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Hybrid artificial bee colony algorithm with a rescheduling strategy for solving flexible job shop scheduling problems

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ABSTRACT

This study mainly focuses on flexible job shop scheduling problems (FJSSPs) in a modern manufacturing enterprise that presents a number of different emergencies, such as new jobs inserted, old jobs cancelled, machinery breakdowns. A feasible mathematical model based on a rescheduling strategy has been constructed as an effective solution. The rescheduling strategy is illustrated by three types of scheduling: reassembling scheduling, intersecting scheduling and inserting scheduling. The objective function is to minimize the maximum completion time (makespan). A hybrid artificial bee colony algorithm (HABC) based on Tabu search (TS) has been developed to solve the model, and a cluster grouping roulette method is proposed to better initialize the population. A crossover operator is introduced for employed bees to improve the exploitation feature. Comparative experiments with other published algorithms have been conducted on well-known benchmark instances, and the analysis results show that the HABC algorithm is efficient and effective. In addition, the proposed algorithm is applied to solve actual FJSSPs in a textile machinery manufacturing enterprise.

1. Introduction

A job shop scheduling problem (JSSP) can be defined as the allocation of service resources to perform a set of jobs over a period of time. This problem can be interpreted as n jobs that will be processed on m machines, and although different jobs may have a separate processing sequence, each operation will be processed on a candidate machine in a specified processing time. JSSPs can be divided into two parts: job operation sequencing, which consists of scheduling all job operations on all candidate machines to obtain a feasible and effective solution, and machine assigning, which consists of assigning a candidate machine to process one operation among all job operations. A flexible job shop scheduling problem (FJSSP) is a sub-class of the classical JSSP. In FJSSPs, one operation can be processed on one or more candidate machines. Therefore, FJSSPs are more complicated than JSSPs because they consider machine assignments determined for each operation, which has been proven to be an NP hard problem (Bruker & Schlie, 1990).

Many researchers have conducted research on FJSSPs in the last three decades. The earliest research on FJSSPs was conducted by Brucker and Schlie in 1990 (Bruker & Schlie, 1990), where a polynomial algorithm was proposed to solve a scheduling problem for two jobs. With the development of mathematics and computer information techniques, many different methods and algorithms have been developed to solve FJSSPs, such as ant colony optimization (ACO) (Huang, Yang, & Cheng, 2013); artificial bee colony (ABC) algorithms (Li, Pan, & Gao, 2011); artificial immune algorithms (AIAs) (Bagheri, Zandieh, Mahdavi, & Yazdani, 2010); evolutionary algorithms (EAs), which contains evolution strategy (Kim, Park, & Ko, 2003); gene expression programming (Fattahi & Fallahi, 2010); genetic algorithms (GAs) (Rabiee, Zandieh, & Ramezani, 2012); genetic programming (Yegane, Khanlarzade, & Fard, 2012); harmony searches (Nagamani, Chandrasekaran, & Saravanan, 2013); learning classifier systems; memetic algorithms; estimation of distribution algorithms (Gao et al., 2014); greedy randomized adaptive search procedure (GRASP) (Rajkumar, Asokan, Anilkumar, & Page, 2011); neighbourhood search (NS) (Lei & Guo, 2014); particle swarm optimization (PSO) (Sadrzadeh, 2013); simulated annealing (SA) (Khalife, Abbasi, & Abadi, 2010); Tabu search (TS) (Saidi-Mehrabad & Fattahi, 2007); and hybrid techniques based on different heuristics and meta-heuristics (Gao, Gen, & Sun, 2006; Imanipour & Zegordi, 2006; Jiang, Wen, Ma, Long, & Li, 2011; Li & Gao, 2016; Li, Pan, & Tasgetiren, 2014; Nagamani, Chandrasekaran, & Saravanan, 2013; Tay & Ho, 2008; Wang & Liu, 2015; Xing, Chen, Wang, Zhao, & Xiong, 2010;

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Zhang, Manier, & Manier, 2012; Zribi, Kacem, El Kamel, & Borne, 2007). These studies encompass the wide research scope of optimization models, such as the makespan, mean completion time, maximum flow time, mean flow time, total tardiness, average tardiness, total workload, critical machine workload and multi-objective models based on different single objectives. Chaudhry and Khan (2016) presented the development of an FJSSP as well as a synthetic investigation of different techniques that have been proposed and employed to resolve these problems from 1990 to 2014 in 404 different publications, including books, conference papers, journal articles, and reports. The details are illustrated in Table 1. Almost 59% of the publications employed hybrid techniques (HTs) or EAs.

ABC algorithm is a meta-heuristic algorithm that is based on relative populations, and it was first introduced by Karaboga (Karaboga, 2005) to solve multi-variable, multi-modal continuous functions. This algorithm has obvious superiority for solving combinational optimization problems compared with other algorithms (Karaboga, 2009; Karaboga & Akay, 2009; Karaboga & Basturk, 2007, 2008). Therefore, more intensive studies on ABC's application have been conducted by many researchers in the research field of job shop scheduling.

