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A two-stage artificial bee colony algorithm scheduling flexible job-shop scheduling problem with new job insertion

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ABSTRACT

This study addresses the scheduling problem in remanufacturing engineering. The purpose of this paper is to model effectively to solve remanufacturing scheduling problem. The problem is modeled as flexible job-shop scheduling problem (FJSP) and is divided into two stages: scheduling and re-scheduling when new job arrives. The uncertainty in timing of returns in remanufacturing is modeled as new job inserting constraint in FJSP. A two-stage artificial bee colony (TABC) algorithm is proposed for scheduling and re-scheduling with new job(s) inserting. The objective is to minimize makespan (maximum complete time). A new rule is proposed to initialize bee colony population. An ensemble local search is proposed to improve algorithm performance. Three re-scheduling strategies are proposed and compared. Extensive computational experiments are carried out using fifteen well-known benchmark instances with eight instances from remanufacturing. For scheduling performance, TABC is compared to five existing algorithms. For re-scheduling performance, TABC is compared to six simple heuristics and proposed hybrid heuristics. The results and comparisons show that TABC is effective in both scheduling stage and rescheduling stage.

1. Introduction

Many researchers studied flexible job shop scheduling problem (FJSP) in the past decade. FJSP is a generation of classic job shop scheduling problem (JSP). In FJSP, an operation can be processed on more than one candidate machines. For solving FJSP problem, two sub-problems have to be considered, machine assignment and operation sequencing. Machine assignment is to assign a processing machine for each operation while operation sequencing is to schedule all operations on machines to obtain feasible and quality solution. Therefore, FJSP is more complicated than JSP problem and is classified as NP-hard problem (Bruker & Schlie, 1990).

The first study to address FJSP was by Bruker and Schlie who proposed a polynomial algorithm for two jobs FJSP. In recent years, many heuristics and meta-heuristics have been employed for FJSP problem, for example tabu search (TS) (Brandimarte, 1993), genetic algorithm (GA) (Gao, Sun, & Gen, 2008), particle swarm optimization (PSO) (Zhang, Shao, Li, & Gao, 2009), simulated annealing (SA) (Li, Pan, & Gao, 2011; Li, Pan, Suganthan, & Chua, 2011), ant colony optimization (ACO) (Xing, Chen, Wang, Zhao, & Xiong, 2010), parallel variable neighborhood search (PVNS) (Yazdani, Amiri, & Zandieh, 2010) and hybrid algorithms based on different heuristics and meta-heuristics.

Among different approaches, artificial bee colony (ABC) is a widely employed swarm intelligence algorithm for scheduling FJSP problems. ABC algorithm is a relatively new population-based meta-heuristic approach that is based on the collective behavior of self-organized systems. It was first proposed to solve the multi-variable and multi-modal continuous functions (Karaboga, 2005). Many comparative studies have shown that the performance of the ABC algorithm is competitive to other population-based algorithms with the advantage of employing fewer control parameters in the continuous space (Karaboga, 2009; Karaboga & Akay, 2009; Karaboga & Basturk, 2007, 2008). The ABC algorithm has received intensive interest from researchers in scheduling fields.

Li (Li et al., 2011; Li, Pan, Suganthan, et al., 2011) proposed a Pareto-based ABC algorithm for multi-objective FJSP problem. In

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the study, a crossover operator was proposed for sharing information between bees. Furthermore, a fast Pareto set update function was designed to decrease the computational times. Wang (Wang, Zhou, Xu, & Liu, 2012; Wang, Zhou, Xu, & Wang, 2012) proposed an effective ABC algorithm for FJSP to minimize makespan. The novelty of the algorithm is employ a combination of several heuristic rules for initializing food sources. Crossover and mutation operators were designed to generate new neighbor food sources for employed bees. A critical path based local search was proposed to improve the intensification capability for the onlooker bees. Wang (Wang et al., 2012; Wang, Zhou, Xu, & Wang, 2012) also proposed an enhanced Pareto-based artificial bee colony algorithm for multi-objective FJSP with makespan, the total workload of machines and the workload of the critical machine. In addition, a recombination and select strategy is employed to determine the survival of the bees and Taguchi method based parameter setting is investigated in design of experiment. For FJSP with fuzzy processing time, Wang (Wang, Wang, Xu, & Liu, 2013; Wang, Yin, & Qin, 2013; Wang, Zhou, Xu, & Liu, 2013) proposed a hybrid ABC algorithm with variable neighborhood search (VNS).

ABC algorithm was also employed for other shop scheduling problem. Lei (Lei & Guo, 2013) proposed a modified ABC for JSP with lot streaming. An effective two-phase decoding procedure is applied in which a schedule is first built and then transportation tasks are dispatched. Swap and insertion were used in the employed bee phase and the onlooker bee phase respectively to produce new solutions. Zhang (Zhang, Song, & Wu, 2013) proposed a hybrid ABC for JSP with total weighted tardiness objective.

