Research on process task scheduling method for complex equipment manufacturing based on genetic algorithm

Yujie Wang¹, Song Huang, Xiang Cao and Xiaopin Qin
CAC Chengdu Aircraft Industrial (Group) Co., Ltd., Chengdu 610092, China

¹E-mail: wyj410245590@163.com

Abstract. The research and application of effective scheduling methods play an important role in manufacturing enterprises to improve production efficiency and reduce production costs. Based on the characteristics of the capability maturity of processors, this paper establishes a process task scheduling strategy that is conducive to guarantee delivery time and reduce labor costs according to the actual production environment of complex equipment manufacturing enterprises. A scheduling two-level planning model with delay time and labor cost as indicators is constructed, and the model is solved by genetic algorithm. The planning scheduling method based on order priority and technician effective working time constraints is studied. Finally, an example is given to verify the feasibility and effectiveness of the proposed method.

1. Introduction
Task scheduling and control technology is the key to achieving high efficiency, high flexibility and high reliability in manufacturing [1]. Using efficient and optimized scheduling technology can help improve the company's production performance indicators, such as improving on-time delivery rate, reducing costs, etc. Task scheduling is a decision-making process that allocates finite resources to different tasks within a certain time under the premise of satisfying the constraints of the system, and rationally arranges the processing order and start time of the tasks to optimize the task completion time or cost [2]. The optimal scheduling of process tasks is of great significance for improving the efficiency of equipment manufacturing. For specific tasks, how to optimize personnel scheduling and more reasonable use of each individual's specialty is the key to the task scheduling problem. That is to say, the efficiency of each task is different for each person. How to determine the personnel scheduling plan makes the task with the highest efficiency.

At present, domestic and foreign scholars have carried out many researches on job scheduling and task scheduling, and have achieved some results. For example, on the one hand, in the scheduling model, the maximum completion time, delivery satisfaction, production cost and equipment load were considered in [3] and the production time, production cost and equipment utilization were considered in [4]. Furthermore, in paper [5], the multi-objective FJSP optimization model was built, where time, cost, delivery satisfaction and equipment utilization rate were all concerned; in paper [6], In order to minimize the maximum completion time, the total workload and the maximal workload simultaneously in the multi-objective flexible job shop scheduling problem, hybrid Tabu Search algorithm with Pareto archives set was put forward. On the other hand, in terms of scheduling algorithms, a Particle swarm optimization (PSO) algorithm was presented in [7], and in the proposed algorithm, the particle and the velocity are redefined, and an efficient approach is developed to move a
particle to the new sequence. In addition, in paper [8], minimizing makespan for a blocking flow shop scheduling problem was considered, which has important application in a variety of modern industries; in paper [9], a novel optimization method based on a differential evolution algorithm and its applications to solving non-linear programming problems containing integer and discrete variables were described; in paper [10], an efficient meta-heuristic algorithm based on electromagnetism-like mechanism (EM) was presented, in which has been successfully implemented in a few combinatorial problems; in paper [11], a multi-objective genetic algorithm was proposed and was applied to flow shop scheduling. The characteristic features of our algorithm are its selection procedure and elite preserve strategy.

In summary, the existing research mainly focuses on the production scheduling of the manufacturing enterprise workshop. The objects to be considered in the scheduling process are usually the relatively good quantitative indicators such as the machine tool capability, and the human factors are rarely considered in the scheduling process. In the field of complex equipment manufacturing, the optimal scheduling of process tasks is of great significance for improving the efficiency of equipment manufacturing. For specific tasks, how to optimize processor scheduling and more reasonable use of each individual's specialty is the key to the task scheduling problem. Therefore, based on the existing research at home and abroad, this paper considers the maturity constraints of processors in process task scheduling, and proposes a process task scheduling method for complex equipment manufacturing based on genetic algorithm. In the process of model establishment, the method comprehensively considers the capability maturity characteristics of the process personnel, and based on the superiority of the genetic algorithm in dealing with flexible scheduling problems, the genetic algorithm is used to solve the model. Finally, an example is given to verify the feasibility and effectiveness of the method. The research of this method has a certain positive effect on the rational dispatching of process tasks and the improvement of process efficiency. At the same time, it has certain theoretical reference value for the study of scheduling problems considering human constraints.

