Research on FJSP Rescheduling Execution Cost Based on Modified Genetic Algorithm

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Abstract. In order to achieve dynamic production of smart plants, it is necessary to dynamically adjust schedule for disturbances in the manufacturing process. An executable optimized rescheduling plan needs developing, so the study of rescheduling cost is necessary. Based on the essential analysis of the rescheduling problem, a new flexible job shop rescheduling execution cost is proposed. The correctness of the execution cost is illustrated by the application in a modified genetic algorithm. The result shows that the rescheduling method with the execution cost as the fitness can generate a new plan with less deviation from the original schedule, which has a great significance for actual manufacturing.

1. Introduction
In the manufacturing process, scheduling is an indispensable task. Many scholars have studied scheduling under various working conditions and many results are valuable to the actual manufacturing. However, the uncertainties and disturbances in the manufacturing process make it difficult to achieve the desired results when the schedule is executed. How to deal with these inevitable uncertainties and disturbances is the subject of this paper.

This paper first solves the FJSP (Flexible Job-shop Scheduling Problem) through double coding genetic algorithm to get a pre-schedule. Then a rescheduling algorithm is built for device failure. By analyzing plant operation process, the essence of the rescheduling problem is discussed. And the composition of the rescheduling execution cost is analyzed as the objective function of the algorithm. Finally, an example is given to prove the feasibility of the algorithm.

2. Problem description
There were lots of researches about deterministic scheduling problems, providing important theoretical support for the manufacturing process, but the uncertainties in the manufacture is inevitable, such as uncertainty in working hours, equipment failure, emergency order and order cancellation, etc. Therefore, some scholars are studying how to deal with these uncertain factors. The main research directions are: 1. Research on rescheduling method after interference occurs; 2. How to generate pre-scheduling scheme with certain robustness; 3. Research on rescheduling strategy. Representative studies include: R. J. Abumaizar proposed a rescheduling method for job shop problems, using makespan, deviation of starting time and sequence as a measure of rescheduling plans [1]; Sanjay V. et al. proposed a predictive scheduling method, by properly inserting idle time between operations, a pre-schedule that can absorb interrupts can be formed without significantly affecting the work performance [2].
In recent years, research on production scheduling has focused on: improvement of algorithms, such as improving evolutionary algorithms through learning methods [3]; proposing new algorithms applied to scheduling, such as hybrid artificial bee colony algorithm [4], flower pollination algorithm, etc. [5]; combining scheduling with production practice, such as applying real-time manufacturing data in scheduling [6],[7].

The FJSP can be stated as follows. It is given a set \( J = \{J_1, J_2 \ldots J_n\} \) of independent jobs. A job has a sequence of operations \( \{O_{i1}, O_{i2} \ldots O_{inj}\} \) to be performed one after the other according to the given sequence. It is given a set of machines \( U = \{M_1, M_2 \ldots M_m\} \). Each operation \( O_{ij} \) can be executed on any among a subset of compatible machines \( U_{ij} \subseteq U \). The processing time of each operation is machine-dependent. \( T^p_{ij} \) stands for the processing time of operation \( O_{ij} \) when executed on machine \( M_k \). Suppose \( S^{ort} \) is the pre-schedule being executed. A new schedule after a disturbance is \( S^{re} \).

The above problems can be well solved theoretically by various algorithms, but in many cases, the new schedules obtained by these algorithms have high execution cost or even are not executable. In order to get executable optimized results, the essence of rescheduling is discussed, providing a reference for the better application of rescheduling theory.

3. Rescheduling execution cost

The above problem description has simplified the problem, leading to a big difference between reality and theory. In order to reduce the deviation, it is necessary to mine the essence of the rescheduling problem.

In the manufacturing process, the production enterprise first determines the batches according to the production demand, and then expands the batches to the self-made parts according to the BOM to form the schedule of each period. And the master production schedule is generated after the capacity check.

The master production schedule is a plan to decide the quantity of each specific final product to be manufactured in each specific period, which is usually months or weeks. And the detailed production schedule is always specific to each hour. Detailed production schedule is formed based on the master production schedule, the manufacturing process, the capacity benchmark data and the working calendar.

The production scheduling problem is abstracted from the detailed production plan. The essence is to arrange working center to complete certain production tasks in certain periods. The optimization of scheduling is essentially the process of improving the production capacity of the working center.

