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Service-oriented disassembly sequence planning for electrical and electronic equipment waste

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A B S T R A C T

Disassembly sequence planning plays an important role in the end-of-life treatment of *electrical and electronic equipment waste* (e-waste). Effective planning methods can improve recovery rates and reduce environmental impacts of e-waste. In previous work, neither mathematical models nor optimization algorithms offered a satisfactory solution for this multi-objective disassembly problem. We present a multi-objective model for the problem and a *modified teaching-learning-based optimization* (MTLBO) algorithm to find the Pareto-optimal frontier. We use numerical simulations to demonstrate and verify the effectiveness and robustness of the algorithm. To do effective disassembly planning, all the participants in the lifecycle of e-waste should work together. Disassembly and recovery of e-waste involve complex processes across the lifecycle. Information support services, disassembly modeling and optimization services must be integrated using computer networks. We also propose a service-oriented framework to support business integration for the participants in the e-waste lifecycle. Effective and optimized disassembly planning can be achieved by invoking the related distributed services. The proposed framework is a novel e-business application for the end-of-life treatment of e-waste.

1. Introduction

E-waste has become one of the major and challenging waste streams in terms of quantity and toxicity. Informal treatments result in environmental pollution and secondary resource waste. The Waste Electrical and Electronic Equipment Directive (2002/96/EC) was enacted in 2003 in Europe.[1] It aims to prevent the generation of e-waste and promote its recovery to reduce disposal. Many other equivalent directives have been developed and implemented in the world. With legislative pressure for environmental protection, electronics companies have come to recognize that they must take on more responsibility. It is crucial for them to balance economic and environmental objectives, for example, to maximize recovery value and minimize environmental impact.

Disassembly sequence planning plays an important role in end-of-life treatment of e-waste. Effective disassembly planning methods can improve recovery rates and reduce environmental impacts of e-waste. The disassembly sequence planning problem has been proven to be NP-hard, and it has been widely studied in previous research. Different meta-heuristic optimization methods have been proposed and implemented to solve the problem (Kongar and Gupta, 2006; Adenso-Diaz et al., 2007; Xia et al., 2014; Yeh, 2012; Li et al., 2013). Different stakeholders related to e-waste (e.g., remanufacturers, recyclers, and regulators) have different legislative and economic considerations when making disassembly planning arrangements. They have to balance multiple objectives. In order to formulate the multi-objective disassembly sequence planning problem, this paper introduces three disassembly indices to evaluate a disassembly sequence, namely index of diminished toxicity, index of potential recovery value and index of potential recovery weight. Accordingly, we formulated a model with the objective of maximizing these disassembly indices.

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[1] For additional background on this European Commission policy on waste electrical and electronic equipment (WEEE), the interest reader should see ec.europa.eu/environment/waste/weee/index_en.htm, to learn about the prior European policy-related legislation in the 2000s. For the current policy, refer to Directive 2012/19/EU at eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0019.

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The traditional method to solve a multi-objective optimization problem is to weight the relative degree of importance of each objective and then transform them into a single-objective optimization problem. However, this method has a drawback for the multi-objective disassembly sequence planning problem. Since disassembly involves different stakeholders with different legislative and economic considerations, one single-objective solution cannot meet the needs of different stakeholders. Furthermore, it makes sense to determine as many non-dominated solutions as possible for a stakeholder to select in order to support better decisions.

Multi-objective evolutionary algorithms have been widely studied and applied to solve multi-objective optimization problems, such as the non-dominated sorting genetic algorithm II (NSGA II) (Deb et al., 2002), the multi-objective evolutionary algorithm based on decomposition (Zhang and Li, 2007), and the multi-objective differential evolution algorithm (Ali et al., 2012). This article proposes a *modified teaching-learning-based optimization* (MTLBO) algorithm to solve the multi-objective disassembly sequence planning problem. Five major components have been designed and incorporated into the algorithm in order to make it applicable for specifying complex disassembly precedence constraints.

