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A solution approach based on beam search algorithm for disassembly line balancing problem☆

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ABSTRACT

The disassembly line balancing (DLB) problem is the process of allocating a set of disassembly tasks to an ordered sequence of workstations in such a way that optimizes some performance measures (e.g., cycle time, number of stations). Since DLB problems belong to the class of NP hard, many heuristic and meta-heuristic algorithms are applied to cope with the complexity of the DLB problems in order to obtain acceptable solutions in a reasonable amount of time. In this study, a beam search (BS) based approach for the DLB problem is proposed. Minimization of number of workstations is used as the performance measure. The proposed algorithm is compared with the optimal solutions of well-known real cases and generated test problems. The results indicate that the proposed approach based on BS is a very competitive and promising tool for further researches.

1. Introduction

Due to rigid environmental regulations, rising public awareness and extended manufacturing liability, manufacturers are recycling and remanufacturing their post-consumer products increasingly. Remanufacturing is an industrial process in which degraded products are recuperated to relish-incipient conditions. In this way, remanufacturing provides the quality standards of incipient products with used components. On the other hand, recycling is a process performed to recover the material content of used and non-functioning products. Product recovery requires acquisition materials and components from outdated products through remanufacturing and recycling to minimize the amount of waste sent to landfills. There are several steps of a product to enhance product recovery. Disassembly is the first essential step on product recovery. It is described as a systematic separation of valuable components from discarded products through a series of operations. Disassembly can be partial if some components and subassemblies are removed or complete if the product is fully disassembled [1]. More detail on recycling, remanufacturing, product recovery can be found in the study of Ilgın and Gupta [2].

Disassembly has acquired reasonably attention in the literature and become an active research area because of the role of disassembly in product recovery. A disassembly system is faced many unique challenges such as complex inventory problems, quality of the returned product and there is a high degree of uncertainty in the structure [3]. The disassembly operations are commonly implemented on a disassembly line that consists of a number of serial workstations. Disassembly line is appropriate layout for disassembly operations, because of its high productivity and suitability to automation. Therefore, the efficiently designed and balanced disassembly line has a remarkable environmental and industrial importance [4]. DLB is crucial in minimizing the use of valuable resources (like money and time) invested in disassembly and also maximizing the level of automation of the disassembly process and develops the quality of the components and materials recovered [5].

The DLB is a related problem to assembly line balancing (ALB) problem and it has been attracting interest from the field of researchers in recent years [6–9]. While there are a number of sub-problems within DLB, line balancing is at the forefront. The

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DLB problem in general can be stated as the assignment of disassembly tasks to workstations via satisfying precedence relations and optimizing performance measures. There are certain differences between DLB and ALB problem in terms of technical and operational aspects, such as uncertainty related to quality of parts, demand sources and complexity of precedence relationships [10]. DLB problem is first described by Güngör and Gupta [1,4] and it is mathematically proven to be NP-hard by McGovern and Gupta [11] making the goal to achieve the optimal balance computationally expensive. Exhaustive search provides optimal solutions to small sized test cases, but its applicability for large size problems is difficult due to problem complexity. Therefore, it is needed to propose suitable heuristic/meta-heuristic approaches for the assignment of tasks to the workstations in terms of balancing disassembly line in a reasonable time. For this reason, there is an increasing trend for using meta-heuristic techniques in the DLB problem literature such as ant colony optimization [12], genetic algorithm [5], and simulated annealing [13].

In this paper, a solution approach based on BS algorithm is proposed to balance the disassembly lines. BS algorithm is similar to branch and bound method in terms of structure. It was already applied to solve various combinatorial optimization problems in the literature (see Table 2). Branch and bound method checks all solutions with back tracking technique. In contrast, BS algorithm searches a solution just on determined points with forward to speed up the solution search [14]. The purpose of this study is to suggest a solution approach based on BS technique for DLB problem to minimize the number of disassembly workstations. Although BS has already been used for different problems, this is the first application to the DLB problem. Performance of BS is compared with shortest route model proposed by Hezer and Kara [15] in terms of objective functions (number of workstations) and speed (CPU times). Moreover, a new set of test problems is formed by using the benchmark problem generation scheme, developed by Koç et al. [16]. Generated test problems are used to compare the proposed BS algorithm with GAMS–CPLEX solver 12.3 and random search (RS) algorithm.

