Research on Flexible Job Shop Scheduling Problem

Xiangnan Li\(^*\) and Xu Liang

School of Mechanical Engineering, Dalian Jiaotong University

*Corresponding author e-mail: liangxu00@263, 2lpongan@163.com

Abstract. The adjustment time and processing time of the job on the machine are studied as an independent factor considering the influence of the adjustment time, such as installation and positioning, on the efficiency of production scheduling. A mathematical optimization model of flexible job shop scheduling with adjustment time is established based on minimizing the makespan. The improved genetic algorithm is used to solve the proposed model and achieve rapid optimization of the solution process. The Matlab software platform is used to solve the case. The experimental results show that the model and the improved algorithm are feasible and effective, and could be more effective in guiding the actual production.

1. Introduction

With the development of society, people's demand for individualization is getting higher and higher, and the processing method of workshops is more and more presented with the trend of multi-variety and small batches. The flexibility and refinement of workshop management are continuously improved [1-2]. Flexible Job-shop Scheduling Problem (FJSP) When optimizing, adjust time, processing time, etc. as a whole or only consider processing time. According to Ford Motor Company's statistics, during the actual machining process, the installation and positioning of the workpiece, the adjustment of the machine, the cleaning and cleaning of the table, etc. account for more than 90% of the total processing time. Auxiliary adjustment time and processing time need to be considered as independent factors at the same time to improve the effectiveness of the optimized scheduling scheme.

At present, there are many research literatures on flexible job shop scheduling problems, focusing on multi-objective scheduling and dynamic scheduling with processing time [3-4]. However, considering the workpiece adjustment time, and processing time as an independent factor simultaneously There is very little literature to consider. In [5], a sorting problem with adjusted time-weighted sets of orders is proposed for the single machine scheduling problem and solved by genetic algorithm. In [6], the scheduling problem is transformed into a classic traveling salesman problem, and the improved genetic algorithm based on priority-based proportional selection, real two-point intersection and pattern mutation operator is used to solve the job shop scheduling problem with adjustment time. The literature [7] proposes to improve the equipment utilization rate and advance the final completion time of the product by changing the process scheduling order forward and the algorithm of adjusting the time comprehensive scheduling process. In [8], a job shop scheduling and preventive maintenance integration method considering adjustment time is proposed. In [9], the flexible job shop scheduling problem with adjustment time is optimized with the minimum delay. In [10], the tabu search algorithm is used to solve the flexible job shop scheduling problem with adjustment time.
In this paper, the adjustment time and processing time are considered as independent influencing factors. By improving the traditional genetic algorithm, the active scheduling and decoding scheme considering the adjustment time, the adaptive function to cross and mutate, and the solution process are realized. Quickly find the best. The experimental data was tested by Matlab programming. The experimental results further verified that the flexible job shop scheduling model considering the work piece adjustment time is more in line with the actual production situation.

2. Establishment of fjsp model with adjustment time

The description and definition of the mathematical model of the FJSP problem with adjustment time is:

The workpiece set \( J = \{ J_1, J_2, J_3, \ldots, J_g, \ldots J_n \} \), \( J_g \) is the \( g \)th workpiece (\( g = 1, 2, 3, \ldots, n \)); Machine set \( M = \{ M_1, M_2, M_3, \ldots, M_i, \ldots, M_m \} \), \( M_i \) is the \( i \)-th machine (\( i = 1, 2, 3, \ldots, m \)); \( O_j(h) \) is the hth of the workpiece \( j \) process, and define \( O_j(h - 1) \) as the last process of the \( O_j(h) \), \( O_j'(h') \) is the previous process of the machine where \( O_j(h) \) is located; \( P_j(h) \) is the process completion time of the hth process of the workpiece \( j \); \( T_{ijh} \) is the workpiece \( j \) time required for the h-th process to be machined on machine \( i \); \( S_{ijh} \) is the machining start time of machine \( h \) on the machine \( i \); \( C_{ijh} \) is the h-th process of workpiece \( j \) on machine \( i \) Processing end time; Installtimei indicates the adjustment time for machine \( Mi \) installation, positioning, etc.; \( C_j \) is the completion time of workpiece \( j \); \( C_{max} \) is expressed as the maximum completion time. When building a mathematical model, the following conditions are assumed:

