Disruption management for solving FJSP with improved genetic algorithm

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Abstract. In order to solve the Multi-objective flexible job shop scheduling, an improved cloud adaptive genetic annealing algorithm is proposed. Firstly, the cross-variation, improved fitness calculations, and selection operations are built. Moreover, a novel multi-objective optimization model for flexible job-shop scheduling (FJSP) is established. At the same time, the idea of gradual optimization for the target is introduced to obtain the optimal scheme of FJSP. According to the similarity test of Hamming ones, the cross operation is selected. It can improve the efficiency and convergence of the proposed algorithm. The experiment result verifies the effectiveness of the proposed improved cloud adaptive genetic annealing algorithm (CAGA), and which is compared with other algorithms experiments the existing classical algorithms.

1. Introduction
Since the FJSP concept was first proposed by Bucker in 1990\cite{1}, some scientific researchers have tried many kinds of optimization algorithms such as genetic algorithm, particle swarm optimization, bacterial foraging algorithm, et al. Because the genetic algorithm (GA) has the ability of the global search, it is widely used to solve various problems related to scheduling. Regarding the flexible job-shop scheduling problem (FJSP), Fatma Qutay et al\cite{2} studied the scheduling of displacement flow shop by using the particle swarm intelligence method with the memetic algorithm. Mark E. Lewis et al\cite{3} published an article on solving the FJSP problem based on the improved binary particle swarm optimization algorithm, which can obtain the optimal approximate solution. Basing on the research of particle swarm optimization (PSO), Erik Brynjolfsson et al\cite{4-5} put forward a hybrid improved particle swarm optimization algorithm (IPSO) combining Baldwinian learning strategy and simulated annealing algorithm (SA). Eleni Petala et al\cite{6} put forward a hybrid adaptive genetic algorithm (HAGA) basing on hormone regulation mechanism to solve FJSP. The simulation results verify the effectiveness of the algorithm.
After the previous research on the status quo at home and abroad, it can be found that the FJSP for the machine deterioration effect is still relatively small. Considering the research on the machine deterioration effect in real life, the authors try to research the flexible job-shop scheduling problem considering the machine deterioration effect.
2. Problem description

In view of the above research, this paper studied the deteriorating effect on the machine in the flexible production scheduling process, and builds a hybrid flexible job shop scheduling model. Dimitris Bertsimas et al. [7] solved flexible job shop scheduling and dynamic scheduling problems through improving the integrated scheduling method, and rescheduled emergency order insertion and machine failure.

Parameter description:
Workpiece set: \( J = \{1,2,\ldots,n\} \), \( n \) represents the sum of workpieces
Machine set: \( M = \{1,2,\ldots,m\} \), \( m \) represents the sum of the processing machine
\( O_{ij} \): Operation \( i \) of workpiece \( j \).
\( M_j \): Set of optional machines for \( O_j \)
\( n_j \): Workpiece \( j \) processing quantity.
\( R_{ij} \): Completion moment of \( i \)th processing of workpiece \( J \).
\( m_{ijk} \): Sum of machines which are available for \( i \)th processing of workpiece \( J \).
\( S_{ijk} \): Starting moment of \( i \)th processing of workpiece \( J \).
\( E_{ijk} \): Completion moment of \( i \)th processing of job \( J \) on machine \( k \) with machine deterioration effect.
\( T_{ij} \): Processing moment of the \( i \)th processing of workpiece \( J \).
\( C_j \): the random completion moment of processing \( J \).
\( \partial_k \): k machine’s deterioration coefficient.
\( \partial_{ij} \): The deterioration of the coefficient of work piece \( J \) on machine \( i \).
\( U_k \): Usage time of machine \( k \).
\( A_k \): Age of machine \( k \).
\( T_j = [0, C_j - T_j] \): Tardiness time of workpiece \( J \).
\( E_j = [0, T_j - C_j] \): Lead time of workpiece \( J \).
\( t_j \): Tardiness penalty cost coefficient in unit time of job \( J \).
\( e_j \): Penalty coefficient of warehousing cost.
\( p_{ijk} \): The cost coefficient of the \( i \)th processing.

Decision variable description:
(1) Minimize the makespan \( f_1 \)
\[
 f_1 = \min(C_{\text{max}}) = \min(\max(\sum_{k=1}^{m} \sum_{j=1}^{n} \sum_{i=1}^{m} R_{ijk} \ast E_{ijk})) \tag{1}
\]
(2) Minimize the total cost \( f_2 \)

The total cost mainly includes the sum of the processing cost and the early delivery/trailer cost penalty. The processing cost mainly considers the product of the operation time. The early or latent cost penalty value is given. For each workpiece delivery date range, if the delivery period range is exceeded, the calculation completion time penalty value is calculated. Considering the deterioration effect of the machine, the deterioration coefficient of the machine is changed regardless of whether the machine works or not, and the deterioration effect of the machine is the start of the machine, linear correlation of time [8]. Then the machine deterioration coefficient formula is expressed in Eq.(2):
\[
 \partial_k = U_k / A_k \tag{2}
\]
According to the deterioration coefficient, it is determined by the ratio of using time to age of machine, and the equation to calculate the completion time is in Eq.(3):

\[ E_{ijk} = a + S_{ijk} * \hat{c}_k \]  

(3)

3. Analysis of the algorithm

For the study of multi-objective FJSP, the authors establish the weight coefficient and use the multi-objective specific weight coefficient to change the multi-objective problem into single-objective problem, and it can be expressed in the following Eq.(4):

\[ f = \min(\sum_{i=1}^{3} w_i * f_i) \]  

(4)

In which, \( w_i \geq 0 \) is the weighting factor.

