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Energy evaluation method and its optimization models for process planning with stochastic characteristics: A case study in disassembly decision-making

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ABSTRACT

Disassembly is not only a premise of products recycling, but also an important link of products remanufacturing. However, used products suffer from the influence of a variety of uncertainties. The randomness of disassembly process is a significant feature. In this paper, a disassembly network is established, in which lengths of arc are stochastic variables with a specified power subject to specified distributions and denote removal times of parts, the energy evaluation method integrating two or more uncertain variables is proposed. According to different disassembly decision-making criteria, three types of typical stochastic programming models of a disassembly process are developed, namely the minimum expected value model, the maximum energy disassemblability degree model and D'-minimum energy model. The energy probability distributions are determined through the application of stochastic linear programming and maximum entropy principle. Synchronously, based on obtained theoretical probability distributions, the quantitative evaluation and stochastic programming of a disassembly process are realized. The simulation results show that the proposed method is feasible and effective to solve the stochastic programming issue with time-varying stochastic characteristics.

1. Introduction

The rapidly growing concern for environmental protection and resource utilization has stimulated many new activities in the industrialized word for coping with urgent environment problems caused by the steadily increasing consumption of industrial products. One of the upsetting problems is a disposal issue of end-of-life products. For example, it is predicted that 9 million refrigerators, 12 million air-conditioners, 11 million washing machines, 58 million televisions and 70 million computers will be scrapped in China in 2010 (Li & Wen, 2006). In order to recycle them, it is necessary that disassembly of end-of-life products should be implemented.

Disassembly is defined by Brennan, Gupta, and Taleb (1994) as “the process of systematic removal of desirable constituent parts from an assembly while ensuring that there is no impairment of the parts due to the process”. Disassembly is conductive and instructive to recycling of products. Only in this way, can we achieve high purity of material recycling and realize good reuse of parts. Two methods are generally used to remove components or materials: destructive and non-destructive disassembly. The most common methods for a destructive disassembly are shredding processes. Shredding processes can damage potential parts. Meanwhile, shredding processes can result in the mixture of materials, which is not conducive to the recovery of high purity of materials (Jovane et al., 1993). Therefore, the current research on disassembly problems mainly focuses on the non-destructive disassembly. Consumed time, cost and energy of a disassembly process are closely related to economic benefits of product recovery, thus, in a non-destructive condition, disassembly evaluation and optimization have become one of the hot ones.

Currently, the research mainly focuses on deterministic disassembly evaluation and planning. However, the disassembly process of actual products has a strong uncertainty due to a variety of unpredictable and uncontrollable factors, such as use and design factors of products. Moreover, most of disassembly operations are performed mainly by hand. The uncertainty of a disassembly process is further increased because of the presence of human factors. Although some authors consider that a removal operation is an event with given certain probability to account for uncertainty (Geiger & Zussman, 1996; Andres, Lozano, & Adenso-Diaz, 2007), based on this assumption, the determination of the optimal path of a disassembly process is merely a probabilistic planning problem.

It can be seen that removal power is also varying in a disassembly process when time-varying. Therefore, it is necessary for the introduction of a new energy evaluation method of a disassembly

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process integrating two or more uncertain variables. What's more, stochastic optimization of a disassembly process can be realized based on this novel evaluation method.

The rest of the paper is organized as follows: Section 2 discusses the literature review on disassembly. Section 2 introduces some assumptions and basic concepts of stochastic disassembly evaluation. Section 4 defines typical stochastic programming models based on energy evaluation method. Section 5 introduces a calculation method of typical stochastic programming models. Section 6 designs a solution algorithm of it. In Section 7, a numerical example is presented to test its effectiveness. Section 8 presents our discussion. Finally, Section 9 concludes our work and describes our future research steps.

2. Literature review

2.1. Disassembly evaluation and optimization

Gungor and Gupta (1997) present an evaluation methodology to choose the best disassembly process among several alternative processes based on the total time for disassembly. Kroll and Carver (1999) examine the problem of assessing product ease of disassembly for recycling in light of the broader issue of manufacturability evaluation. The disassembly time estimation method is shown to provide one of several needed metrics for use during product design. Desai and Mital (2003) propose the evaluation of disassemblability to enable design for disassembly in mass production. The disassemblability evaluation methodology strives to include all relevant factors that directly or indirectly affect the process of non-destructive disassembly of products.

