Expert Systems With Applications 51 (2016) 161–176

Contents lists available at ScienceDirect

Expert Systems With Applications

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

A self-guided differential evolution with neighborhood search for permutation flow shop scheduling

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ARTICLE INFO

Keywords:
Permutation flow shop scheduling
Guided individual
Differential evolution
Markov chain
Variable neighborhood search

ABSTRACT

The permutation flow shop scheduling problem (PFSSP) is one of the most widely studied production scheduling problems and a typical NP-hard combinatorial optimization problems as well. In this paper, a self-guided differential evolution with neighborhood search (NS-SGDE) is presented for the PFSSP with the objectives of minimizing the maximum completion time. Firstly, some constructive heuristics are incorporated into the discrete harmony search (DHS) algorithm to initialize the population. Secondly, a guided agent based on the probabilistic model is proposed to guide the DE-based exploration phase to generate the offspring. Thirdly, multiple mutation and crossover operations based on the guided agent are employed to explore more effective solutions. Fourthly, the neighborhood search based on the variable neighborhood search (VNS) is designed to further improve the search ability. Moreover, the convergence of NS-SGDE for PFSSP is analyzed according to the theory of Markov chain. Computational simulations and comparisons with some existing algorithms based on some widely used benchmark instances of the PFSSP are carried out, which demonstrate the effectiveness of the proposed NS-SGDE in solving the PFSSP.

1. Introduction

The permutation flow shop scheduling problem (PFSSP) is an important part of scheduling in the manufacturing system and has been widely used in actual production, especially in one-piece mass production. The PFSSP can be described as to find the processing sequence of n jobs over m machines to minimize the total makespan, minimize the total flowtime or satisfy other objectives. The computational complexity of the PFSSP with the makespan minimization criterion ($m \geq 3$) and the total flowtime minimization criterion ($m \geq 2$) have been proved to be a NP-complete problem (Pinedo, 2012). Since the PFSSP has great engineering application background, many scholars have made deep research on the PFSSP and many scheduling methods have been proposed. These methods mainly can be classified into two categories: exact methods and heuristic algorithms. Exact methods such as linear programming (Stafford, 1988) and branch-and-bound (Bansal, 1977) can obtain exact solutions, however the computational complexity and storage of these algorithms grow with the increase of the problem size, and the computing time increases exponentially. Therefore, exact methods can only apply to solve problems with instances of small size. The heuristic algorithms include two kinds, one is the constructive heuristic algorithm and the other is meta-heuristics algorithm. Constructive heuristic algorithms employ the problem-oriented specific knowledge and the production experience to solve problems. These algorithms can obtain the near-optimum solutions in a short period, but the qualities of solutions are not satisfactory. Nawaz–Enscore–Ham (NEH) (Nawaz, Enscore, & Ham, 1983) is one of most effective constructive heuristic algorithms, which first assigned priorities on each job based on the total processing time and then inserted jobs successively into the sequence to obtain a complete scheduling. The most important steps of NEH are how to construct the priority sequence of jobs and how to insert jobs.

Due to the limitation of exact methods and constructive heuristic algorithms, the meta-heuristic have been given special focus for they could obtain high-quality solutions with within a reasonable time limit. The meta-heuristics algorithms improve the solutions with domain dependent knowledge, which have features such as self-adaptation, self-learning and self-organization. Now the meta-heuristics algorithms for PFSSP mainly include Particle Swarm Optimization (Lian, Gu, & Jiao, 2008; Zhang & Sun, 2009), Simulated Annealing (SA) (Wodecki & Bożzejko, 2002), Genetic Algorithm (GA) (Tseng & Lin, 2009), Ant Colony Optimization (ACO) (Tzeng & Chen, 2012; Ying & Liao, 2004), Tabu Search (TS) (Grabowski & Wodecki, 2004), Iterated Local search(ILS) (El-Bouri, 2012), Estimation of Distribution Algorithm(EDA) (Chen, Chen, Chang, & Chen, 2012). For the recent short time period, a lot of literatures discuss many innovative hybrid meta-heuristic algorithms or improved meta-heuristic for

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http://dx.doi.org/10.1016/j.eswa.2015.12.001
0957-4174/