FJSP has strong industry background, such as semiconductor manufacturing process, automobile assembly process and mechanical manufacturing systems etc. al. For actual industry related scheduling, many constraints or uncertain conditions have to be considered when solving FJSP. Mousakhan (2013) considered sequence-dependent setup time in FJSP with total tardiness. A mathematic model was developed to formulate FJSP with sequence-dependent setup time and an iteration based meta-heuristic was proposed for solving the same problem. Wang Ling and Wang Shengyao (Wang, Wang, et al., 2013; Wang, Yin, et al., 2013; Wang, Zhou, et al., 2013) studied FJSP with fuzzy processing time using ABC and estimation of distribution algorithm (EDA). The influence of parameter setting was considered in both ABC and EDA. The novelty of the algorithm is that a left-shift scheme was employed for improving the scheduling solution in decoding stage. In addition, crossover based exploitation and variable neighborhood search (VNS) were employed for improving the performance of ABC. Xiong (Xiong, Xing, & Chen, 2013) researched into robust scheduling multi-objective FJSP with random machine breakdowns. Two surrogate measures for robustness were developed. One was for machine breakdown and another was for the location of float times and machine breakdown at the same time. Al-Hinai (Al-Hinai & ElMekkawy, 2011) researched robust and stable scheduling for FJSP with random machine breakdowns using a two-stage hybrid genetic algorithm. The first stage considered general FJSP while the second stage was for machine breakdown in the decoding space. Calleja (Calleja & Pastor, 2014) and Wang (Wang, Wang, et al., 2013; Wang, Yin, et al., 2013; Wang, Zhou, et al., 2013) also considered and studied FJSP with constrains, for example, transfer batches and machine disruption. Li, Pan, & Tasgetiren (2014) researched on the FJSP with maintenance activities using ABC algorithm. A self-adaptive strategy was proposed to generate new neighboring solutions and tabu search based local search was employed to improve performance. For multi-objective function, the algorithm was compared to ten existing algorithms to verify algorithm's effectiveness.

In this study, we consider the FJSP problem in remanufacturing environment. Remanufacturing is the process of disassembly and recovery at the module level and, eventually, at the component level (Lund, 1984). It requires the repair or replacement of worn out or obsolete components and modules. Parts subject to degradation affecting the performance or the expected life of the whole are replaced. Remanufacturing is a form of a product recovery process that differs from other recovery processes in its completeness: a remanufactured machine should match the same customer expectation as new machines (Krupp, 1992). Guide (2000) considered the production planning when inputs have different and uncertain quality levels and discussed different decision variables in remanufacturing engineering. Junior and Filho (2012) reviewed the literatures on production planning and control in remanufacturing. Seventy-six papers were examined and classified. However, there are few literatures on reprocessing scheduling in remanufacturing. Uncertainty in timing of returns is one of seven major complicating characteristics in remanufacturing (Ferguson, 2009; Krupp, 1993). Li Yongjian (Li, Chen, and Cai, 2006) proposed a dynamic programming approach to derive the optimal solution in the case with large returned products and different arriving time. Li Jianzhi (Li, González, and Zhu, 2009) proposed a simulation optimization model with a prioritized stochastic batch arrival mechanism to plan and control the remanufacturing process. The uncertainty in timing and quantity are factors cannot be controlled by remanufacturers. It means that new returned product(s) or job(s) may need to be inserted into the ongoing existing scheduling solution. It is therefore important to handle this uncertainty in remanufacturing scheduling. As many discrete manufacturing systems, remanufacturing processes can be modeled as FJSP problem.

Building on the successful application of ABC for solving FJSP, a two-stage artificial bee colony (TABC) algorithm is proposed for FJSP with new job inserting. The first stage is for the general FJSP scheduling problem while the second stage is for rescheduling after new job inserting. To improve the algorithm performance, we add crossover operator and critical path based local search method.

The motivation to design two-stage ABC algorithm is scheduling and rescheduling FJSP with new job inserting. The first stage is to schedule the existing job at start stage. After that, the scheduling solution will be executed in shop floor. The second stage is to reschedule for new job inserting. After new job inserting, the second stage will be activated to reschedule the new inserted job(s) and the existing jobs' operations that are not yet started at the inserting time. The second stage will be executed repeatedly for each new job inserting. In the first stage, all machines and jobs have the same start time. In the second stage, one machine is available for rescheduling after completing the current operation if there is an operation on this machine at new job inserting time. The jobs and machines may have different start time for rescheduling. The objective considered in this paper is to minimize the maximum complete time (makespan).

The remainder of this paper is organized as follows. Section 2 describes the FJSP with new job inserting. In Section 3, the ABC algorithm is introduced. The two-stage ABC algorithm is proposed in Section 4. Experiment design, comparison and discussion are in Section 5. We conclude this paper with future work in Section 6.

2. Description of FJSP with new job inserting

In FJSP, each job consists of a sequence of operations. An operation can be executed by one machine out of a set of candidate machines. Each operation of a job must be processed only on one machine at a time, while each machine can process only one operation at a time. The following notations and assumptions are used for the formulation of FJSP.