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Letters

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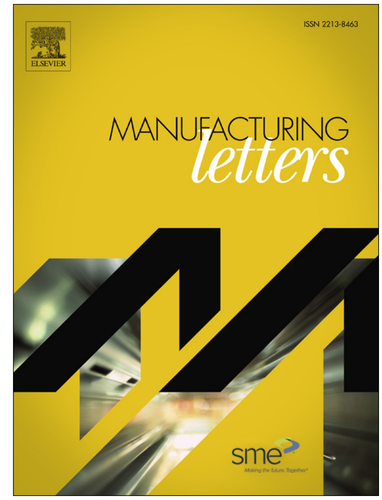

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Customized disassembly and processing of waste electrical and electronic equipment

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Abstract: Customized disassembly and processing of Waste Electrical and Electronic Equipment (WEEE) to meet the legislative and economic considerations of different stakeholders is a challenging research issue. This paper presents a new customized disassembly and processing approach for WEEE based on the Analytic Hierarchy Process (AHP) and Particle Swarm Optimization (PSO) algorithms. The merits of the approach include the flexibility to handle WEEE to meet various requirements of stakeholders, and the capability to achieve selectively optimized WEEE processing. The feasibility of the approach has been verified through an industrial case of Liquid Crystal Display (LCD) television WEEE processing. The case study shows that with the selective optimized plan, the potential recovery values during the disassembly process can be improved at least two times.

Keywords: Disassembly, Waste electrical and electronic equipment (WEEE), Analytic Hierarchy Process (AHP)

1. Introduction

Waste Electrical and Electronic Equipment (WEEE) have been growing much faster than any other municipal waste streams in terms of quantity and toxicity. WEEE contain hazardous materials posing considerable environmental and health risks, and valuable materials for recycle and recovery. To keep the Earth cleaner and sustainable, it has been attracting escalating attentions of researchers and practitioners to develop more effective End-of-Life (EoL) recovery technologies to follow stricter legislative pressures for environmental protection (e.g., WEEE Directive, RoHS Directive, Extended Producer Responsibility (EPR)) and to obtain better profit margins from WEEE recovery [1-3]. WEEE disassembly and processing can significantly facilitate the overhaul, repairing and re-use rate of valuable components, maximize hazardousness removal and improve material recovery rate from the disassembled components. Some pilot industrial cases have demonstrated the technical and economic feasibility of the process, including single use cameras (Eastman Kodak and Fuji Film), toner cartridges (Xerox), personal computers (IBM, HP, Toshiba, Reuse network-Germany), photocopiers (Fuji Xerox–Australia, Netherlands and UK), commercial cleaning equipment (Electrolux), washing machines (ENVIE-France), mobile phones (Nokia, ReCelluar-USA, Greener solution-UK), LCD Televisions (Apparec-Holland, Hitachi-Japan), etc [1-2, 4-5]. On the other hand, with the increasing customization and diversity of WEEE and complex disassembly processes, it becomes difficult for recyclers to solely depend upon their experiences to plan disassembly operations so as to recover a larger proportion of materials and fulfill environmental targets at a reasonable cost. Meanwhile, complete disassembly and processing are rarely ideal solutions due to the high cost and low efficiency. Customized disassembly, which dismantles hazardous or valuable components for recovery, is a promising alternative and a new research trend [6-7].

A research challenge in customized disassembly and processing is how to efficiently address a number of constraints and considerations from legislative, technical and economic perspectives leading to different decision-making models. For instance, WEEE regulators would license recyclers who are able to follow the WEEE Directive, which expects at least 75% of WEEE to be dismantled, and all the components containing hazardous materials need to be taken apart from WEEE for further specific processing [1]. Apart from fulfilling the environmental targets, recyclers would also improve the economic recovery efficiency by prioritizing valuable components during disassembly for component recovery. In order for stakeholders to process various types of WEEE and meet their requirements, this paper presents an effective approach for disassembling and processing WEEE with intelligent strategies (i.e., Analytic Hierarchy Process (AHP) and Particle Swarm Optimization (PSO)). The approach, illustrated in Figure 1, is explained in the following sections in detail. An industrial WEEE case is introduced to demonstrate a real application scenario.

