Expert Systems with Applications 38 (2011) 10812–10821

Contents lists available at ScienceDirect

Expert Systems with Applications

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

A new hybrid multi-objective Pareto archive PSO algorithm for a bi-objective job shop scheduling problem

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ARTICLE INFO

Keywords:
Bi-objective job shop
Pareto archive PSO
Genetic operators
VNS
Ready time
Sequence-dependent setup times

ABSTRACT

This paper presents a new mathematical model for a bi-objective job shop scheduling problem with sequence-dependent setup times and ready times that minimizes the weighted mean flow time ($\overline{F}_w$) and total penalties of tardiness and earliness (E/T). Obtaining an optimal solution for this complex problem especially in large-sized problem instances within reasonable computational time is cumbersome. Thus, we propose a new multi-objective Pareto archive particle swarm optimization (PSO) algorithm combined with genetic operators as variable neighborhood search (VNS). Furthermore, we use a character of scatter search (SS) to select new swarm in each iteration in order to find Pareto optimal solutions for the given problem. Some test problems are examined to validate the performance of the proposed Pareto archive PSO in terms of the solution quality and diversity level. In addition, the efficiency of the proposed Pareto archive PSO, based on various metrics, is compared with two prominent multi-objective evolutionary algorithms, namely NSGA-II and SPEA-II. Our computational results show the superiority of our proposed algorithm to the foregoing algorithms, especially for the large-sized problems.

1. Introduction

A job shop scheduling problem is one of the most difficult NP-hard combinatorial optimization problems (Niu, Jiao, & Gu, 2008). It can be used in industries with different routine of operation sequences in each job, so in job shop scheduling there are more potential for flexible manufacturing that is a vital system nowadays and consequently is a popular scheduling system. In a job shop scheduling problem, there are n jobs that should be processed on m machines. Each job consists of a predetermined sequence of task operations, each of which needs to be processed without interruption for a given period of time on a given machine. Tasks of the same job cannot be processed concurrently. We take into account the sequence-dependent setup time needed for each operation on each machine constraint. In addition, we assume that all jobs are not available at time zero, they arrive to the shop floor at different time that is given at the start of the production horizon planning.

A lot of studies have been carried out in this case of scheduling problems with very different conditions of work and criteria. It is worth noting that multi-objective problems are more realistic in industrial environments; however, the related research is considered less in the powerful literature of job shop scheduling. Some studies in job shop scheduling problems are presented as follows. Holthaus (1999) proposed a simulation-based analysis of dispatching rules to solve a dynamic job shop scheduling with machine breakdown. Mascis and Pacciarelli (2002) used the alternative graph formulation to study a job shop scheduling problem with blocking and no wait constraints. They represented that the common method used to solve job shop with unlimited buffer were not useful for this problem. Kis (2003) applied tabu search and genetic algorithms for job shop scheduling problems. In their model, the job routings are presented in a directed acyclic graph. Lee, Vassiliadisb, and Park (2004) proposed a novel lost based threshold accepting algorithm for solving the job shop scheduling problem. Tavakkoli-Moghaddam and Daneshmand-Mehr (2005) used a simulation-based network model to minimize makespan in job shop problems. Grabowski and Wodecki (2005) described a very fast tabu search to solve a job shop scheduling problem minimizing the makespan. They used some properties of the problem associated with blocks to design a very fast local search procedure based on tabu search. Suresh and Mohanasundaram (2006) applied Pareto achieved simulated annealing to the multi-objective job shop problem, in which the related objective functions were to minimize the makespan and mean of flow time. They assumed that ready times for all jobs are equal to zero so the second objective function is the same as the mean completion time.

Al-Anzi, Sotskov, Allahverdi, and Andreev (2006) addressed the job shop scheduling problem with unit operation time that mini-

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doi:10.1016/j.eswa.2011.02.050

mizes the total completion of jobs. This problem can be modeled as finding the optimal coloring of a special mixed graph. They developed a branch-and-bound method to solve such a hard problem. Tavakkoli-Moghaddam, Jolai, Vaziri, Ahmed, and Azaron (2005) presented a nonlinear mathematical programming model for a stochastic job shop scheduling problem and proposed a hybrid method to obtain a near-optimal solution within a reasonable amount of time. They applied a neural network approach to generate initial feasible solutions and then a simulated annealing algorithm to improve the quality and performance of the initial solutions in order to produce the optimal (or near-optimal) solution. Lian, Jiao, and Gu (2006) proposed a similar particle swarm optimization (PSO) algorithm for a job-shop scheduling problem to minimize makespan. They presented a similar PSO algorithm to solve the JSSP. At the same time, some new valid algorithm operators were proposed in their study, and they found out the effectiveness of operators by simulation. Niu et al. (2008) proposed a particle swarm algorithm with some genetic operators to solve a job shop scheduling problem with fuzzy processing times to minimize the makespan. Zhang, Li, Rao, and Guan (2008) applied a combination of simulated annealing (SA) and tabu search (TS) algorithms to solve a job shop scheduling problem. They used simulated annealing to generate a good initial solution for the tabu search algorithm.