When the production process is disturbed, the production capacity of the working center is reduced, and there are many ways to cope with insufficient capacity, including: 1. delaying the unfinished work to next period; 2. the working center working overtime; 3. requesting help from other departments; 4. change the self-made parts to the outsourcing. According to the above description, the rescheduling method can be interpreted as utilizing the extending working hours to cope with the disturbance. The rescheduling optimization process is essentially to maintain the capacity of the working center with minimal overtime when the disturbance occurs. Therefore, the overtime and any process reducing production capacity are considered as rescheduling costs.

Some scholars have already studied the rescheduling cost: Georgios et al. [8] believed that only using time as the objective function of rescheduling is a short-sighted method, which is easy to produce pseudo-optimal results that are not available for actual production, then the rescheduling cost consisting of starting time deviation, equipment change, and process sequence change is proposed; some other scholars also proposed ideas on the cost of rescheduling [9]. But they only enumerated the composition of the rescheduling cost, lacking the basis for their selection. What’s more, they did not consider overtime as rescheduling costs, but differentiated overtime from rescheduling costs as a part of the rescheduling objective function, which is not reasonable enough from the perspective of this work.

Based on the above analysis, the rescheduling cost should include:
Completion Time Delay for Each Machine. The delay in the completion time reflects the overtime. Essentially, the rescheduling optimization process hopes that the overtime hours are as small as possible, and the overtime hours are negative in terms of manpower, energy consumption and economy. Overtime can be defined as following:

\[ A_1 = \sum_{i \in U}(L_i^{re} - L_i^{ori}) \]  

Where:
- \( U \) is the collection of machines;
- \( L_i^{ori} \) is completion time of machine \( i \) in the pre-scheduling plan;
- \( L_i^{re} \) is completion time of machine \( i \) in the rescheduling plan;

Total Starting-time Deviation. The total starting-time deviation of all batches from pre-schedule was first introduced by S. David Wu as a schedule stability measure [10]. The biggest impact of the starting-time deviation is the material accumulation in each work unit. In the ideal case of JIT, the materials will arrive at the units just when they are needed, but under the practical circumstances, the work units will often storage the materials required for subsequent processes. If the deviation of the starting time is large, the accumulation of materials will result in insufficient space for the working process, which will affect the manufacturing process. Sometimes some materials need shipping back to the warehouse, which increase the logistics cost. If the preparation amount in the units is large, the weight of this part in execution cost needs to be increased during the rescheduling process.

\[ A_2 = \sum_{i \in I} \sum_{j \in O_i}|ST_{ij}^{re} - ST_{ij}^{ori}| \]  

Where:
- \( J \) is a collection of jobs to be processed;
- \( O_i \) is a set of operations for the job \( i \);
- \( ST_{ij}^{ori} \) is the starting-time of the operation \( j \) of the job \( i \) in the pre-scheduling plan;
- \( ST_{ij}^{re} \) is the starting-time of the operation \( j \) of the job \( i \) in the rescheduling plan;

Logistics Cost Due to Machine Reallocation. Machine reallocation for an operation changes the material requirements of the work unit. Materials prepared in advance at the work units do not match actual demand. The possible consequences include the transfer of materials between the units, the materials need to be replenished from the warehouse, and even the production may stagnate, which indirectly reduce production capacity.

\[ A_3 = \sum_{i \in J} \sum_{j \in O_i} D(eq_{ij}^{ori}, eq_{ij}^{re}) \]  

Where:
- \( D \) is a matrix of distances between units;
- \( eq_{ij}^{ori} \) is the device selected for \( j \) process of job \( i \) in the pre-scheduling plan;
- \( eq_{ij}^{re} \) is the device selected for \( j \) process of job \( i \) in the rescheduling plan;

Processing Time Change Due to Machine Reallocation. The increase in processing time obviously reduces production capacity.
\[ A_4 = \sum_{i} \sum_{j \in O_i}(PT_{ij}^{ori} - PT_{ij}^{re}) \] (4)

\( PT_{ij}^{ori} \) is the processing time of the \( j \) process of the job \( i \) in the pre-scheduling plan;  
\( PT_{ij}^{re} \) is the processing time of the \( j \) process of the job \( i \) in the rescheduling plan;

The Rescheduling Cost can be expressed as:

\[ A = \omega_1 A_1 + \omega_2 A_2 + \omega_3 A_3 + \omega_4 A_4 \] (5)

\( \omega_1, \omega_2, \omega_3, \omega_4 \) are the weights of rescheduling execution cost components.

