Applied Soft Computing 21 (2014) 180–193

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

A comparison of five hybrid metaheuristic algorithms for unrelated parallel-machine scheduling and inbound trucks sequencing in multi-door cross docking systems

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ARTICLE INFO

Article history:
Received 3 May 2013
Received in revised form 2 February 2014
Accepted 28 February 2014
Available online 25 March 2014

Keywords:
Hybrid metaheuristic
Simulated annealing
Ant colony optimization
Unrelated parallel machine scheduling
Makespan
Inbound truck sequencing

ABSTRACT

The objective of this paper is to develop five hybrid metaheuristic algorithms, including three hybrid ant colony optimization (hACO) variants, and compare their performances in two related applications: unrelated parallel machine scheduling and inbound truck sequencing in a multi-door cross docking system in consideration of sequence dependent setup, and both zero and nonzero release time. The three hACO variants were modified and adapted from the existing literature and they differ mainly in how a solution is coded and decoded, how a pheromone matrix is represented, and the local search methods employed. The other two hybrids are newly constructed hybrid simulated annealing (hSA) algorithms, which are built based on the authors' knowledge and experience. The evaluation criteria are computational time and the objective function value, i.e., makespan. Based on the results of computational experiments the simulated annealing-tabu search hybrid turns out to be the best if maximal CPU time is used as the stopping criterion and the 2-stage hACO variant is the best if maximal number of evaluations is the stopping criterion. The contributions of this paper are: (i) being the first to carry out a comparative study of hybrid metaheuristics for the two selected applications, (ii) being the first to consider nonzero truck arrival time in multi-door cross docking operations, (iii) identifying which hACO variant is the best among the three, and (iv) investigating the effect of release time on the makespan.

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1. Introduction

Scheduling and sequencing problems are pervasive in the real world. Researchers have been very interested in developing various algorithms to help find (near-) optimal schedule/sequence for various applications. A number of reviews already exist with each focuses on different facets of the scheduling and sequencing problems. For examples, Allahverdi et al. [1] review the literature on scheduling problems involving setup times (costs). Of particular interest in this paper is parallel machine scheduling. A brief introduction follows.

An identical parallel-machine scheduling problem involves the scheduling of jobs on multiple identical machines in a production system, in which a job can be processed by any one of the free machines and each finished job will free the machine used and leave the system. If those machines are not identical, then we have a non-identical parallel machine scheduling problem, for which two cases can be further distinguished: uniform and unrelated. A uniform parallel machine scheduling problem assumes that different machines process the same job with different speeds. In other words, the processing times of a job on different machines can be related to each other by speed factors. On the contrary, an unrelated parallel machine scheduling problem considers the case that the processing times of a job on different machines are different and unrelated, or cannot be related by speed factors. Identical or similar problems can also be found in other systems such as computing systems, cross-docking warehouse systems, and port crane systems.

Other than whether the parallel machines are identical or not, jobs characteristics and optimization criteria of concern might also vary from one application to another. Two different notation schemes have been used to classify research in parallel machine

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http://dx.doi.org/10.1016/j.asoc.2014.02.026
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scheduling. The three-parameter notation, $\alpha/\beta/\gamma$, introduced by Graham et al. [2] specifies the machine environment ($\alpha = P$ for identical, Q, uniform, and R unrelated), job characteristics (β), and the chosen optimization criterion (γ), respectively. On the other hand, the four-parameter notation, $A/B/C/D$, introduced by Conway et al. [3] denotes number of jobs (A), number of available machines (B), flow pattern and special system conditions (C), and the criterion used to evaluate a schedule (D). The former scheme is followed in this paper.

Most researchers study scheduling problems as deterministic problems. All deterministic scheduling problems, with deterministic parallel machine scheduling included, are combinatorial optimization problems. Many deterministic parallel machine scheduling problems have been proved to be NP-hard. Most of the complexity results for parallel machine scheduling and other scheduling problems can be found in the Internet address http://www.informatik.uni-osnabrueck.de/knust/class/. Hence, for solving large scale deterministic parallel machine scheduling problems approximation algorithms, metaheuristics, and heuristics have been popular. Approximation algorithms are algorithms used to find approximate solutions to optimization problems. Unlike heuristics, approximate algorithms have provable solution quality and provable run-time bounds. Ideally, the approximation is optimal up to a small constant factor (for instance within 5% of the optimal solution). Meta-heuristics, such as ant colony optimization, are one kind of heuristics that find a good solution based on some intelligent search scheme and problem-dependent local search methods. Heuristics include the algorithms developed for specific problems that have no performance guarantees and are not metaheuristics; examples include the heuristic developed by Srivastava [4] for minimizing makespan on unrelated parallel machines and the heuristic developed by Yu and Egbelu [5] for sequencing trucks in a single door cross docking system.

