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Computers & Operations Research 34 (2007) 536–551

computers & operations research

www.elsevier.com/locate/cor

Optimizing disassembly processes subjected to sequence-dependent cost

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Available online 27 April 2005

Abstract

Detection of the optimum disassembly sequence for a given product can proceed via mathematical programming, which is based on the AND/OR graph representation of its disassembly process. This is called the exact method for it reveals the global optimum. This paper describes an extension of the exact method in case sequence-dependent costs are considered. Previously presented methods confined themselves either to sequential disassembly, or were based on heuristics. The only exact method for the full problem known so far, needs an elaborate transformation of the AND/OR graph, and is based on integer linear programming. This paper discusses an alternate approach that uses a binary integer linear programming approach and that lacks the need of transforming the AND/OR graph. The proposed method is applied to arbitrary instances of some product structures that have been taken from the literature. Apart from this, the method is applied to an expandable AND/OR graph, that enables gradual increase of product complexity. It is demonstrated that the convergence of the iteration process is satisfactory, and the required CPU time appears comparatively small and only moderately increases with the number of constraints. It appears that the method applies to products with a complexity that cannot be managed with the integer linear programming model. The iterative method is promising for dealing with modularized products and as a benchmark for heuristic algorithms, which are used if products exhibit still higher complexity.

Keywords: Disassembly planning; Assembly; Network; Mathematical programming; Optimization; Traveling salesperson problem

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doi:10.1016/j.cor.2005.03.012

1. Introduction

Disassembly is the non-destructive detachment of components or modules from a product. Analysis of disassembly processes includes disassembly planning, which is related to the design of such processes, and disassembly scheduling, which is involved with the proper management of the disassembly process. Three main applications of disassembly studies are: assembly optimization, maintenance and repair, and end-of life disassembly.

End-of life disassembly is encouraged for its environmental benefit. Appropriate processing of discarded complex products is aimed at the recovery of as much as possible of their original functionality, which is expressed via the hierarchy: repair–remanufacturing–reuse–recycling–disposal. Disassembly guarantees the integrity of the components. Unfortunately, the disassembly process is labor-intensive and thus appears expensive compared with destructive processes such as dismantling and shredding. But, because disassembly leaves components intact, it also offers an opportunity for obtaining higher revenues compared with materials recycling.

Technical, economic and environmental issues are determining to the extent in which disassembly is carried through, which is referred to as selective disassembly. This plays a dominant role in end-of-life disassembly, because the revenue of some components is low compared with the corresponding disassembly costs.

Disassembly of a specific product can usually take place in many different ways. These are commonly expressed as sequences of disassembly unit operations. Disassembly sequencing is involved with graphically representing the set of all the possible disassembly sequences and selecting the optimum sequence out of this set via heuristics, metaheuristics, or mathematical programming. Usually, maximum profit is aimed at, subjected to a set of environmental and technical criteria, such as the compulsory recovery of hazardous materials.

Heuristic and metaheuristic methods usually return a 'good enough' solution. In contrast with this, mathematical programming generates the exact optimum solution. Therefore, mathematical programming is potentially useful in design and evaluation of algorithms based on heuristics as it can determine to what extent the result of a heuristic calculation is a 'good' one indeed. Unfortunately, the calculation time (CPU time) that is needed for performing an exact solution procedure tends to increase with the size of the problem. If this increase is exponential, the method is confined to products with a restricted complexity only. If it is assumed that operation costs are sequence independent in the model, the problem is relaxed to a linear programming problem. If costs are sequence dependent, which frequently occurs in practice, an integer linear programming problem is encountered. This can be solved for rather simple products only because of the required CPU time, which is steeply increasing with the product's complexity.

This paper deals with the exact method for disassembly sequencing subjected to sequence-dependent costs. The AND/OR graph is applied for graphically representing the complete set of possible disassembly operations. It is demonstrated that an explicitly iterative approach relaxes the original integer linear programming problem into a binary integer linear one. Although repetitive calculation of the binary linear programming problem is required here, each time with the addition of a specific constraint, a considerable relaxation in CPU time can be observed. This implies that the problem can be solved for products with increased complexity compared with the integer linear programming problem, for it appears that the series of intermediate solutions that are generated by the iterative process, unexpectedly quickly converges to the exact optimum.