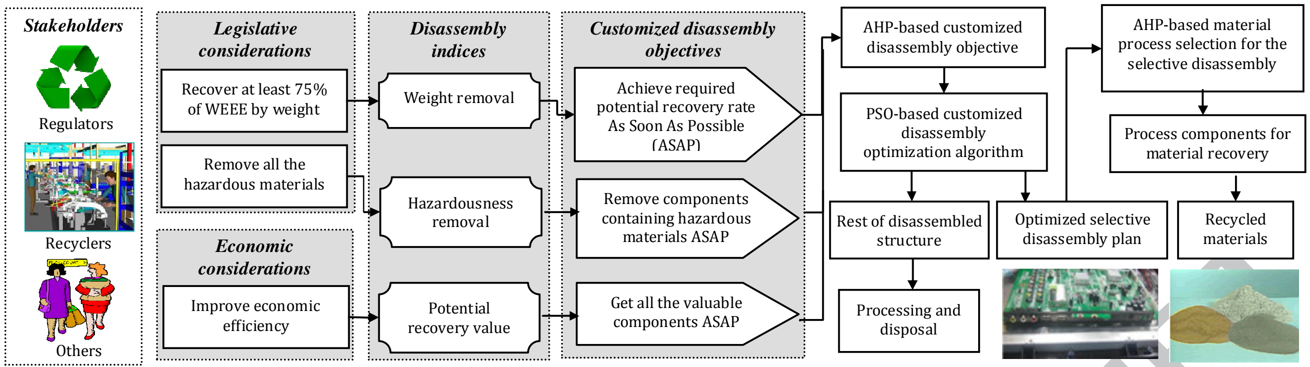


Figure 1. Customized disassembly and processing approach

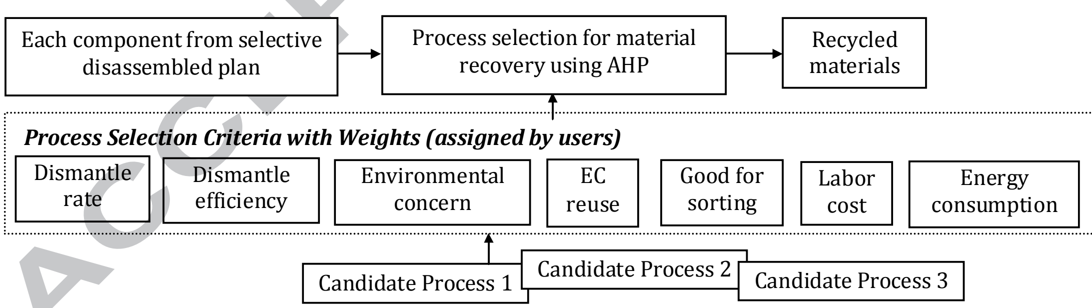
2. Customized disassembly and processing of WEEE

In Figure 1, customized disassembly for processing WEEE has been modeled as a multi-objective optimization problem. AHP is used here to structure the optimization objectives to reflect varied priorities of stakeholders in selecting and sequencing disassembly operations. Priority weights for objectives in AHP should be decided by stakeholders according to their needs. Disassembly usually brings forth a large search space with precedence constraints. A PSO algorithm, which is an evolutional optimization algorithm and robust on problems that are irregular, noisy, change over time, etc, is applied to identify the best customized disassembly plan (i.e., selected components for disassembly according to the multi-objectives, while the rest part of un-disassembled of WEEE will be handled using a standard material recovery process) [7-8].

Once disassembled components are obtained, material recovery processes will be applied for further processing the components. AHP is also used here to prioritize candidate material recovery processes for a disassembled component, e.g., the material recovery processes of a Print Circuit Board (PCB) are below [9]:

- FDH (Fully Dismantling by Heating): PCBs are exposed to the heater which can rapidly bring the solder up to its melting point by using methods such as hot wind gun heating, resistance stove heating or infrared radiation heating. Using this method, Electronic Components (ECs) can be easily separated;
- FDOS (Fully Dismantling by Open-Solder): Use a liquid as a heating medium. The process of dismantling waste PCBs is performed in a hot fluid. The average temperature of the welding point is 215 Degree Celsius;
- MDM (Moderately Dismantling Manually): During the manual dismantling process, recyclers use chisels, hammers and cutting torches to open solder connections and separate metals and components. PCBs are dismantled moderately for removing valuable/hazardous ECs.

