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Effective ensembles of heuristics for scheduling flexible job shop problem with new job insertion

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ABSTRACT

This study investigates the flexible job shop scheduling problem (FJSP) with new job insertion. FJSP with new job insertion includes two phases: initializing schedules and rescheduling after each new job insertion. Initializing schedules is the standard FJSP problem while rescheduling is an FJSP with different job start time and different machine start time. The time to do rescheduling is the same as the time of new job insertion. Four ensembles of heuristics are proposed for scheduling FJSP with new job insertion. The objectives are to minimize maximum completion time (makespan), to minimize the average of earliness and tardiness (*E*/*T*), to minimize maximum machine workload (Mworkload) and total machine workload (Tworkload). Extensive computational experiments are carried out on eight real instances from remanufacturing enterprise. The results and comparisons show the effectiveness of the proposed heuristics for solving FJSP with new job insertion.

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1. Introduction

Flexible job shop scheduling problem (FJSP) is an extension of classical job shop scheduling problem (JSP) (Jain & Meeran, 1998). FJSP includes two sub-problems, machine assignment and operation sequence. Machine assignment is to select a processing machine from candidate machines for each operation. Operation sequence is to schedule all operations on all machines to obtain feasible and satisfactory solutions. Hence, FJSP is very complicated and have been proven to be an NP-hard problem (Garey, Johnson, & Sethi, 1976).

Brucker and Schlie (1990) first study FJSP problem and proposed a polynomial algorithm for FJSP problem with two jobs. In recent years, many research works solve FJSP problem using heuristics and meta-heuristics. Heuristics include machine assignment component and operation sequence component. For machine assignment component, Pezzella, Morganti, and Ciaschetti (2008) proposed operation minimum processing time heuristic and global minimum processing time heuristic. Li, Pan, and Gao (2011) and Li, Pan, Suganthan, and Chua (2011) developed operation minimum processing time heuristic to generate initial solutions. Vilcot and Billaut (2011) proposed two-step greedy rule. Gao, Suganthan, and Pan (2014) mixed operation minimum processing time rule and earliest available machine rule to construct a new heuristic. For operation sequence component, Brandimarte (1993) proposed most work remaining and shortest processing time heuristics. Pezzella et al. (2008) proposed most number of operations remaining heuristic. The advantage of simple heuristics is their ability to find a feasible solution in a very short time. Simple heuristics cannot ensure obtaining the optimal solution or approximately optimal solutions. For meta-heuristics, tabu (TS) (Li, Pan, & Liang, 2010), genetic algorithm (GA) (Gao, Sun, & Gen, 2008), partial swarm optimization (PSO), artificial bee colony (ABC) (Li et al., 2010; Wang, Zhou, Xu, Wang, & Liu, 2012), estimation of distribution algorithm (EDA) (Wang, Wang, Xu, & Liu, 2013) and harmony search algorithm (HS) (Gao et al., 2014; Yuan & Xu, 2013) were employed for solving FJSP with an objective or multiple objectives. Generally, meta-heuristics can obtain better quality solutions than simple heuristics. However, meta-heuristics need longer time than simple heuristics, especially for large problem.

FJSP exists in many industry fields, such as mechanical manufacturing, remanufacturing, semiconductor manufacturing, and automobile assembly process. There are many in these industry

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fields. However, most existing literatures do not consider practical constraints and uncertainty related issues in real industrial environments. Few researchers focused on FJSP problem considering real-life processing constraints. Mousakhani (2013) considered sequence-dependent setup time in FJSP with total tardiness. A mathematical model was developed to formulate FJSP with sequence-dependent setup time and an iteration based meta-heuristic was proposed. Wang, Wang, and Liu (2013) and Wang, Zhou, Xu, and Liu (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. A left-shift scheme was employed for improving the scheduling solution in decoding stage. In addition, crossover and variable neighborhood search (VNS) were employed for improving the performance of ABC. Xiong, Xing, and Chen (2013) researched 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 and EIMekkawy (2011) researched robust and stable scheduling for FJSP with random machine breakdowns using a two-stage hybrid genetic algorithm. The first stage considered the standard FJSP while the second stage was for machine breakdown in the decoding space. In addition, Calleja and Pastor (2014) and Wang, Yin, and Qin (2013) studied FJSP with considerations for transfer of batches and machine disruption.