Nasiri (2015) proposed a modified ABC for the stage shop schedule problem, which is a sub-class of the mixed shop based on job shop and open shop. To enhance the ABC algorithm's exploitation capability, an effective neighbourhood strategy for the stage shop schedule problem and a PSO were applied in the employed bee phase and onlooker bee phase, respectively. Ribas, Companys, and Tort-Martorell (2015) presented a high-performing discrete ABC (DABC) algorithm to solve the blocking flow shop problem based on a flow time criterion, and four strategies were considered for the food source phase and two strategies were also considered for the employed bee phase, onlooker bee phase and scout bee phase. Xie and Wang (2016) proposed an enhanced ABC algorithm for order acceptance of single machine and class setups for scheduling, and they designed appropriate neighbourhood operators to maximize the total revenue. To solve the scheduling problem in a new steelmaking continuous casting enterprise, Pan (2016) divided the problem into two sub-problems: a charge scheduling problem in a hybrid flow shop and a cast scheduling problem with parallel machines. A novel cooperative co-evolutionary ABC algorithm was proposed.

The ABC algorithm has received intensive interest from many scholars also studying the FJSSP. Li et al. (2011) proposed a hybrid discrete ABC algorithm based on Pareto for solving the multi-objective FJSSP, a crossover operator was developed for the employed bee phases to learn valuable information from each other, an external Pareto archive set was proposed to record the identified non-dominated solutions, and a fast Pareto set update function was constructed. Wang, Zhou, Xu, Wang, and Liu (2012) proposed an effective ABC algorithm designed to minimize the makespan, utilized multiple strategies with higher quality and better diversity to initialize the solution, designed two variation factors to introduce new neighbourhood food resources in the employed bee phase, and proposed a local search strategy based on critical paths to enhance the local intensification capability of onlooker bees. Wang, Zhou, Xu, and Liu (2013) developed a hybrid ABC algorithm to solve the fuzzy FJSSP, introduced a local search strategy to strengthen the local intensification capability, which was based on a variable NS, and updated the population with a new source in an adjustable search radius to prevent premature convergence during the scout bee phase. Lei (2013) proposed an effective multi-objective ABC for interval JSSPs with flexible maintenance and non-resumable jobs to minimize the makespan and total interval tardiness. Caniyilmaz, Benli, and Ilkay (2015) proposed a hybrid technique based on ABC and GA for FJSSP, and the setup times based on job sequence and two constraints were considered. Gao et al. (2015) proposed a two-stage ABC algorithm for a scheduling problem and rescheduling problem with new jobs in remanufacturing engineering, a new rule has been proposed for bee colony population initialization, and an ensemble local search strategy was introduced to enhance the algorithm performance. Han, Gong, and Sun (2015) proposed a novel discrete ABC for solving the blocking FJSSP with a makespan criterion that incorporated the ABC algorithm with other different evolution strategies, and three operators were proposed: employed bee operator, onlooker operator and local search operator based on insert-neighbourhood with a small probability. Li, Pan, and Duan (2016) proposed an improved DABC algorithm to solve the hybrid FJSSP in a molten iron system, in which the operations included dynamic skipping, and a dynamic encoding mechanism and a flexible decoding method were developed; in addition, a right-shift strategy and an improved local search strategy were introduced to improve the solution quality and exploitation ability.

In a practical workshop, dynamic events occur, such as new jobs inserted, old jobs cancelled, machine breakdowns. For an effective solution, a feasible mathematical model based on a rescheduling strategy is constructed in the following sections. The rescheduling strategy will be illustrated with three types of scheduling: reassembling scheduling, intersecting scheduling and inserting scheduling. A hybrid artificial bee colony algorithm based on the ABC algorithm and TS algorithm is developed for solving the FJSSP with new jobs inserted, old jobs cancelled and machine breakdowns. The objective function is to minimize the makespan. A hybrid artificial bee colony algorithm (HABC) based on TS has been developed to solve the model, and a cluster grouping roulette

Table 1
Details of the various techniques applied in 404 different publications.

No.	Technique	Number of publications	Percentage (%)	Number of citations
1	Hybrid techniques	69	35.03	3572
2	Evolutionary algorithms	47	23.86	1940
3	Heuristic	19	9.64	598
4	Tabu search	12	6.09	1297
5	Integer/liner programming	10	5.08	233
6	Particle swarm optimization	8	4.06	60
7	Miscellaneous techniques	7	3.55	221
8	Neighbourhood search	6	3.05	187
9	Artificial immune algorithm	5	2.54	110
10	Mathematical programming	4	2.03	26
11	Simulated annealing	4	2.03	104
12	Ant colony optimization	3	1.52	117
13	Greedy randomized adaptive search procedure	2	1.02	32
14	Artificial bee colony	1	0.51	48