

Unrelated Parallel Batch Machine Scheduling Using a Modified ABC Algorithm [†]

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Abstract: This paper introduces a multi-objective discrete artificial bee colony (MODABC) algorithm, which aims to simultaneously minimize the makespan, total earliness and tardiness (ET), and total energy consumption (TEC) by efficiently scheduling a variety of jobs on unrelated parallel batch machines. Machines have different capacities and consume varying amounts of processing energy, whereas the jobs differ in sizes, release times, and due dates. In the employed bee and follower bee phase, three neighborhood structures are employed to generate feasible solutions, improving the population's quality. In the scout bee phase, three multi-objective local search strategies are used to fully search the solution space. The experimental results show that the MODABC algorithm is superior to the NSGA-III algorithm in terms of convergence and diversity.

Keywords: artificial bee colony algorithm; multi-objective optimization; unrelated parallel batch machine scheduling



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1. Introduction

It is of great practical significance to study the scheduling problem of parallel batch processing machine (PBPM) in intelligent manufacturing, such as chemical processing, pharmaceutical, semiconductor manufacturing, and other industries.

At present, the research on the PBPM scheduling problem is very extensive. For example, Wang and Chou studied the identical parallel batch machine scheduling problem with different sizes and arrival times of jobs and proposed a hybrid genetic algorithm to minimize the maximum completion time [1]. Beldar et al. studied the equivalent parallel batch machine scheduling problem considering machine variable maintenance, job dynamic arrival, and due date and proposed two meta-heuristic methods to minimize the total tardiness time [2]. Zhou et al. proposed a multi-objective differential evolution algorithm to simultaneously minimize the maximum completion time and total power cost, considering the uniform parallel batch machine scheduling problem with the dynamic arrival of jobs [3]. Li et al. studied the uniform parallel batch machine scheduling problem of jobs with different processing times, sizes, and due dates considering dynamic arrivals and proposed a differential evolution algorithm to minimize the maximum delay and total pollution emission cost [4].

In contrast, few studies exist on unrelated parallel batch machine scheduling methods based on artificial bee colony algorithms. In this paper, the MODABC algorithm is proposed for the multi-objective optimization problem of unrelated parallel batch machine scheduling and compared with the classical NSGA-III algorithm.

2. Problem Formulation

There are n independent jobs to be processed on m unrelated parallel batch machines. The processing time of the jobs J_j on the machine M_i is p_{ij} , the release time is r_j , the job size

is s_j , and the due date is d_j . The capacity Q_i of different batch machines are different, and the energy consumption l_i per unit time is also different. The optimization objective is to minimize makespan, ET, and TEC simultaneously. The scheduling problem is denoted by $R_m | Q_i, r_j, d_j, s_j | C_{max}, ET, TEC$. The main decisions include: 1. How the n jobs $J = \{J_1, J_2, \dots, J_n\}$ are assigned to m machines $M = \{M_1, M_2, \dots, M_m\}$; 2. How to group batches of n_i jobs assigned to machine M_i ; 3. The processing sequence of batches on the machine M_i .

3. MODABC Algorithm

3.1. Basic Flow of the MODABC Algorithm

ABC is a global optimization algorithm, including three search phases: employed bee, follower bee, and scout bee. The process of MODABC algorithm is shown in Figure 1.

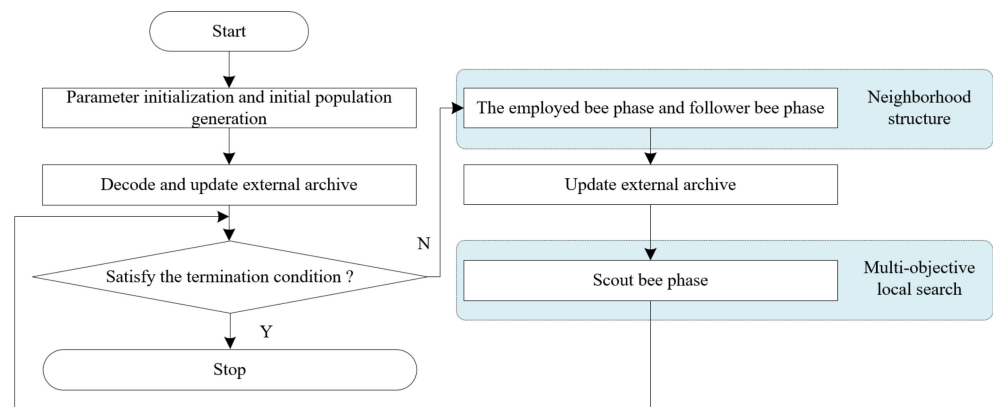


Figure 1. Flow chart of the proposed MODABC.