To date, there have been at least four reviews on "parallel machine scheduling", which include Cheng and Sin [6], Mokotoff [7], Li and Yang [8], and Kravchenko and Werner [9]. Cheng and Sin review 80 papers organized in three categories in terms of optimization criteria: completion time based, due date based, and flow time based. To the best of our knowledge, no metaheuristic algorithm was included in their review. Mokotoff review mostly research works that employ completion time based optimization criteria, organized based on the solution approaches: efficient algorithms for solving particular and simple cases, enumerative algorithms, and approximation algorithms. They further distinguish two types of approximation algorithms: improvement algorithms and constructive algorithms. The category of improvement algorithms includes threshold algorithms (including iterative improvement, threshold accepting, and simulated annealing), tabu search, and genetic algorithms. The review of Li and Yang focuses on a class of non-identical parallel-machine scheduling problems in which the goal is to minimize total (or mean) weighted (or unweighted) completion time. Kravchenko and Werner survey existing approaches for the problem of scheduling n jobs with each requiring an identical execution time on a set of parallel machines, with preemption either allowed or forbidden. They focus mostly on dynamic programming and liner programming approaches, trying to describe the most fruitful ideas and pose problems with an open complexity status.

Of particular interest in his paper is the use of hybrid metaheuristic algorithms for solving unrelated parallel machine scheduling problems and inbound trucks sequencing in a multi-door cross docking system with minimizing makespan as the objective. Hybrid metaheuristic algorithms have been found to outperform pure metaheuristics for various applications in many studies, including ours such as Liao [10], Liao et al. [11]; Liao et al. [12]; Liao et al. [13], and Yi et al. [14]. So far the use of hybrid metaheuristic algorithms in parallel machine scheduling and/or truck sequencing in cross docking systems has been limited, as reviewed below.

Anghinolfi and Paolucci [15] propose a hybrid metaheuristic (HMH) approach which integrates several features from tabu search (TS), simulated annealing (SA) and variable neighborhood search (VNS) to minimize total tardiness for a class of scheduling problems characterized by a set of independent jobs to be executed on a set of parallel machines with non-zero ready times and sequence dependent setups. Guo et al. [16] study the unrelated parallel machine problem for minimizing the makespan by using a hybrid of Simulated Annealing (SA) and Tabu Search (TS) with Neighborhood Search (NS). Chen and Chen [17] proposes several hybrid metaheuristics that integrate the principles of the variable neighborhood descent approach and tabu search for the unrelated parallel-machine scheduling problem with sequence-dependent setup times given the objective of minimizing the weighted number of tardy jobs.

For the minimization of makespan in scheduling problems with parallel machines and sequence-dependent setup times, Behnamian et al. [18] propose a hybrid metaheuristic, which comprises three components: an initial population generation method based on an ant colony optimization (ACO), a simulated annealing (SA) for solution evolution, and a variable neighborhood search (VNS) which involves the use of three local search procedures to improve the population. Arnaout et al. [19] introduce a two-stage ant colony optimization (ACO) algorithm enhanced by a local search procedure to minimize the makespan for the unrelated parallel machine scheduling problem with machine-dependent and sequence-dependent setup times when the number of jobs to the number of machines ratio (N/M) is large. Keskinturk et al. [20] develop an ant colony optimization algorithm to solve the problem of minimizing average relative percentage of imbalance (ARPI) with sequence-dependent setup times in a parallel-machine environment. Note that the only similarity among the above-mentioned three studies is that they all consider sequence-dependent setup times. Both Behnamian et al. and Arnaout et al. use minimizing makespan as the evaluation criterion while Keskinturk et al. focus on minimizing average relative percentage of imbalance (ARPI) instead. Both Behnamian et al. and Keskinturk et al. consider identical parallel-machine while Arnaout et al. focus on unrelated parallel-machine instead. Most importantly, the ant colony optimization algorithms developed in the above three works are all different, mainly in how a solution is coded and decoded, how a pheromone matrix is represented, and the use of different local search methods.

As far as truck sequencing in cross docking operations are concerned, very few studies have employed hybrid metaheuristics. Soltani and Sadjadi [21] propose two hybrid metaheuristics, i.e., hybrid simulated annealing and hybrid variable neighborhood search, to solve truck sequencing in a single-door cross docking system. Liao et al. [11] develop two hybrid differential evolution algorithms for both inbound and outbound truck sequencing in a single-door cross docking system. Liao et al. [22] report that both hybrid differential evolution and ant colony optimization perform best among six metaheuristic algorithms, when applied to solve the problem of simultaneous dock assignment and inbound trucks sequencing in a multi-door cross docking system, with the objective to minimize total weighted tardiness under a fixed outbound truck departure schedule.

This research is motivated by the desire to determine which hybrid metheuristic and which variant of hybrid ant colony optimization algorithms perform better. To enable the comparative study, two related application domains are chosen, which include the unrelated parallel machine scheduling problem with sequence-dependent setup and inbound truck sequencing with nonzero release time in a multi-door cross docking system. The evaluation is

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