3.1. Description of real number coding

FJSP coding adopts integer coding method and is divided into two-stage coding, which is mainly divided into process sequencing and machine selection coding. Therefore, it is necessary to first sort the processes, and then perform the selection of the machine based on the determined process sequencing.

The first 36 digits represent the processing sequence of the workpiece process, and the next 36 digits represent the processing machine selected for the workpiece process.

3.2 Description of fitness

To improve the acceptability of bad solution and make the global search ability of the proposed algorithm better, the simulated annealing algorithm is introduced and it uses its probability jump property.

3.3 Description of improving crossover and mutation

In the crossover operation, two chromosomes were selected from the population, and then two positions were randomly selected (the crossing position and the standard position). If the crossing one is less than the normal position, the gene before will be exchanged, else the latter one will be exchanged. If the crossing position equal to is the standard one, it will expand to both sides and exchange two chromosomes in the middle position. If the intersection position is less than the standard one, the pre-random \( \sum_{j=1}^{3} n_m \) selection of the intersection position of each chromosome is selected for the cross operation. The example is as follows:

123213132 After crossing 132213132
132231123 123231123

4. Analysis of experiments

In Table 1, it can be seen that the processing scheduling of a 6workpiece \( \times \) 10 machine.

| Workpiece Process | \( M_1 \) | \( M_2 \) | \( M_3 \) | \( M_4 \) | \( M_5 \) | \( M_6 \) | \( M_7 \) | \( M_8 \) | \( M_9 \) | \( M_{10} \) |
|-------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| \( J_1 \)          | \( O_{11} \) | --     | --     | --     | --     | --     | --     | --     | --     | --     |
| \( O_{12} \)       | --     | --     | --     | --     | --     | --     | --     | --     | --     | --     |
| \( O_{13} \)       | --     | --     | --     | 9      | --     | --     | --     | --     | --     | --     |
| \( O_{14} \)       | --     | 5      | --     | --     | --     | --     | --     | --     | 4      | --     |

**Table 1.** Scheduling of twoworkpiece \( \times \) 10 machine
In order to solve the FJSP in this paper, the parameters of the proposed algorithm can be described as the following:
The initial size of population NIND=60, the algebra of population evolutionary MAXGEN=50, the crossing probability $P_c=0.75$, that of the mutation $P_m=0.7$, the weight coefficient are set as 0.5, 0.2 and 0.3.
The simulation results with Matlab can be seen in Figure 1-Figure 3.

![Figure 1. Iterative graph of GAA](image1)

![Figure 2. Iterative curve of CAGA](image2)

![Figure 3. Iterative curve of ICAGA](image3)

In the iteration diagram of the above figure, the convergence speed of the proposed ICAGA is faster than that of the genetic annealing algorithm. In the case of the same optimal solutions, ICAGA has a better convergence speed than the cloud algorithm. Both adaptive genetic annealing algorithm and genetic annealing algorithm have faster operating effectiveness and convergence speed, but the optimal solution of the improved algorithm proposed is better than genetic annealing algorithm. At the same time, ICAGA converges faster, and the optimal solution and running speed are better.

In the above table, the best solution is the average shortest completion time of the ten scheduling plans. On this basis, the proposed algorithm is compared with the improved HS [9] and the improved DCSO [10]. The proposed algorithm has certain advantages. In Kacem Benchmark case 4×6, the optimal solution and the average solution are better than the improved HS. In the Kacem Benchmark case 8×8, the proposed algorithm and the improved HS have an equivalent average solution, but the operating effect is better than DCSO. The test shows that the proposed algorithm is feasible for FJSP.

5. Conclusion
Comparing with the common GA (Genetic Algorithm), the proposed ICAGA can accelerate the convergence speed and converge to the optimal solution through the above simulation. Meanwhile, by adding Hamming similarity and comparing the similarity threshold to improve the calculation speed. By using the conventional cloud model to determine the efficiency and effectiveness trend of cloud drops, using x-condition cloud generator to adaptively generate the crossover probability and the mutation probability, and using the probability jump in the SA to calculate the effectiveness of this algorithm. It can be concluded that the proposed ICAGA may obtain the global optimal solution and avoid premature convergence of common GA. However, this algorithm is more suitable for
small-scale flexible job shop scheduling.

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