Pan and Huang (2009) described a hybrid genetic algorithm for no-wait job shop scheduling problems with the objective of minimizing the total completion time. They defined a genetic operator by cutting out a section of genes from a chromosome and treated as a subproblem. This subproblem was then transformed to an asymmetric traveling salesman problem (ATSP) and solved with a heuristic algorithm. Subsequently, a new sequence was put back to replace the original section of the chromosome. The incorporation of this problem-specific genetic operator was responsible for the hybrid adjective. Huang and Liao (2008) presented a hybrid algorithm combining ant colony optimization (ACO) algorithm with the TS algorithm for the classical job-shop scheduling problem. Instead of using the conventional construction approach to construct feasible schedules, the proposed ACO algorithm employs a novel decomposition method inspired by the shifting bottleneck procedure and a mechanism of occasional re-optimizations of partial schedules. They also applied the TS algorithm to improve the solution quality. Adibi, Zandieh, and Amiri (2010) proposed a variable neighborhood search (VNS) for a dynamic job-shop scheduling problem with random job arrival and machine breakdown. They applied a multi-objective performance measure in their scheduling process. They considered the minimization of the makespan and total tardiness as their optimization criteria for the given problem.

Some researches done in scheduling job shop problems with dependent setup times are as follows. Low, Wu, and Hsu (2005) developed a mathematical model for multi-objective job shop scheduling to minimize the total job flow time, total job tardiness, and machine idle time. They considered sequence-dependent setup time and re-entrant operations in their presented model. At first, they used integer programming to solve this problem according to each objective individually. Then, they employed multiple-decision-making technique to evaluate three objectives simultaneously. Vinoda and Sridharan (2008) addressed dynamic job-shop scheduling with sequence-dependent setup times. They used a simulation model and applied different scenarios to realize which of them has better performance for different criteria in the given problem. Roshanaei, Naderi, Jolai, and Khalili (2009) represented a VNS method to solve job shop scheduling with sequence-dependent setup times with respect to minimizing the makespan. Naderi, Fatemi Ghomi, and Aminnayeri (2010) used a SA method to solve job- shop scheduling problems with sequence-dependent set-up time that minimizes the makespan. Naderi, Zandieh, and Fatemi Ghomi (2009b) represented job shop scheduling with dependent setup time and preventive maintenance that minimizes the makespan. They proposed two techniques to integrate production planning and preventive maintenance problems. Naderi, Khalili, and Tavakkoli-Moghaddam (2009a) represented a hybrid approach of simulated annealing and artificial immune algorithm to solve job shop scheduling with sequence dependent setup time and flexible machine availability constraints. The minimizing the total completion time is considered as the optimization criteria. Tavakkoli-Moghaddam, Khalili, and Naderi (2009) presented a hybrid method of SA and electromagnetic- like mechanism to solve job shop scheduling problems with sequence-dependent setup times and availability constraint with respect to minimizing the total weighted tardiness.

Thiagarajan and Rajendran (2005) addressed the problem of scheduling in dynamic assembly job-shops (i.e., shops that manufacture multi-level jobs) with the consideration of jobs having different earliness, tardiness and holding costs. An attempt was made in their study to present dispatching rules by incorporating the relative costs of earliness, tardiness and holding of jobs in the form of scalar weights. In the first phase of their study, relative costs (or weights) for earliness and tardiness of jobs were considered, and the dispatching rules were presented in order to minimize the sum of the weighted earliness and tardiness of jobs. In the second phase of their study, the objective considered was the minimization of the sum of the weighted earliness, tardiness and flow time of jobs, and the dispatching rules were presented by incorporating the relative costs of earliness, tardiness and flow time of jobs. Sha and Lin (2010) presented particle swarm optimization (PSO) for an elaborate multi-objective job-shop scheduling problem. The original PSO was used to solve continuous optimization problems. Due to the discrete solution spaces of scheduling optimization problems, they modified the particle position representation, particle movement, and particle velocity in their study. The modified PSO was used to solve various benchmarks. Lin et al. (2010) described an efficient job shop scheduling algorithm based on PSO. They used a new hybrid swarm intelligence algorithm consisting of PSO, SA and multi-type individual enhancement scheme in order to solve the job-shop scheduling problem. Rabbani, Aramoon-Bajestani, and Khoshkhou (2010) described a multi-objective PSO algorithm for a multi-objective project selection problem maximizing the total benefits and minimizing the total risk and total coat, simultaneously. Since solving an NP-hard problem becomes demanding as the number of projects grows, the multi-objective PSO with new selection regimes for the global and personal best particles for swarm members was designed to find the locally Pareto-optimal frontier.

In this paper, we discuss about multi-objective problems in Section 2. Then we describe our problem and the related mathematical model in Section 3. In Section 4, the general PSO and proposed algorithm are defined. The experimental results of comparison between the proposed PSO algorithm and two well-known evolutionary algorithms, namely NSGA-II and SPEA-II are shown in Section 5. Finally, the concluding remarks are presented in Section 6.

2. Multi-objective optimization

Many real-world problems involve simultaneous optimization of several objective functions. In general, these functions often compete and conflict with themselves. Multi-objective optimization with such conflicting objective functions provides a set of optimal solutions (called Pareto-optimal), rather than one optimal solution. This set includes the solutions that no other solution is