1. All machines are available at zero time and all workpieces can be machined at zero time.
2. Any process can only be processed in one machine, and the process is not allowed to be interrupted during the process.
3. Any machine can only process the same process of the same workpiece at the same time.
4. There is no processing order constraint between different workpieces, and there are sequential processing order constraints between different processes of the same workpiece. With the minimum completion time as the optimization goal, the objective function and constraints are:

\[
C_{max} = \min(\max_{1 \leq j \leq n} (C_j))
\]

\[
C_{ijh} = S_{ijh} + T_{ijh}
\]

\[
C_{ijh} - C_{ij'h'} \geq T_{ijh} + \text{Adjustment}_i
\]

\[
C_{ej(h-1)} + \text{Adjustment}_i \quad \text{if} \quad C_{ij'h'} < C_{ej(h-1)} + \text{Adjustment}_i
\]

\[
C_{ij'h'} \quad \text{if} \quad C_{ij'h'} > C_{ej(h-1)} + \text{Adjustment}_i
\]

Equation (1) represents the total objective function, that is, the maximum completion time is minimized; Equation (2) indicates that the completion time of the process is equal to the sum of the process start time and the process time; Equation (3) represents the resource constraint of the machine, and the same machine is Only one workpiece can be processed at the same time; Equation (4) indicates that if the starting machining time (gap start time) of the machine where the process is located is less than the adjustment time of the previous process, it is subject to the adjustment time; otherwise (the gap start time is greater than the previous process End time), the processing process is constrained by the resources of the current processing machine. Therefore, if the adjacent process of a workpiece is processed on the same machine, it is only limited by the machine resource; for the adjacent two processes in the same workpiece, the adjustment time is considered, instead of the sequence of the process in the traditional machining model. constraint.
3. Improved genetic algorithm to solve fjsp with adjustment time

3.1. fjsp chromosome encoding and decoding

When using genetic algorithm to solve the target problem, coding and decoding are the first problems to be solved by genetic algorithm. As mentioned above, fjsp contains two sub-problems: machine selection and process sequencing. Machine selection is used to solve each processing operation. Select the machine to select which machine to process; Process sequencing is used to solve the problem of process sequencing and start-up time of all workpieces after selecting the processing machine. Encoding in the literature [11], encoding two sub-problems On a chromosome, it represents a feasible solution for fjsp, see figure.

![Figure 1. Chromosome coding](image.png)

(1) Machine selection part: The length of the chromosome is the total number of steps, and each gene position is represented by an integer. From left to right, the order of the workpieces is sequentially arranged. Each integer indicates that the current process of machining the workpiece is optional. The serial number of the machine set. Take Table 1 as an example. As shown in the left part of Figure 1, the gene string is 4 - 2 - 3 - 1 - 3 - 2, indicating that the operation O11 is the fourth in the optional processing machine set. Machining on the machine, that is, the actual processing machine is M4; the process O12 is processed on the second machine in the optional processing machine set, that is, the actual processing machine is M3, and so on.

(2) Process sequencing: The length of the chromosome is the total number of processes, and each gene is coded by the workpiece number. The number of occurrences of the workpiece number indicates the number of processes of the workpiece. As shown in the right half of Figure 1, the gene string is 2 - 1 - 2 - 1 - 2 - 1, and the corresponding processing steps are O21 - O11 - O22 - O12 - O23 - O13.

In the decoding process, since the chromosome contains two parts, the machine selection sub-problem and the operation order sub-problem. The machine selection is first decoded: The machine part of the chromosome is read sequentially from left to right and converted into a machine order matrix and a time sequence matrix. Secondly, the process sequence is decoded: the process chromosome portion is read sequentially from left to right, and the machine matrix corresponding to the machining process of each workpiece is sequentially obtained according to the machine matrix, the processing time matrix and the adjustment time matrix decoded by the machine selection portion. Processing time and adjustment time.