The decision making process using AHP for selecting a suitable process from FDH, FDOS and MDM for processing a disassembled PCB is illustrated in Figure 2.



Type	**Dismantle rate**	**Dismantle efficiency**	**Environmental concern**	**EC reuse**	**Good for sorting**	**Labor cost**	**Energy consumption**
FDH	High	Quite High	High	High	High	Moderate	Quite high
FDOS	High	High	Moderate	Low	High	Moderate	Moderate
MDM	Moderate	Quite low	Moderate	High	Moderate	High	Low

Figure 2. AHP-based process selection for material recovery

After the disassembly of the selected components, the rest of the unselected structure can go through a standard recovery process of crushing, material separating (e.g., magnetic separation and Eddy current separation), incinerating or landfill.

3. A case study

Liquid Crystal Display (LCD) televisions have been developed quickly and are now the market leader [2, 5]. The LCD televisions studied here are produced by the Changhong Electronics Company, Ltd., which is the biggest television producer in China and one of the biggest exporters to Europe. Current EoL strategies for LCD televisions are typically landfill or incineration. Through this project, the company has been investigating a more suitable recovery route for its LCD television WEEE.

For a LCD television, there are three main parts: front cover assembly, back cover assembly and base assembly. The front cover assembly is composed of a surface frame, a remote control receiver board, a control button board, a main board, a power supply board, a Low-Noise Block (LNB) converter board (optional), and a DVD ROM (optional). Among the component/material composition, PCBs, such as main boards and power supply boards, and LCD screens are quite complex in terms of recycling processes. Meanwhile, the required recycling hazardous materials for LCD televisions are:

- Mercury from backlight lamps provided by a series of Cold Cathode Fluorescent Lamps (CCFLs) at the back of the screen;
- PCBs with a surface larger than 10 cm2, which often contain Cu, Al, Iron (Fe), Tin (Sn), Lead (Pb), Cadmium (Cd), and capacitors containing Polychlorinated Biphenyls;
- LCDs larger than 100 cm2 together with their casing.

The target of a customized disassembly plan (part of the full disassembly plan) is to meet the environmental protection targets (100% hazardousness removal and 75% component disassembled for the WEEE) and achieve the optimized potential recovery value by disassembling components with valuable materials in an efficient way. The disassembly planning selection and optimization process is shown in Figure 3, which includes Initial Plan (i.e., the plan that the factory is using) and Optimized Plan.

