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A co-evolutionary algorithm for open-shop scheduling with disassembly operations

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Abstract

In recent years, many used products are returned from customers through reverse supply chains in order to be reused and recycled. Therefore, it is necessary to provide suitable disassembly procedures from the view point of economic efficiency. This research proposes a scheduling method for open-shop scheduling problems containing both disassembly operations and post-processing operations. A co-evolutionary algorithm is proposed to modify not only the sequences of disassembly and post-processing operations of products but also the sequences of products loaded on disassembly and post-processing machines. Two different kinds of individuals are modeled for both the sequences of operations and the sequences of products in the co-evolutionary algorithm. These individuals alternately repeat evolution at short time intervals, and affect their fitness values each other. We developed a prototype of scheduling system and applied it to some computational experiments for open-shop type scheduling problems including disassembly and post-processing operations. The experimental results of the proposed method were compared with the one of another scheduling method with various heuristic rules in order to evaluate the effectiveness of the proposed method.

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Keywords: Disassembly scheduling ; Co-evolutionary algorithm ; Make-span

1. Introduction

Sustainability issues have become one of the most serious problems facing the international community in these last few decades. The growing amount of waste requires a vast area of landfill and a high cost of waste disposal. The Japanese government made the Home Appliance Recycling Law in 2001 to collect and recycle the used home appliances for the reduction of waste materials [1]. The European Union enacted the WEEE Directive in 2005 and the RoHS Directive in 2006. The WEEE Directive was designed to prevent the generation of electrical and electronic waste and to promote reuse, recycling and other forms of recovery in order to reduce the quantity of such waste to be eliminated [2]. Many companies focus on incorporating environmental concerns into their strategic decisions [3]. In recent years, many products are designed for easily disassembly to reuse and recycle. Some companies have also been constructing a closed loop system of collecting used products for reusing and recycling from the market. However, the closed loop system is not fully functioning in the actual marketing environment due to economic reasons. Gungor and Gupta [4] indicate that effort must be made for environmentally conscious manufacturing and product recovery systems to be profitable so that the incentive for development and planning of these systems continues.

It is necessary to provide suitable disassembly procedures from the view point of economic efficiency in consideration of all the time to remove parts from used products and to obtain reusable parts for reusing and recycling. Some existing researches have proposed disassembly scheduling methods to find a suitable disassembly schedule. However most of the researches about disassembly schedules proposed a method to find a suitable disassembly schedule for a single product. In addition, these scheduling methods are considered neither the disassembly processes of various products nor the post-processes such as cleaning and inspecting processes of the parts removed from the products for reusing and recycling.

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These methods cannot make an optimal disassembly schedule in consideration of the whole disassembly procedures of various products.

This research provides a scheduling method for open-shop scheduling problems containing both disassembly operations and post-processing operations. An evolutionary algorithm is proposed to modify not only the sequences of disassembly and post-processing operations of products and parts but also the sequences of products and parts loaded on disassembly and post-processing machines.

The reminder of this paper is organized as follows. Section 2 presents a background. Section 3 shows nomenclatures. Section 4 explains the proposed scheduling method for open-shop scheduling problems containing both disassembly operations and post-processing operations. Section 5 assesses the effectiveness of the proposed method by using a developed simulation system and demonstrates results of experiments. Finally, Section 6 concludes this study.

2. Background

There are some researches considering scheduling problems containing disassembly operations. Seo et al. [5] proposed a scheduling method based on a genetic algorithm (GA) to find an optimal disassembly sequence of a product considering both economic and environmental aspects. The precedence relationships of disassembly operations for refrigerator door modules are considered in the study. However, the proposed method may generate infeasible information in a gene model during the evolutionary process. The genes with the infeasible information should be eliminated during latter evolutionary process. The genes with the infeasible information weaken the searching ability of GA. Kongar et al. [6] proposed a method using a GA for efficiently retrieving parts which have been already determined to reuse or recycle from a product. The precedence preservative crossover (PPX) technique was used as a crossover method for disassembly problems. This method preserves the precedence relationship of parts during a crossover function of a GA. Shimizu et al. [7] developed a prototype system using a genetic programming (GP) for supporting a strategy to retrieve desired parts or subassemblies from a product efficiently. ElSayed et al. [8, 9] proposed an evolutionary algorithm for generating near optimal and/or optimal sequences for selective disassembly of end-of-life (EOL) products. The algorithm utilized the bill of materials (BOM) data including material, EOL processing option, fasten type, disassembly time, and coordinates, and the precedence relationships in the product structure. Surendra and Gupta [10] considered the disassembly sequencing problem subjected to sequence dependent disassembly costs. They proposed an iterative method that repeatedly solves a binary integer linear programming problem. Kara et al. [11] presented a selective disassembly methodology for EOL products. The methodology was developed by reversing and modifying a methodology developed by Nevins and Whitney [12] for assembly.

These existing studies have been proposed disassembly scheduling methods to find a suitable disassembly procedure for a single product. These methods are considered neither the disassembly processes of various products nor the post-processes such as cleaning and inspecting processes of the parts removed from the products for reusing and recycling. These methods cannot make an optimal disassembly schedule in consideration of the whole disassembly procedures of various products.

This paper deals with an open-shop scheduling problems for various products containing both disassembly operations and their post-processing operations, such as cleaning and inspecting of the parts disassembled from the products. It is considered that all parts are firstly removed from each product through the disassembly process. After that, the post processing operations are applied to the removed parts sequentially to make easy reusing and recycling.

3. Nomenclatures

The following terms are used for the scheduling problem in this paper.

- Job: $J_{i,k}$ (i = 1,2,…,m. k=1,2,…,p). Job is a component of a product. One part is removed from a product through a disassemble process. $J_{i,k}$ represents a part removed from the i-th product through the k-th disassembly process.
- Disassembly: $D_{i,h}$ (i = 1,2,…,m. h=1,2,…,q). It represents a product and a semi-product which is generated for the i-th product by the h+1-th disassembly operation. Then, $D_{i,1}$ means an initial product. A disassembly operation generates a semi-product and/or a part which is named as a Job. The number of disassembly machine is not included in $D_{i,h}$, since it is assumed that only one disassembly machine DR_1 carries out all disassembly operations in this research.
- Resource: R_j (j = 1,2,…,n). Resources are elements which carry out manufacturing operations of jobs. In this paper, R_j mean machines which carry out post-processing operations for jobs. The post-processing operation such as cleaning and inspecting operation is carried out after removing a part from a product. A disassembly machine DR_1 is also a kind of resources.
- Operation: $O_{i,k,j}$. Operations represent activities executed by the combinations of the jobs and the resources or the the ones of a disassembly and a disassembly machine. Each operation has the information about processing time $pt_{i,k,j}$, starting time $st_{i,k,j}$ and finishing time $ft_{i,k,j}$. The processing time $pt_{i,k,j}$ of the operation $O_{i,k,j}$ is predetermined by a set of the job $J_{i,k}$ and the resource R_j or a set of the disassembly $D_{i,h}$ and the disassembly machine DR_1. And, the starting time $st_{i,k,j}$ and the finishing time $ft_{i,k,j}$ are determined in the scheduling problems.

In this paper, a schedule containing disassembly operations is created though the following three activities. They are,

- Selection of suitable resources and determination of their sequences, which means a sequence of disassembly and post-processing operations, for individual products,
- Determination of sequences of disassembly and jobs on the resources, which is called as loading sequences, and