In order to ensure the active scheduling after chromosome decoding, this paper proposes a left-shifting insertion decoding method that considers the adjustment time. The decoding principle is as follows:

(1) If the process O_{jh} of the workpiece j is the first process on the machine M_{hi}, the workpiece can be adjusted and machined directly after the machining of its previous process O_{j(h-1)},
(2) If the two processes of the workpiece j, that is, the processes $O_{jh}$ and $O_{j(h-1)}$ are processed on the same machine, and the two processes are in close proximity, that is, there is no other workpiece between them, only one adjustment time is considered at this time. Otherwise, consider the respective adjustment time;

(3) If the process $O_{jh}$ is the first process of the workpiece j, the workpiece is directly adjusted from the zero time of the machine and then processed. Otherwise, look for all idle time periods $[TS_i, TE_i]$ from the left side of the machine, $TS_i$ indicates the start time of the idle time period, and $TE_i$ indicates the end time of the idle time period. Considering the workpiece adjustment time, the earliest machining start time $t_a$ of the process $O_{jh}$ is obtained according to the equation (6), which can satisfy the order constraint of the workpiece machining process.

$$t_a = \max\{P_{j(h-1)}, \; TS_i\}$$ (6)

According to equation (7), it can be judged whether the idle interval period satisfies the insertion condition, and if it is satisfied, it is inserted into the current idle time period; otherwise, it is processed on the machine $M_i$ according to the time $t_b$ of equation (8), where $TM_i$ represents the current Machine $M_i$. The end time of the last machining process. By analogy, the chromosome of the process part is sequentially read until the end of the chromosome.

$$t_a + \text{Adjustment}_i + T_{ijh} \leq TE_i$$ (7)

$$t_b = \max\{P_{j(h-1)}, \; TM_i\}$$ (8)

3.2. Fjsp initialization method

When using genetic algorithm to solve the target problem, the pros and cons of the initial solution directly affect the solution quality and the convergence speed of the solution. Because FJSP not only solves the problem of machine selection, but also solves the problem of sorting the process. For the characteristics of FJSP, the machine selection part adopts the GLR machine selection method proposed in [11]. The method includes: Radom Selection (RS), Local Selection (LS), and Global Selection (GS). In order to ensure the diversity of the initial population and increase the selectivity of the population so that it does not end prematurely in the calculation process, the process ordering part adopts the initialization method of Radom Selection (RS).

3.3. Fjsp crossover and variation

3.3.1. Adaptive Crossover Operator

The crossover operation is based on the principle of natural biological mating, randomly pairs the chromosomes in the population, and exchanges the gene fragments between the populations with a certain probability. In the process of crossover, some genes of the two paired chromosomes are exchanged in a certain way, resulting in two new chromosomes. The crossover method includes: single point intersection method, two point intersection method, multi-point intersection method, uniform intersection method, etc. According to the characteristics of the adjustment time fjsp problem studied in this paper, and satisfying the calculation efficiency and generation at the time of intersection. The feasibility of the chromosome's solution to the problem sought.

Machine selection part: To ensure that the order of the genes generated after the crossover is unchanged, a uniform crossover method is adopted.

(1) Randomly generate an integer $r$ within the interval $[1, L]$.

(2) Randomly generate $r$ unequal integers according to the random number $r$.

(3) Copy the gene contained in P1 /P2 in the parent chromosome to the progeny C1 /C2 according to the random integer $r$ generated by (2), keeping the order and position unchanged.
(4) The remaining genes in p1 /p2 in the parent chromosome are copied into the progeny c2 /c1, keeping the order and position unchanged.

Process Sorting Section: Operation of multiple workpieces per chromosome using an improved sequential crossover method. Better inheritance of superior genes in the parental chromosome.

1. The parent chromosome P1 /P2 randomly generates a workpiece set job.
2. Copy the gene containing the Job in the P1/P2 of the parent chromosome into the progeny, keeping the order and position unchanged.
3. Delete the gene contained in the Job from the other parent chromosome P2 /P1, and fill in the blank gene position in the daughter chromosome according to the principle from left to right.

In the process of intersection, the adaptive crossover probability is used to improve the retention of good individual information. As the number of population iterations increases, the crossover probability decreases gradually in order to reduce the damage to the excellent solution information. The adaptive crossover probability formula

\[ P_c = P_{c\_max} \times \left(1 - \frac{Cur\_Inter\_Step}{Max\_Iter\_Step}\right) \]

\( P_c \) represents the adaptive crossover probability, \( P_{c\_max} \) represents the maximum crossover probability, \( Cur\_Inter\_Step \) represents the current number of iterations, and \( Max\_Iter\_Step \) represents the maximum number of iterations.

3.3.2. Adaptive mutation operator
The mutation operation is based on the process of biological variation in nature, and changes the population to increase the diversity of the population with a certain probability. Change the genetic segment of the gene in the chromosome with a small probability.