This study researches on FJSP problem with new job insertion. This problem is modeled from remanufacturing environments. New job insertion is one of seven features of remanufacturing. In remanufacturing environment, the account of returned products and the return time are factors that cannot be controlled by remanufacturers. There may be job(s) coming and be inserted into the current solution when the solution is being executed. In this condition, new job(s) and non-started operations of existing jobs will have to be rescheduled. The start time of different jobs may be different and the start time of different machines may also be different. Hence, the initial scheduling phase is the standard FJSP problem while the problem in rescheduling phase is an FJSP with different start times for different machines depending on their completion times of on-going operations. Rescheduling time should be very short to make sure continue processing in shop floor. We proposed several ensembles of heuristics for solving FJSP with new job insertion constraint. Experiment results show that these ensembles of heuristics can obtain better quality solutions than simple heuristics and do not need long time as meta-heuristics. The objectives are to minimize maximum completion time (makespan), to minimize the average of earliness and tardiness (E/T), and to minimize the maximum machine workload (Mworkload) and total workload (Tworkload). The discussions and comparisons show the performance of ensembles of heuristics for solving FJSP with new job insertion.

The remainder of this paper is organized as follows. Section 2 describes the FJSP with new job insertion. In Section 3, the heuristics and proposed ensembles of heuristics are presented in detail. Experimental design, comparisons and discussions are presented in Section 4. We conclude this paper in Section 5.

2. FJSP with new job insertion

2.1. Flexible job shop problem

In FJSP, each job includes a sequence of operations. An operation can be processed on one set of candidate machines. One operation must be processed only on one machine with no interruption, while one machine can process only one operation at a time. The following notations and assumptions are used for the formulation of FJSP:

(1) Let $J = \{J_i\},\ 1 \leqslant i \leqslant n$, indexed i, be a set of n jobs to be scheduled. q_i denotes the total number of operations of job J_i.
(2) Let $M = \{M_k\},\ 1 \leqslant k \leqslant m$, 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

$$x_{i,h,k} = \begin{cases} 1, & \text{if machine } k \text{ is selected for operation } O_{i,h} \\ 0, & \text{otherwise} \end{cases}$$

$c_{i,h}$ denotes the completion time of operation $O_{i,h}$
c_i denotes the completion time of job J_i

(6) The objectives are to minimize Makespan, E/T, Mworkload and Tworkload.

Makespan, denoted by C_M, can be calculated as follows:

$$\text{Min } C_M = \max_{1 \leqslant i \leqslant n}\{C_i\} \tag{1}$$

where c_i is the completion time of job i.

Average of earliness and tardiness, denoted by E/T, is the earliness or tardiness of job J_i compared to the due date of job J_i.

$$\text{Min } E/T = \frac{\sum_{i=1}^{n}|c_i - d_i|}{n} \tag{2}$$

where c_i is the completion time of job J_i and d_i is the due date of job i.

Maximum workload, denoted by W_M, can be calculated by:

$$\text{Min } W_M = \max_{1 \leqslant j \leqslant m}\{w_j\} \tag{3}$$

Total workload, denoted by W_T, can be calculated by:

$$\text{Min } W_T = \sum_{j=1}^{m} w_j \tag{4}$$

where w_j is the workload of machine j.

2.2. New job insertion

New job insertion constraint is modeled from remanufacturing environment (Daniel & Guide, 2000; Ferguson, 2009). Rescheduling operator is necessary when a new job comes and is inserted into the scheduled solution that is being executed in shop floor. For existing job, the start time is the insertion time or the completion time of current processing operation. For each machine, start time is the insertion time or the completion time of the on-going operation on this machine. Hence, the problem in rescheduling phase is FJSP with different job start times and different machine start times.

To explain FJSP problem with a new job insertion, an example is shown in Fig. 1. Fig. 1(a) shows a Gantt chart for 3-jobs and 3-machines FJSP problem. The number operations in Job1, Job2, and Job3 are 3, 2 and 2, respectively. The makespan value in this scheduling solution is 10. The completion times of M1, M2, and M3 are 8, 10 and 8. Fig. 1(b) shows the new job, Job4, comes and will be inserted into the executing schedule at Time 3. Job4 has three operations. Fig. 1(c) shows the result with no rescheduling

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