The above-mentioned rescheduling cost components are difficult to normalize, so the weight of each component must be formulated according to the actual situation of the production enterprise.

4. Algorithm construction
For the problem of flexible job shop, scholars have developed various effective algorithms, such as: Tabu search algorithm, genetic algorithm, simulated annealing algorithm, etc.

![Algorithm block diagram](image)

**Figure 1.** Algorithm block diagram.
Genetic Algorithm (GA) is a metaheuristic inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms (EA). Genetic Algorithm has been used extensively "as a powerful tool to solve various optimization problems such as integer nonlinear problems (INLP)" [11]. Therefore, an improved genetic algorithm is used as an example of rescheduling cost application.

Scheduling is derived by modified genetic algorithm as shown in the figure 1, and a double coding method is used here, one chromosome represents the job sequence, and the other chromosome represents the selected device. The fitness of the algorithm is makespan, which is replaced by rescheduling cost in the rescheduling process. When machine $M_i$ fails at time $t$, it is estimated that it takes $T$ hours to repair. Rescheduling is triggered, and the chromosomes need recoding. The part that has been executed and is being executed needs to be removed in the chromosomes. The initial operation time $MT_i$ of machines should be modified.

5. Case analysis

Apply the algorithm to an $6 \times 5$ FJSP example, which means 6 jobs need to be machined, and each job has 5 operations. Equipment available for each operation and processing time are shown in the Table 1 ([Available machines]/ [Processing time]). Assuming the units are linearly arranged by machine number, the machine number difference is used as the distance metric of the two units.

|       | $O_1$     | $O_2$     | $O_3$     | $O_4$     | $O_5$     |
|-------|-----------|-----------|-----------|-----------|-----------|
| $J_1$ | [1,2]/[3,4] | [2]/[8]   | [3,4]/[9,7] | [2,4]/[5,4] | [2,5]/[3,3] |
| $J_2$ | [1]/[6]   | [2,4]/[8,6] | [3]/[4]   | [3,4]/[2,6] | [5]/[3]   |
| $J_3$ | [3]/[4]   | [1,3]/[5,7] | [2]/[7]   | [1,2]/[5,5] | [4,5]/[6,6] |
| $J_4$ | [5]/[7]   | [2]/[3]   | [2,4]/[4,6] | [5]/[3]   | [2,5]/[3,7] |
| $J_5$ | [1,2]/[6,4] | [3]/[7]   | [4,5]/[7,9] | [1]/[8]   | [3,4]/[5,5] |
| $J_6$ | [2,3]/[3,7] | [4]/[7]   | [3]/[6]   | [3,4]/[6,7] | [2,4]/[4,4] |

First, pre-schedule the operations that need to be processed. The convergence curve can be seen in figure 2, and the optimal individual makespan is stable at 39h after 50 generations. Pre-schedule is as shown in the (b) Gantt chart. Assume that the fault occurred on machine 2 at the time of 15h, and the estimated recovery time is 8 hours. Rescheduling by two methods, one is rescheduling with makespan as fitness, and the other is rescheduling with execution cost as fitness, the result is shown in figure (c) (d) (e) (f) of figure 2.

Comparing to right-shift rescheduling, both above methods have better results, and the makespan of both rescheduling methods are the same. A labeling method is used to show the difference between the rescheduling plan and the pre-scheduling plan. As shown in 2-2 3-2 of figure 2, change of starting-time, operation machine and processing time in 2-2 is significantly more than 3-2. That means rescheduling with execution cost as fitness forms a new schedule with minimal changes to the original plan. It maintains production capacity in an executable and optimized way when the disturbances occur.
6. Conclusion
The rescheduling of FJSP is studied in this work, and a modified genetic algorithm is used to solve the problem. The rescheduling execution cost is mainly discussed, and the viewpoint is presented: the rescheduling optimization process is essentially to maintain the capacity of the work center with minimal overtime when the disturbance occurs. According to this viewpoint, the components of the
rescheduling execution cost is analyzed, which consists of 1. Completion time delay for each machine, 2. Total starting-time deviation, 3. Logistics cost due to machine reallocation, 4. Processing time change due to machine reallocation. The feasibility of the algorithm and the rescheduling execution cost are proved by an example.

The ideal of production management is to realize real-time optimal operation of dynamic production. This work provides a viable method for the ideal realization.

7. References
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