROACH TO EoL

A definitely new approach for Reuse is presented. Mostly in developing countries laboratory equipment for education and research is very expensive. Therefore we produced such equipments form hard- and software scrap.

The experimental, build and process methodology was involved to develop a "Piano RObot Arm-UBT (PROA-UBT)". Electronic-Mechanical scrap has been used as a raw material for this project.

Fingers are made from old aluminium TV antenna, pulled by solenoids taken off from used door bells. Solenoids were placed in the modified metal construction taken off from old PC chassis (Kopacek et.al, 2013).

Also the interface between electromechanical part and controller has been developed from scrap. Relays, transistors, PCB were taken off from damaged UPS whereas bridge rectifier circuit, filters, fuser, cable plugs and LED`s were taken off from PCs power supply.

The low cost controller Arduino UNO together with the interface scheme and the bridge rectifier circuit is used to rectify AC voltage to DC 220V, in order to avoid vibration when the fingers hit keyboard.
This novel idea for reuse, matches perfect with research in University level education and the state of the arts in mechatronics. Furthermore it is a very good example for cost oriented automation (COA).

Tab. 2 Project costs

Elements Used	Price Average	Our Costs
1 x Old TV antenna	20.95 €/Piece	Nothing
6 x Door bells	6.00 €/Piece	Nothing
1 x Arduino UNO	10.00 €/Piece	10.00 €
1 x Bridge Rectifier	5.00 €/Piece	Nothing
1 x PC chassis	7.00 €/Piece	Nothing
8 x Transistor	1.50 €/Piece	Nothing
4 x Capacitor	2.50 €/Piece	Nothing
8 x Relay	6.00 €/Piece	Nothing
Fuse	0.50 €/Piece	Nothing
LED	0.84 €/Piece	Nothing
PCB	8.00 €/Piece	Nothing
Cable Plug	0.65 €/Piece	Nothing
Screws, Nuts & Bolts	1.50 €/Piece	Nothing
Wire	5.00 €/kg	Nothing
Wood	2.00 €	Nothing
Total Average:	138.94 €	10.00 €

Implementing EoL to develop this artefact, which is a test bed for the research under the assumption that the work hours are free of charge in form of student projects.

Next steps will be the development of similar laboratory equipment like a robot arm with three degree of freedom and two movable and one fixed fingers probably actuated by cheap servos or pneumatic muscles.

Usually students in frugal countries should be educated with up-to-date equipment but with our approach the students are learning by development such "scrap" equipment. First experiences show – the students are in favour.

6. EXTRACTION OF RARE MATERIALS

In 2010 the Raw Materials Initiative of the European Commission defined 14 critical raw materials, most of rare metals (including rare earths oxide) which are used for electr(on)ic devices belong to this category.
The idea is to recover rare and precious metals from WEEE including lamps and spent batteries by hydrometallurgical

processes. Furthermore to develop a mobile plant using hydrometallurgical processes to extract metals like yttrium, indium, lithium, cobalt, zinc, copper, gold, silver, nickel, lead, tin in a high purity (above 95%) from scrap.

By making this plant mobile (in a container) several SMEs can benefit from the same plant at different times and therefore limit the necessary quantities of waste as well as investments. By making the processes universal several fractions (lamps, CRTs, LCDs, printed circuit boards and Li-batteries) can be treated in the same mobile plant in batches (Kopacek,B., 2011).

Such a mobile pilot plant with a reactor size of 1 m³ has been developed that has been and still can be used for process development and optimisation. However in order to really demonstrate the stability, financial credibility and resource-efficiency of our innovative processes an industrial stationary plant as well as a full-scale mobile plant (2-3 m³ reactor) is currently in realisation.

Finally the previously developed processes of extracting yttrium, indium, lithium, cobalt, zinc, copper, gold, silver, nickel, lead, tin will be improved even more and new processes to recover additional metals which are still in this fractions (e.g. cerium, platinum, palladium, europium, lanthanum, terbium, …) from WEEE or other sectors (e.g. automotive, …) as well as innovative solutions for the integrated treatment of waste water as well as solid wastes will be developed.

The major differences between the 2 new plants built during this project in comparison to the existing mobile pilot plant are:

In the stationary plant a continuous process will be used instead of a batch process which increases the throughput a lot.

In the mobile plant the maximum size of reactors (approx. 2-3 m³) that still fit into a container will be used in order to maximise the throughput as well. Another emphasis will be put on professional feeding and unloading of the plant as well as on piping and fittings that withstand rough shocks during transport without being damaged.

For both plants the process will be highly automated with PLCs, etc. in order to decrease the personnel costs and even enable a process cycle without personnel during the night.

With the detailed process analysis in the laboratory and the practical experience gained from the pilot plant tests it will be possible to design and build a flexible mobile plant for hydrometallurgical extraction of WEEE in the coming year. Both plants (stationary and mobile) will be fully operational before summer 2014. The following demonstration activities will give useful indications about this new approach to the WEEE recycling business (Kopacek,B.,2013).

7. SUMMARY AND OUTLOOK

After a short introduction in the field of EoL for electr(on)ic and especially automation and IT devices a new method for choosing the optimal End-of-life strategy for automation and IT devices is presented. Based on this model, important devices within the modern automation technology are analyzed and ranked according to different criteria. The variety of the chosen factors shows, that it is very important to understand the products and the surrounding environment in detail. Further research is necessary to get statistical data for the determination of the weighting factors.

EoL of industrial robots is currently and will be in the future more and more important. As an example the EoL of a more than 20 years old robot is presented. Further work is going on to apply the new method on this example.

Finally two completely new approaches of EoL are presented. Mostly in developing countries laboratory equipment for education and research is very expensive. Therefore the idea is, producing such equipment form hard- and software scrap. As an example a piano playing device is presented.

To extract rare and very expensive raw materials from electr(on)ic scrap is also new. In the framework of two projects financed by the EU a mobile as well as a stationary plant is realised.

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