3.2. The Employed Bee Phase and Follower Bee Phase

To improve the quality of the solution and improve the convergence of the algorithm, in this study, three neighborhood structures are designed based on the characteristics of the problem, which are used to perform a local search on the food sources in the population at the phase of employed bee and follower bee. In the employed bee, each food source performs a local search operation in order. In the following bee phase, the population uses the roulette rule to select the food source according to the HV index value of the food source (the volume of the cuboid whose diagonal is formed by the position of the food source and the reference point) and performs a local search operation in turn. An example of neighborhood structure can be seen in Figure 2, i represents the machine, and b represents the batch on machine i .

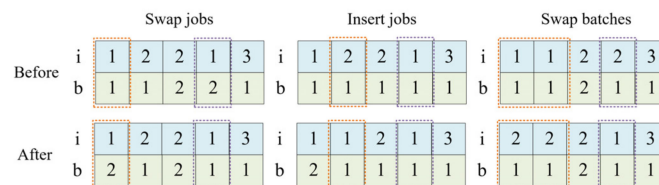


Figure 2. Example of neighborhood structure.

Among them, job swapping is to select any job in any two batches on any two machines for swapping; job insertion is to select any job in any batch to be inserted into another batch; and batch exchange is to select two batches on any two machines for exchange.

3.3. Scout Bee Phase

To enhance the diversity of the algorithm and make the obtained Pareto front as close to the real Pareto front as possible and evenly distributed, we propose three multi-objective local search strategies for different target values at this phase. These strategies aim to perform a local search on non-dominated solutions in external archive sets and

food sources, obtain three non-dominated solution sets, and merge them with the current population. Next, according to the non-dominated sorting method, we select individuals to enter the next generation. The following will introduce these three multi-objective local search strategies, respectively.

(1) Minimizing Makespan Local Search: The machines with the largest and smallest makespans are defined as CM_{max} and CM_{min} , respectively. Each batch on CM_{max} is exchanged with all possible batches in CM_{min} .

(2) Total energy consumption local search: The machines with the maximum and minimum processing energy consumption are defined as TM_{max} and TM_{min} , respectively. Each batch on TM_{max} is exchanged with all possible batches in TM_{min} .

(3) Total earliness/tardiness local search: The batch with the largest ET is selected and exchanged with any batch other than this in all machines.

4. Numerical Example and Analysis

4.1. Parameters Setting

Based on the actual enterprise production data, the test data generation method of reference [4] is used to generate the p_{ij} , r_j , d_j , s_j , Q_i , and l_i . A total of 6 sets of test data; the number of small-scale jobs $n = 10, 20$, the number of machines $m = 2$; the number of scale jobs $n = 40, 80$; the number of machines $m = 3$; the number of large-scale jobs $n = 100, 200$; and the number of machines $m = 5$. For different job and machine combinations, 10 test data are generated for each group, and 60 test data are generated for all scales.

4.2. Parameters Tuning

The parameter values that affect the performance of MODABC and NSGA-III algorithms are determined by Taguchi design experiments. The algorithm parameter values under different problem scales are shown in Table 1. N represents the population size, MAXT represents the maximum number of iterations, and p_C and p_m represent the crossover rate and mutation rate (as MODABC is a meta-heuristic algorithm based on neighborhood search, there is no p_C and p_m).

Table 1. Parameter values for algorithms.

Parameter	MODABC			NSGA-III		
	Small	Medium	Large	Small	Medium	Large
N	100	100	100	100	100	100
MAXT	30	50	50	150	150	200
p_C	\	\	\	0.65	0.65	0.7
p_m	\	\	\	0.2	0.15	0.2

4.3. Computational Experiments and Discussion

In this study, each problem instance was ran 10 times, and the average Inverted Generational Distance IGD, non-dominated rate NR, and the number of Pareto solutions Nd obtained by different algorithms were calculated. The results are shown in Table 2.

Table 2. The performance of the algorithms. (n*m indicates the size of the problem).

Size	n*m	MODABC			NSGA-III		
		IGD	NR	Nd	IGD	NR	Nd
Small	n10m2	13.7824	0.9623	6.4	167.2477	0.0433	1.1
	n20m2	47.6821	0.9714	6.1	616.5514	0.0368	1.1
Medium	n40m3	117.3464	0.9733	6.9	2933.09	0.0314	1.1
	n80m3	416.3641	0.9718	4.2	10,980.8	0.0301	1.3
Large	n100m5	425.2905	0.9823	3.7	11,595.26	0.0214	1.6
	n200m5	1122.9323	0.9853	6.8	29,313.3	0.0203	2.1

It can be found from Table 2 that the IGD, NR, and Nd values of the MODABC algorithm are better than other algorithms, and the advantages increase with the increase in scale.

5. Conclusions

The MODABC algorithm is introduced to address the multi-objective optimization problem of unrelated parallel batch machine scheduling. It aims to minimize the objectives of Cmax, TEC, and ET concurrently. The experimental results show that the MODABC algorithm can improve the diversity and convergence of the solution. In the future, it is necessary to study the method proposed in this paper to solve the practical problems considering the constraints of machine failure and workpiece compatibility.

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