Disassembly planning is considered as the optimization of a disassembly process. Its objective can include the shortest time, the lowest cost and the minimum energy consumption. Early approaches to disassembly process planning are developed based on graph theory. Common methods of building disassembly model mainly include tree-level diagram, undirected graph, directed graph, AND/OR graph and Petri nets (Tang, Zhou, Zussman, and Caudill, 2002; Moore, Gungor, & Gupta 1998). In terms of AND/OR graph, it is first applied to assembly by Homen de Mello and Sanderson (1991) and later introduced for disassembly, unfortunately, it is considered as the reversing an assembly process. After graph-based disassembly model is established, removal operation is an activity with given standard time, cost or energy parameters, the optimization of disassembly sequences can be achieved by Dijkstra algorithm. Later, with the development of knowledge, people's understanding on disassembly problems is also deepened. Mathematical programming method is adapted to solve the optimization problem of disassembly sequences. Xanthopoulos and Iakovou (2009) propose a goal-programming analysis for the identification and optimal selection of the most desirable subassemblies and components to be disassembled for recovery, from a set of different types of EOL products. Lambert (1997) presents a dynamic programming algorithm for determining the optimal disassembly sequence for selective disassembly of complex products with the objective of maximizing the revenue. In addition, Lambert (2006) proposes exact methods in optimum disassembly sequence search for problems subject to sequence dependent costs. Still later, with the development of computer technology, intelligent algorithms become a powerful tool for optimization of disassembly sequences. According to the generated disassembly sequences based on disassembly constraint graph, Li, Khoo, and Tor (2005) present the optimization of disassembly sequences by genetic algorithm. In addition, neural network algorithm (Huang, Wang, & Johnson, 2000) and ant colony algorithm (Failli & Dini, 2001) are used to solve the optimization of disassembly sequences.

2.2. Uncertainty management on disassembly process

Disassembly can not be simply interpreted as the inverse process of the assembly of a product due to the influence of much uncertainty, thus disassembly issue is more difficult and complex than the assembly problem. Uncertainty of disassembly is similar with the other issues and it exits two aspects, namely randomness and fuzziness. Some related studies can be summarized as follows.

Salomonski and Zussman (1999) present an on-line predictive model for a disassembly process. The prediction enable a planner to adapt the process plan based on the condition of the product (e.g., degree of rustiness, deformation) during process execution. This model tries to correlate the product physical condition (the explanatory variable) with the component value and disassembly cost (response variables). Geiger and Zussman (1996) present a model-based planner which relies on a probabilistic inference mechanism. Reactive planner employs a predictive plan which is represented using a Bayesian Network. From the perspective of the probability, it is pointed out that removal operation is likely to be failure or successful due to the influence of removal state. That is, removal operation is a probability event. Andres et al. (2007) point out that the disassembly condition or disassembly depth in which the product reaches has strong randomness feature in a specified environment. In addition, Ilgin and Gupta (2010) point out that a high degree of uncertainty exists in disassembly systems. The most popular approaches to deal with this uncertainty are simulation, stochastic programming, robust optimization, sensitivity and scenario analysis. Reveliotis (2007) proposes the uncertainty management in optimal disassembly planning through learning-based strategies.

Tripathi, Agrawal, Pandey, Shankar, and Tiwari (2009) propose the real world disassembly modeling and sequencing optimization by Algorithm of Self-Guided Ants based on the uncertain quality of recycled products. Teunter (2006) presents a stochastic dynamic programming algorithm for determining the optimal disassembly and recovery strategy. Wang and Allada (1998, 2000) use fuzzy logic aimed at dealing with the uncertainty associated with different disassembly variables. In addition, a fuzzy Petri net model can be used in which the uncertainty is represented by fuzzy disassembly rules, i.e. fuzzy relations between two propositions (Tang, Zhou, & Gao, 2006).

3. Theoretical foundation of disassembly evaluation

3.1. Assumptions of disassembly evaluation

In order to understand the substance of product disassembly problems, first of all, the concepts of removal and disassembly should be distinguished. Removal can be understood as an operation that removes a part from an assembly. While disassembly can be understood as the reverse process of the assembly of a product, i.e., dismantling a product into parts, it represents the result of many removal operations (Tian, Liu, Tian & Chu, 2011).

According to the above related concepts, the following assumptions on disassembly evaluation can be made: Disassembly of a product is carried out by a non-destructive disassembly approach, and removal times and powers are stochastic with pre-given probability distributions.

3.2. Basic concepts

Definition 1. Removability degree is defined as the probability of removing a part from an assembly given time.

Because the actual removal time of a part T_0 is a random variable, if t is the given removal time, then the probability of removing it from an assembly in $T_0 \leqslant t$, namely removability degree $R(t)$ can be expressed as: