ARTICLE IN PRESS
JID: KNOSYS [m5G;June 21, 2016;13:59]

Knowledge-Based Systems 000 (2016) 1–16

Contents lists available at ScienceDirect

Knowledge-Based Systems

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

Artificial bee colony algorithm for scheduling and rescheduling fuzzy flexible job shop problem with new job insertion

Kai Zhou Gao [a,b], Ponnuthurai Nagaratnam Suganthan [b], Quan Ke Pan [c,*], Mehmet Fatih Tasgetiren [d], Ali Sadollah [b]

[a] School of computer, Liaocheng University,Liaocheng, 252059, P. R. China
[b] School of Electrical and Electronic Engineering, Nanyang Technological University, 639798, Singapore
[c] State Key Lab of Digital Manufacturing Equipment & Technology in Huazhong University of Science & Technology, Wuhan, 430074, P. R. China
[d] Department of Industrial Engineering, Yasar University, Izmir, Turkey

ARTICLE INFO

Article history:
Received 27 October 2015
Revised 12 June 2016
Accepted 13 June 2016
Available online xxx

Keywords:
Artificial bee colony
Flexible job shop scheduling
Fuzzy processing time
New job insertion
Remanufacturing.

ABSTRACT

This study addresses flexible job shop scheduling problem (FJSP) with two constraints, namely fuzzy processing time and new job insertion. The uncertainty of processing time and new job insertion are two scheduling related characteristics in remanufacturing. Fuzzy processing time is used to describe the uncertainty in processing time. Rescheduling operator is executed when new job(s) is (are) inserted into the schedule currently being executed. A two-stage artificial bee colony (TABC) algorithm with several improvements is proposed to solve FJSP with fuzzy processing time and new job insertion constraints. Also, several new solution generation methods and improvement strategies are proposed and compared with each other. The objective is to minimize maximum fuzzy completion time. Eight instances from remanufacturing are solved using the proposed TABC algorithm. The proposed improvement strategies are compared and discussed in detail. Two proposed ABC algorithms with the best performances are compared against seven existing algorithms over by five benchmark cases. The optimization results and comparisons show the competitiveness of the proposed TABC algorithm for solving FJSP.

1. Introduction

Flexible job shop scheduling problem (FJSP) is an extension of the classical job shop-scheduling problem (JSP). In JSP, an operation can only be processed on one machine. In FJSP, an operation can be processed on any machine among a set of candidate machines. The FJSP includes two-sub problems, namely machine assignment and operation sequencing. Machine assignment is to assign a processing machine for each operation while operation sequencing is to schedule all operations to obtain a feasible solution. Hence, the FJSP is more complicated than the classical JSP problem and is proven to be an NP-hard problem.

Bruker and Schlie [1] are the pioneers to research on the FJSP. They proposed a polynomial algorithm for two jobs and identical machines used in an FJSP. In recent years, many researchers focused on meta-heuristics for tackling the FJSP. Karimi [2] proposed a knowledge-based algorithm for the FJSP, which combined variable neighborhood search to improve the algorithm's performance. Gutiérrez [3] designed a hybrid genetic algorithm (HGA) for solving the FJSP, where GA is combined with repair heuristics. For stochastic job shop scheduling problem, Zhang [4] developed a hybrid particle swarm optimization algorithm to minimize the expected total weighted tardiness as the objective function. Some researchers focused on FJSP with practical constraints in different industries. For example, Wang and Yu [5] addressed the FJSP with machine maintenance activities using a filtered beam search (FBS) based algorithm. Also, for the FJSP with maintenance activities constraint, Lin [6] proposed a hybrid biogeography-based optimization algorithm. Rossi [7] investigated the FJSP with sequence-dependent setup and transportation times. Karthikeyan and Asokan et al. [8] studied the FJSP with limited resource constraint.

The FJSP with fuzzy processing time constraint has been investigated by many researchers and engineers in recent years. Lei [9,10] proposed a decomposition-integration GA (DIGA) and a co-evolutionary GA (CGA). In the two aforementioned papers, five benchmark cases with fuzzy processing time were tested. Wang and Zhou et al [11] proposed a hybrid artificial bee colony (HABC) algorithm with variable neighborhood search (VNS) for the FJSP with fuzzy processing time. The HABC obtained better results than DIGA for four benchmark cases solved by DIGA.

* Corresponding author at. Wuchang district, Wuhan, China.
E-mail address: panquanke@qq.com (Q.K. Pan).

http://dx.doi.org/10.1016/j.knosys.2016.06.014
0950-7051/© 2016 Published by Elsevier B.V.

Wang and Wang et al. [12] proposed an estimation of distribution algorithm (EDA) for the FJSP with fuzzy processing time. In the EDA, a left-shift scheme was employed to improve solution when idle time exists among machines. Numerical testing results and comparisons showed that the EDA performed better than the DIGA and CGA for five reported benchmark cases. Xu and Wang [13] addressed the FJSP with fuzzy processing time using teaching-learning-based optimization (TLBO) algorithm. A bi-phase crossover scheme and local search operators are incorporated to balance the exploration and exploitation capabilities. The experimental results showed that the TLBO algorithm had better performance than the DIGA, CGA, HABC and EDA. In the HABC, EDA, and TLBO algorithms, Taguchi method was employed to investigate the influence of parameters settings.

Palacios et al. [14] proposed a GA with Tabu search and heuristic seeding (HGTS) for the fuzzy FJSP. In their paper, a feature based heuristic was proposed to generate high-quality and diverse initial solutions. The numerical results showed that the HGTS algorithm was superior over the CGA, HABC, EDA, and swarm-based neighborhood search algorithm (SNSA) algorithms [15] that was also proposed for the FJSP with fuzzy processing time.

Furthermore, Gao et al. proposed a discrete harmony search (DHS) [16] algorithm to handle the FJSP with fuzzy processing time. In their paper, a simple and effective heuristic was proposed to initialize the population. A novel coding method and a new harmony generating strategy were employed. The DHS was compared to the DIGA, CGA, HABC and EDA algorithms for the five well-known benchmark cases. The experimental results showed the competitiveness of the DHS algorithm. In addition, DHS also effectively solved eight instances with fuzzy processing time. These instances came from practical remanufacturing problems.

The fuzzy or uncertainty of processing time is one of seven characteristics of remanufacturing [17–20]. Beside the fuzzy or uncertainty of processing time, there is another scheduling related constraint in remanufacturing industry, which is new job insertion. In remanufacturing environment, new job arrival is unpredictable [21–23]. When a new job arrives and it is inserted into the processing job sequence, conflicts may arise and the objective may be affected. Therefore, rescheduling may be needed in this condition. Because the scheduling solution is being executed in workshop, the machines are available for rescheduling when the current operations on them are completed. It means that machines and jobs may have different restart times when rescheduling is performed. However, most existing literatures for the FJSP have considered only one constraint. In this paper, especially for the remanufacturing, fuzzy processing time and new job insertion have been added in the FJSP model.

Among the existing meta-heuristics for the FJSP, artificial bee colony (ABC) algorithm is a relatively recent meta-heuristic method developed by Karaboga [24]. Originally, the ABC algorithm was developed for solving multi-variable and multi-modal continuous functions. Many researches demonstrated the ABC algorithm's competitive performance for continuous and discrete optimization problems. To name a few, Kiran analyzed the performance of discrete ABC algorithm with neighborhood operator on traveling salesman problem [25] and proposed an XOR-based ABC algorithm for binary optimization problem [26]. In recent years, the ABC algorithm has been applied to solve shop scheduling problems successfully. Banharnsakun et al. [27,28] employed the best-so-far ABC (B-ABC) to solve the JSP. Zhang [29] proposed an ABC algorithm for the JSP with random processing times. Wang [30,31] designed two effective ABC algorithms for mono-objective and multi-objective the FJSP. Thammano [32] designed a hybrid ABC algorithm with local search to solve FJSP. Li [33] proposed a Pareto-based discrete ABC algorithm for multi-objective FJSP problem. Pan [34] proposed a discrete ABC algorithm for the lot-streaming flow shop scheduling problem. A self-adaptive strategy was employed in their study to improve the performance of the algorithm.

Most existing ABC algorithms for shop scheduling problem have not considered the practical constraints. Few ABC algorithms have focused on one constraint and to the best knowledge, no research has been done on ABC algorithm for multiple practical constraints, particularly for the remanufacturing constraints, fuzzy processing time and new job insertion.

This study presents two innovative concepts. The first one is that fuzzy processing time and new job insertion are modeled from remanufacturing industry and the two constraints are considered together in the FJSP. Fuzzy processing time is used to describe the uncertainty of processing time. Rescheduling is executed when new job(s) is (are) inserted into existing scheduling solution. The second one is that a two-stage artificial bee colony (TABC) algorithm is proposed to solve the FJSP having two constraints. Several novel solution generating and improving strategies are proposed to improve the performance of TABC. The objective is to minimize the maximum fuzzy completion time. The proposed TABC and its variants solved eight instances from remanufacturing engineering effectively and efficiently. Two best variants of TABC are compared with seven existing algorithms over five benchmark cases with fuzzy processing time. The results and comparisons highlight the efficiency of TABC algorithm for solving the FJSP with remanufacturing constraints.

The rest of this paper is organized as follows: Section 2 describes the FJSP problem with fuzzy processing time and new job insertion constraints. The basic ABC algorithm is introduced in Section 3. Section 4 represents the TABC algorithm. Section 5 gives experimental results discussions and comparisons. Finally, conclusion is drawn in Section 6.

2. FJSP with two constraints

2.1. FJSP

In the FJSP, each job consists of a sequence of operations. An operation can be executed by 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.

(1) Let $J = \{J_i\}, 1 \le i \le n$, indexed i, be a set of n jobs to be scheduled. q_i denotes total number of operations of job J_i.
(2) Let $M = \{M_k\}, 1 \le k \le m$, indexed k, be a set of m machines.
(3) Each job J_i consists of a predetermined sequence of operations. Let $O_{i,\,h}$ be operation h of J_i .
(4) Each operation $O_{i,\,h}$ can be processed without interruption on one of a set of candidate machines $M(O_{i,\,h})$. Let $P_{i,\,h,\,k}$ be the processing time of $O_{i,\,h}$ on machine M_k.
(5) Decision variables

$$x_{i,h,k} = \begin{cases} 1, & \text{ifmachine}k\text{isselectedfortheoperation}O_{i,h} \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

$c_{i,\,h}$ denotes the completion time of the operation $O_{i,\,h}$, c_i denotes the completion time of job J_i
(6) The objective is to minimize makespan and maximum machine workload.

Makespan denoted by C_M, can be calculated by the following equation:

$$Min\ C_M = \max_{1\le i\le n}\{c_i\} \tag{2}$$