The remainder of the paper is organized as follows. In Section 2, literature review on DLB and BS are given. In Section 3, mathematical model of DLB problem proposed by Koç et al. [16] is presented. In Section 4, BS algorithm is explained. Its applicability is demonstrated on realistic cases and test problems from literature in Section 5. Finally, conclusion and future directions are given in Section 6.

2. Literature review

This section first presents a brief review on the most relevant and recent literature on DLB, followed by the same for BS.

2.1. Review of the literature on disassembly line balancing problems

The DLB is a related problem to ALB problem and has been attracting interest from the field of researchers in recent years [7]. While there are a number of sub-problems within disassembly, line balancing is at the forefront. The DLB problem in general can be stated as the assignment of disassembly tasks to workstations to optimize performance measure while satisfying the precedence relations [10].

There are some mathematical models [16,39] to solve DLB problems. Nevertheless, after the proof of DLB's NP-hard nature by McGovern and Gupta [11], different heuristic/meta-heuristic approaches [1,5,10,40] were also developed and applied to get a good solution in a reasonable time, as a result of exponentially increasing time with increasing problem sizes for the exact models.

In terms of objective functions, minimization number of workstations [16] is the most preferred performance measure, followed by removing hazardous and high demand parts as early as possible [1,4,40,41,42]. A summary of the relevant DLB literature is given in Table 1, differentiated with respect to the objective functions and solution methods.

According to Table 1, there is no paper which uses BS for the DLB problem. Our choice of BS was motivated by the fact that the crucial algorithmic component of one of the current state-of-the-art methods for the ALB problem is strongly based on BS [21]. Due to similarity of ALB and DLB problems, potential success of BS on DLB problem is wondered and tested in this paper. The contributions of this paper are as threefold and are stated as follows: (i) application of BS algorithm to DLB problem, (ii) generating new DLB test problems; and (iii) comparing proposed BS approach with network-based shortest route model and RS.

2.2. Review of the literature on beam search algorithm

BS technique was applied first in the artificial intelligence area by Lowerre [17]. Later, this technique was used in many domains such as flexible manufacturing systems [14], data mining [18], artificial intelligence [19], bin packing [20], ALB [21] problems and so on. Certain variation and application area of BS technique are given in Table 2. BS is an adaption of the branch and bound method in terms of its structure. Branch and bound method checks all solutions with back tracking technique. In contrast, BS algorithm searches a solution just on determined points with forward to speed up solution search.

In the standard version of BS, beams progress independently. If meta-heuristic methods are used in local search of BS algorithm, such an algorithm is called hybridized BS. If enhancement tools are integrated to the standard BS, for example backtracking mechanism and look-ahead techniques, the algorithm is considered as an improved BS algorithm. Finally, the filtered BS algorithm is an additional extension and an improved BS. The aim of the use of filtered mechanism is to reduce computational time because it helps to eliminate certain nodes prior to global evaluation [22].

As shown in Table 2, – to the best of our knowledge – this study is the first application of the BS technique to solve the DLB problem.

3. Problem definition

In this study, a solution approach based on BS algorithm is proposed to balance the disassembly lines. Minimization of number of workstations is used as the performance measure. Task precedence diagram (TPD) developed by Koç et al. [16] is employed in this paper. An AND/OR graph is a graph that depicts all possible ways of the complete disassembly of a product into its basic components. All the possible ways of completely disassembling in a product into its basic components are shown by AOG graph. A detailed characterization of AOG representation can be found in Ref. [63]. Moreover, Koç et al. [16] proves that using AND/OR graph instead of precedence graph leads to better solutions of the traditional ALB problem. While an AND/OR graph shows all possible subassemblies, it does not give information on precedence relations among the disassembly tasks. Therefore, Koç et al. [16] presented new graph called transformed AND/OR (TAOG) to overcome this problem. TAOG is a modified version of an AND/OR graph (AOG) which contains specific information on the precedence relations between tasks on all the disassembly trees. In this study, transformed AND/OR graph is used as precedence diagram.

Each node in the AOG corresponding to a subassembly is symbolized by an artificial node (A_k). A task is symbolized by normal node (B_i) in the graph. The transformed AND/OR graph of the