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Discrete Optimization

Backtracking and exchange of information: Methods to enhance a beam search algorithm for assembly line scheduling

İhsan Sabuncuoğlu [a,*], Yasin Gocgun [b], Erdal Erel [c]

[a] *Industrial Engineering Department, Bilkent University, 06800 Ankara, Turkey*
[b] *Industrial Engineering, University of Washington, Seattle, WA 98195-2650, United States*
[c] *Management Department, Bilkent University, 06800 Ankara, Turkey*

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Abstract

Beam search (BS) is used as a heuristic to solve various combinatorial optimization problems, ranging from scheduling to assembly line balancing. In this paper, we develop a backtracking and an exchange-of-information (EOI) procedure to enhance the traditional beam search method. The backtracking enables us to return to previous solution states in the search process with the expectation of obtaining better solutions. The EOI is used to transfer information accumulated in a beam to other beams to yield improved solutions.

We developed six different versions of enhanced beam algorithms to solve the mixed-model assembly line scheduling problem. The results of computational experiments indicate that the backtracking and EOI procedures that utilize problem specific information generally improve the solution quality of BS.

Keywords: Beam search; Heuristic; Assembly line sequencing

1. Introduction

In this paper, we propose an enhanced beam search (BS) algorithm to solve combinatorial optimization problems. The proposed algorithm is developed by incorporating specific enhancement tools into the traditional BS method.

BS is a constructive type heuristic and has been around for at least two decades. It was first used in artificial intelligence for the problem of speech recognition (Lowerre, 1976). Later, it was applied to optimization problems (see Ow and Morton, 1988; Chang et al., 1989; Sabuncuoglu and Karabuk, 1998).

It is a fast and approximate branch and bound method, which operates in a limited search space to find good solutions for optimization problems. It searches a limited number of solution paths in parallel, and progresses level by level without backtracking.

In this paper, we introduce two new features, namely backtracking and exchange-of-information (EOI); these enhance the traditional BS method.

* Corresponding author. Tel./fax: +90 312 2664126.
E-mail addresses: sabun@bilkent.edu.tr (İ. Sabuncuoğlu), gocgun@u.washington.edu (Y. Gocgun), erel@bilkent.edu.tr (E. Erel).

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The enhanced BS is applied to the mixed-model assembly line (MMAL) sequencing problem. The results of our computational experiments indicate that the proposed BS algorithm with these additional enhancements is superior to the traditional BS method and other heuristic approaches in the literature. Based on the experience gained in this study, we see great potential for the BS enhancement tools to solve other optimization problems.

The rest of the paper is organized as follows: we review the literature in Section 2. We discuss the problem domain and the state-of-the-art heuristic procedures in Section 3. We give the description of the proposed algorithm and the enhancement tools in Section 4. We present the results of our computational experiments in Section 5. Finally, we give concluding remarks and further research directions in Section 6.

2. Literature review

Beam search (BS) is an adaptation of the branch and bound method in which only some nodes are evaluated in the search process. In this method, only β promising nodes, called beam width number of nodes, are kept for further sprouting at any level (Sabuncuoglu and Bayiz, 1999). The potential promise of each node is determined by a global evaluation function that selects the best nodes and eliminates others. In order to reduce the computational burden of global evaluation, a filtering mechanism can also be used, by which some nodes are eliminated by a local evaluation function prior to the global evaluation.

Since BS was first employed in artificial intelligence (Lowerre, 1976), it has been used in various problem areas. Ow and Morton (1988) use BS to solve the single machine early/tardy problem and the flow shop problem. Chang et al. (1989) develop a BS algorithm for the FMS scheduling problem. In another study, Sabuncuoglu and Karabuk (1998) develop a filtered BS for the FMS scheduling problem with finite buffer capacity, routing and sequencing flexibilities. The studies of Sabuncuoglu and Bayiz (2000), Shayan and Al-Hakim (2002), and Pacciarelli and Pranzo (2004) are other scheduling examples of BS.

BS has also been applied to other problems: assembly line sequencing (Leu et al., 1997; McMullen and Tarasewich, 2005), assembly line balancing (Erel et al., 2005), stochastic programming (Beraldi and Ruszczynski, 2005), marketing (Alexouda and Paparrizos, 2001), and tool management (Zhou et al., 2005). There are also a few studies in which the solution construction mechanism of local search methods such as the ant colony optimization (ACO) approach and genetic algorithms are hybridized with BS applications (see Alexouda and Paparrizos, 2001; Tillmann and Ney, 2003; Blum, 2005).

In recent years, several enhancement tools have been developed to improve the performance of BS. For example, Honda et al. (2003) propose a backtracking BS algorithm for a multi-objective flowshop problem. In the proposed method, the traditional BS is first performed, and then a backtracking mechanism is repeatedly invoked at some selected nodes to obtain non-dominated solutions. The results of their computational experiments indicate that the proposed algorithm yields better solutions than the standard BS.

Della Croce and T'kindt (2002) and Della Croce et al. (2004) develop a recovering BS (RBS) method for combinatorial optimization problems. The recovering phase aims to recuperate the previous decisions. This step is invoked for each of the beam-width number of best child nodes. For a given node, the recovering phase, by means of interchange operators applied to the current partial schedule, checks whether the current solution is dominated by another partial solution sharing the same search tree level. If so, the current solution is replaced by the new solution. The results indicate that RBS outperforms the traditional BS. Several RBS approaches have also been proposed for other problems (see Valente and Alves, 2005; Ghirardi and Potts, 2005; Esteve et al., 2006). Table 1 further summarizes all these existing studies and BS application in various problem domains.

3. Problem domain

Even though the idea of the proposed enhancement tools is general enough to be applied to any optimization problem, its details are problem specific. Hence, we first introduce our problem domain prior to the description of the algorithm.

Mixed-model assembly lines (MMALs) are multi-level production lines in which a variety of product models are simultaneously assembled one after each other. In these systems, raw materials are fabricated into components, which in turn are combined into sub-assemblies that are transformed into final products.