For the machine selection part, in order to preserve the information of good individuals, the order of the machines is not destroyed. \( R \) positions are randomly selected in the variant chromosome. Then, according to each position selected, the machine at its position is set to the machine with the shortest processing time in the current machine.

For the ordering part of the process, this paper adopts the neighborhood search mutation operation, that is, in the process of mutation, it searches for multiple children in the neighborhood, and selects the children whose performance is better as the individual after mutation. Specific steps are as follows:

1. Generate a random number \( r \) in \([0,1]\), if \( r \) is less than the mutation probability \( P_m \), go to (2), otherwise go to (4);
2. Randomly generate 3 gene positions in the sorting chromosome of the parent process, sort the genes, and use each sorted result as the gene of the offspring at the position. The other 5 sub-chromosomes;
3. Calculate the fitness values of the current six chromosomes, and select the optimal sub-chromosomes as the mutation results;
4. End.

In this paper, the adaptive mutation calculation method is used to improve the evolution performance, and the best individuals have been retained as much as possible. The adaptive mutation formula

\[ P_m = P_{m\_max} \times \left(1 - \frac{Cur\_Inter\_Step}{Max\_Iter\_Step}\right) \]

\( P_m \) represents the adaptive crossover probability, \( P_{m\_max} \) represents the maximum crossover probability, \( Cur\_Inter\_Step \) represents the current number of iterations, and \( Max\_Iter\_Step \) represents the maximum number of iterations.

4. Conclusion
In the actual production process, there is an adjustment time when the workpiece is processed on the processing equipment, in order to guide the actual production more effectively. In this paper, the adjustment time and processing time are considered as independent factors. With the minimum completion time as the optimization goal, a flexible job shop scheduling problem model considering the adjustment time is established. By solving the proposed model by improving the genetic algorithm, a left-shifting insertion decoding method considering the adjustment time is designed, which is decoded into active scheduling to improve the efficiency of the algorithm. Finally, the actual case is calculated in the Matlab simulation environment. By comparing the results without considering the
adjustment time and considering the adjustment time, it is verified that the problem model considering the adjustment time is more in line with the actual production, and also the established model and the improved The algorithm is feasible and effective and can guide actual production more effectively.

References

[1] Long J, Zheng Z, Gao X, et al. Scheduling a realistic hybrid flow shop with stage skipping and adjustable processing time in steel plants [J]. Applied Soft Computing, 2018, 64: 536 — 549.

[2] Zhang Guohui, Dang Shijie. Research on flexible job shop scheduling problem considering workpiece moving time [J]. Computer Application Research, 2017, 34 (8): 2329 — 2331.

[3] Lu Guangming, He Qingren, Xu Jianping, et al. Robust scheduling and preventive maintenance integration optimization for flexible job shop [j]. Combined machine tools and automated machining technology, 2018 (6): 159 — 162.

[4] Yu Pengfei, Yuan Yiping, Li Xiaojuan. Research on multi-objective flexible job shop scheduling problem based on hybrid genetic algorithm [J]. Combined machine tools and automated processing technology, 2017 (9): 157 — 160.

[5] Su Ya. Research on genetic algorithm for single-machine belt adjustment time-weighted complete order number problem, 2007 (3): 119 — 122.

[6] Huang Xiaoling, Yu Hongbo, Zhao Lijie. Application of improved genetic algorithm in scheduling with adjustment time, 2009, 21 (8): 2224 — 2228.

[7] Xie Zhiqiang, Zhang Weitao, Yang Jing. Algorithm for adjusting time comprehensive scheduling process 2012, 48 (12): 169 — 177.

[8] Yu Mingrang, Zhang Yingjie, Chen Wei, et al. Job Shop Scheduling and Preventive Maintenance Integration Method Considering Adjustment Time, 2015, 49 (6): 16 — 21.

[9] Mousakhani M. Sequence-dependent setup time flexible job shop scheduling problem to minimise total tardiness [J]. International Journal of Production Research, 2013, 51 (12): 3476 — 3487.

[10] Shen L, Dauzère-Pérès S, Neufeld J S. Solving the Flexible Job Shop Scheduling Problem with Sequence-Dependent Setup Times [J]. European Journal of Operational Research, 2018, 265 (2): 503 — 516.

[11] Zhang Guohui, Gao Liang, Li Peigen, et al. Improved genetic algorithm for flexible job shop scheduling problem, 2009, 45 (7): 145 — 151.