solving PFSSP with the makespan minimization criterion. Ahmadizar (2012) proposed a new ant colony algorithm named PACO, which initialized the pheromone trails based on an initial sequence, and the pheromone trail intensities changed dynamically. Chen et al. (Chen, Chang, Cheng, & Zhang, 2012; Chen & Chen, 2013) proposed two novel genetic algorithms based on EDA: the self-guided genetic algorithm (SGGA) and the ensemble self-guided genetic algorithm (eSGGA). In the SGGA, the univariate probabilistic model was use to predict the fitness of individuals and guide the crossover and mutation to generate the offspring, while the eSGGA combined the univariate probabilistic model and the bi-variate probabilistic model to learn different populations characteristic. Chang, Huang, Wu, and Cheng (2013) proposed a novel block mining method that is able to locate common structures or to establish new blocks from a set of high fit individuals. Ceberio, Irurozki, Mendiburu, and Lozano (2014) introduced a Mallows EDA whose model is a distance-based exponential probabilistic model. Li and Yin (2012) compensated the defects of the single mutation scheme with composite mutation strategies and used the fast local search to enhance the best individual. Liu and Liu (2013) proposed a hybrid discrete artificial bee colony algorithm (HDABC) in which Greedy Randomized Adaptive Search Procedure (GRASP) based on NEH were used to generate the initial population and the discrete operators are applied to generate new solution for the employed bees, onlookers and scouts. Li and Yin (2013a) proposed a cuckoo search (CS)-based memetic algorithm (HCS), where the NEH is combined with the random initialization to initialize the population, and the CS based on Lévy flights is utilized to evolve nest vectors, then a fast local search is embedded to further improve the solution. Dasgupta and Das (2015) presented a discrete inter-species cuckoo search (ISCS) algorithm. This algorithm employed the breeding strategy of different cuckoo species living in different regions and the different nature of Lévy flights depending on the region. Marinakis and Marinaki (2013) introduced a hybrid approach which combined PSO with expanding neighborhood topologies including the VNS and a path relinking strategy. Zhao, Zhang, Wang, and Zhang (2015) proposed an improved shuffled complex evolution algorithm with opposition-based learning (SCE-OBL) the PFSSP to obtain the minimum makespan. Xie, Zhang, Shao, Lin, and Zhu (2014) proposed a hybrid teaching-learning-based optimization algorithm (HTLBO), which combines the teaching-learning-based optimization algorithm to generate solution and a variable neighborhood search (VNS) to improve solution. Lin, Gao, Li, and Zhang (2015) applied backtracking search algorithm (BSA) to solve the PFSSP with the objective to minimize the makespan and used the random insertion local search to avoid premature. Chen, Tzeng, and Chen (2015) presented a population-based heuristic based on the local best solution (HLBS). The method employed three strategies: to produce a trace-model for guiding the search, to modify a filter strategy to filter the solution regions and to initiate a new jump strategy to help the search escape. Dong, Nowak, Chen, and Lin (2015) studied the limitation of ILS and proposed a self-adaptive strategy for ILS which evaluates the neighborhoods and adjusts the perturbation strength according to the evaluation. Ribas, Companys, and Tort-Martorell (2010) proposed a new heuristic which consists of three steps: The first consists of a sequencing order, the second consists of the insertion of NEH and the third step incorporates an iterated local search procedure. Vasiljevic and Danilovic (2015) studied and analyze the information about the ties in the insertion phase of NEH and proposed an improved NEH. Fernandez-Viagas and Framinan (2014) proposed a tie-breaking mechanism for the iterated greedy, which is based on an estimation of the idle times of the different subsequences.

The differential evolution algorithm (DE) proposed by Storn and Price (1997) is a population-based stochastic search technique and an effective global optimizer in the continuous domain. In recent years, the DE algorithm has gained increasing attention and has been widely used in the PFSSP. Because the standard DE algorithm is used to solve continuous problems, therefore it cannot be applied directly for the PFSSP in discrete domain. In order to solve the mapping relationships from the continuous domain to the job sequence, several improved DE algorithms for the PFSSP were presented recently, which mainly included building mapping methods and discrete methods. Tasgetiren, Liang, Sevkli, and Gencyilmaz (2004) applied the standard DE algorithm for the PFSSP with a smallest position value (SPV) method. Nearchou and Omirou (2006) proposed a novel solution encoding scheme named the sub-range encoding, and compared it with the random-keys encoding scheme. The results showed a higher performance for the sub-range encoding. Onwubolu and Davendra (2006) applied the mapping function to build the relationship between job sequences and the real-coding. Qian et al. (2008) proposed a hybrid DE (HDE) algorithm which employed a largest-order-value (LOV) rule to convert the continuous value to job permutations and used a problem-dependent local search to enhance exploitation. The convergence property of the HDE was analyzed based on Markov chains. Pan, Tasgetiren, and Liang (2007) combined the optimization mechanism of the DE algorithm with the feature of the PFSSP, and proposed a discrete DE (DDE) algorithm which introduced mutation and crossover operators based on permutations. Later on, Pan, Tasgetiren, and Liang (2008) improved the structure of the DDE algorithm and integrated a local search algorithm to enhance exploitation. The probabilistic jumping of the SA algorithm was utilized to avoid trapping in the local optimum. Li and Yin (2013b) suggested an opposition-based differential evolution algorithm to solve PFSSP with the criteria of makespan and maximum lateness. The ODDE combines DE with the opposition-based learning, the fast local search and the pairwise based local search to enhance the searching ability. Liu, Yin, and Gu (2014) proposed a hybrid differential evolution named L-HDE which combines the DE with the individual improving scheme (IIS) and Greedy-based local search.

In this paper, a self-guided differential evolution with neighborhood search (NS-SGDE) is proposed for solving the PFSSP with a criterion to minimize makespan, which combines DE with a self-guided mechanisms and some local searching strategy. Accordingly, the main contributions of NS-SGDE for solving PFSSP can be summarized as follows.

(1) In order to construct more promising initial individuals, an initial method based on the discrete harmony search algorithm is proposed to construct a few good individuals. The initial method first uses several effective constructive heuristic algorithms including the NEH (Taillard, 1990), Raj (Rajendran, 1994), FRB1 (Rad, Ruiz, & Boroojerdian, 2009), construct some guided solutions and then the discrete harmony search algorithm (Yu-Yan, Quan-ke, Liang, & Jun-qing, 2010) is employed to produce other solutions randomly by using the guided solutions.
(2) To avoid the blindness of global search, a guided agent generated by the probabilistic model (Jarboui, Eddaly, & Siarry, 2009) is proposed to guide mutation and crossover operations. The weight mechanism is proposed to address the shortcoming of the origin probabilistic model. Since the probability model used in this paper considers the similar blocks of jobs in the same positions, multiple mutation and crossover operations such as INSERT, SBOX, SJOX based on the similar blocks and the similar points are proposed to explore more effective solutions.
(3) The two neighborhood searches based on the variable neighborhood search are designed to enhance the local searching ability, which includes INSERT_VNS and SWAP_VNS. INSERT_VNS removes a job from its initial position, and then inserted into other possible positions. SWAP_VNS exchanges a job with other possible jobs.
(4) The convergence of NS-SGDE for PFSSP is analyzed according to the theory of Markov chain.