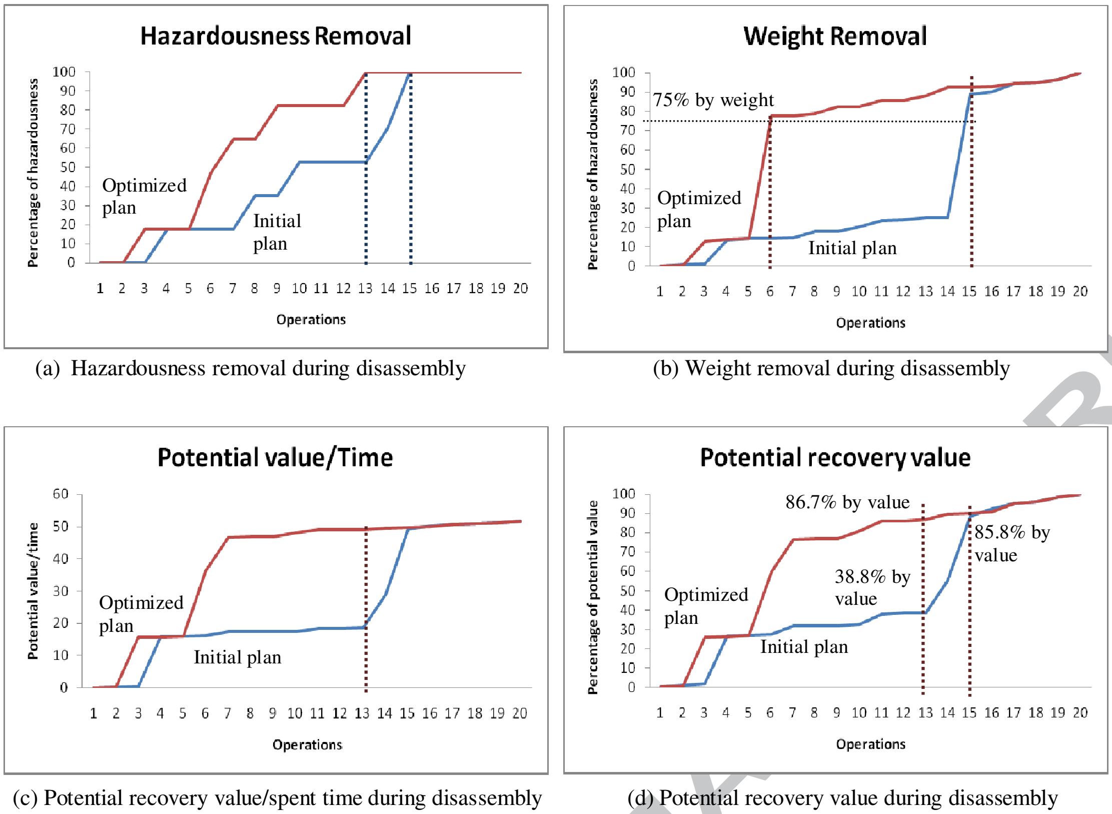
During the computation process, results were normalized, i.e., the index result of each operation was converted to the percentage of the overall results of all the operations. Y axis stands for accumulated values for the operations. The hazardousness removal, weight removal and potential recovery value for the initial plan and an optimized plan are shown in Figure 3. In (a), a 100% hazardousness removal target was obtained after 13 disassembly operations for the optimized plan, while the initial plan took 15 operations, In (b), a target to achieve 75% component disassembled by weight (of the total weight of the WEEE) took 6 operations for the optimized plan, while the initial plan took 15 operations. In (c), the result of potential recovery value divided by spent time for each operation is shown, which is a target to achieve the most potential recovery value within the shortest time. The potential value/time in (c) can be separated and interpreted in (d). It shows that with the selective optimized plan, the potential recovery values during the disassembly process are 86.7% (of the total potential value of all the disassembled components in the WEEE) for 13 operations, and 38.8% and 85.8% for the initial plan after 13 and 15 operations respectively. Therefore, if the first 13 operations are selected for both plans (**selected plans**), it can be observed that significant potential value is recovered (86.7% vs 38.3%).

To choose a suitable process for a dissembled main board PCB, a survey conducted by the company involved 15 experienced people from WEEE regulators, recyclers and LCD producers, and the priority weights was set as (0.4, 0.4, -0.1, 0.2, 0., -0.1, -0.1) based on the survey results. The set of (Quite high, High, Moderate, Low, None) in Figure 2 was quantified as (1.0, 0.8, 0.5, 0.3, 0.0). After applying the AHP process, the recommended process is FDOS, and the process for the waste main board is shown in Figure 4 in detail.

4. Conclusions

An effective customized disassembly and processing approach for WEEE is reported. The contributions of the research include:

- Customizable decision-making models are embedded, which are capable to process different types of WEEE and achieve optimized disassembly for processing efficiently;
- An industrial case on LCD WEEE has been carried out to verify the effectiveness and generalization of the developed research. It demonstrates that this research is promising for practical problem solving.



(a) Hazardousness removal during disassembly (b) Weight removal during disassembly

(c) Potential recovery value/spent time during disassembly (d) Potential recovery value during disassembly

Figure 3. Initial plan and optimization plan

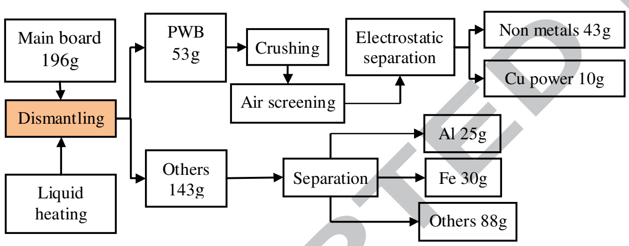


Figure 4. The FDOS process for material recovery from a disassembled main board

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