Disassembly sequence planning for e-waste always involves globally-distributed participants in the lifecycle of this kind of equipment, such as manufacturers, distributers, retailers, disassemblers, recyclers, remanufacturers, management authorities and so on. To make an effective disassembly plan, all the participants should work together. However, information flows about e-waste in the lifecycle have not yet been effectively established. It is usually not effective to get information and decision support for disassembly planning from the participants (Xia et al., 2015). In this research, we propose a service-oriented framework to support business integration for disassembly planning. Effective and optimized disassembly planning can be done via the Internet by integrating the related distributed services provided by the participants.

E-business is the term used to describe the administration of conducting business via the Internet. Service-oriented technologies are the main supporting technologies for e-business engineering, and there is high interest in their further development (Chao, 2016). Huang and Chung (2003) proposed a service-based framework that adopted a web services-based approach to developing business integration solutions for e-business application. Rehman et al. (2015) presented a decision-making approach that assisted a cloud service user in selecting a cloud service provider based on the quality of its services. Johnson (2008) proposed a framework for pricing government e-services to help governments to expand online service delivery quickly and broadly, and increase the net benefits to stakeholders.

Enterprises are moving toward service-oriented architecture with web services to modernize their legacy applications by using wrapping techniques (Baghdadi and Al-Bulushi, 2015). Baresi et al. (2016) proposed a solution to integrate existing registries, along with a match-making approach to ease the publication and retrieval of services. The service-oriented disassembly sequence planning framework that we describe is a novel e-business application for the end-of-life treatment of e-waste. The e-service concept that is introduced for the disassembly context will transform the business model of the disassembly industry.

2. Problem formulation

Different considerations have led stakeholders to pursue different objectives for disassembly planning. For instance, according to the Waste Electrical and Electronic Equipment Directive, e-waste regulators need to check whether an end-of-life treatment operator is able to recover (reuse and recycle) at least 75% of the weight, and remove all of the hazardous materials. The components containing hazardous materials need to be removed from the equipment for further processing. Apart from fulfilling these fundamental environmental objectives, remanufacturers want to improve the economic efficiency by prioritizing the valued components during disassembly. We develop a multi-objective disassembly sequence planning model according to these considerations by introducing three disassembly indices as shown in Fig. 1. The multi-objective disassembly sequence planning model involves different e-waste stakeholders distributed across different areas. It is a complex business process that needs to be optimized, and the enabling technologies to support e-business engineering need to be implemented to handle it through the Internet.

- Decision variable

The decision variable $X = (x_1, x_2, \ldots, x_m)$ is a disassembly sequence, representing the order in which each disassembly operation is undertaken. Each disassembly operation x_i in X has a corresponding sequence number i. And m is the total number of disassembly operations.

- Objective functions

Each component c has three important properties: toxicity level $h(c)$, potential recovery value $v(c)$ and potential recovery weight $w(c)$. The indices for an X are computed according to these properties of each component and the sequence number of each disassembly operation.

Index of diminished toxicity $f_h(X)$. Some of the components in e-waste are hazardous. The level of their toxicity can be repre-

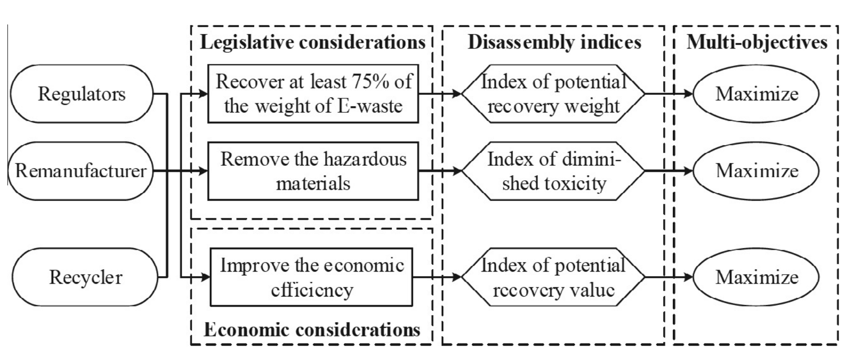

Fig. 1. Multi-objective disassembly sequence planing model.