2. Characteristics of complex equipment manufacturing tasks

The manufacturing mode of complex equipment has the characteristics of small batch customized production, strict delivery time and uneven distribution of equipment capacity. The task scheduling of complex equipment manufacturing is to arrange the operation sequence and manufacturing resources reasonably under various constraints, so as to shorten the product cycle and reduce the manufacturing cost. The actual manufacturing process is a dynamic and uncertain process, which is subject to external factors such as order changes and equipment failures. As a result, the execution result of the pre-defined scheduling scheme is inconsistent with the expected result, the scheduling performance is reduced, and even the scheduling scheme is invalid. Therefore, there must be a rescheduling mechanism in the complex equipment manufacturing operation system, which can quickly process the uncertain disturbances frequently occurring in the operation flow to ensure the stable operation of the system.

The technical tasks of complex equipment manufacturing enterprises studied in this paper mainly include: ① Preparation and maintenance of manufacturing documents such as fabrication order and process specification. ② Relevant documentation of auxiliary tools such as fixture and tools, etc. ③ NC programming. ④ Application of measurement data and preparation and maintenance of measurement process cards. These process tasks are mainly derived from: performing design changes, performing handovers, process preparation, process optimization, machine tool migration, process review and on-side coordination.

3. A process task scheduling model that target delivery and cost

3.1. Problem description

Process task scheduling is a typical flexible job scheduling problem. Each part can be machined on multiple machine tools, and the machining time on each machine tool is usually different.
There is a following process task scheduling problem:

1. \( n \) process tasks \( (J_1, J_2, \ldots, J_n) \) are processed by \( m \) optional processors \( (M_1, M_2, \ldots, M_m) \).
2. Each process task contains one or more phase, and the order of the task is predetermined.
3. Each phase of the task can be processed by any one of the optional processors.
4. Each processor can handle several phases of a task, and the set of task phases that each processor can handle is usually different.
5. The processing time for different task phases varies from person to person.

The goal of scheduling is to select the most appropriate processor for each phase of each task and determine the optimal sequence and time for each processor to handle tasks, so that some of scheduling performance indicators can be optimized. There are two sub-problems in the process task scheduling: one is to identify the processor of each task, and another is to determine the tasks processors will handle at different time.

3.2. Assumptions

Process task scheduling is a complex multi-objective optimization problem. Before modeling, the following assumptions are given:

1. The same processor can only process one task at a time.
2. The same phase of the same task can only be processed by a processor in a certain moment.
3. Once each phase of the task begin, the processor is not allowed to interrupt without cause.
4. The priority of each task is represented by the priority of the belong order, and each task in the same order has the same priority.
5. There are no successive constraints between the various phase of different tasks, and there are successive constraints between the various phase of the same task.
6. All tasks are manageable at zero time.

3.3. Characteristics variable

This paper describes the characteristics variable involved in the model. The details are as follows:

1. Time to process the task \( (p_{ij}) \): The time required for processor \( i \) to complete task \( j \).
2. Date of submission \( (r_j) \): The earliest time that task \( j \) can start processing.
3. Delivery date \( (d_j) \): The deadline of task \( j \). In some cases, the delivery date can be extended. If the delivery date must be met, it will be the deadline and will be expressed as \( ( \bar{d}_j ) \).

The mathematical symbols appearing in the model of this paper are explained as follows:

\( n \) ----------- Number of tasks
\( m \) ----------- Number of processors
\( \Omega \) ----------- Processor set
\( i, e \) ----------- Code of processors, \( i, e = 1, 2, \ldots, m \)
\( j, k \) ----------- Code of tasks, \( j, k = 1, 2, \ldots, n \)
\( h, j \) ----------- Number of phases of task \( j \)
\( l \) ----------- Index of phases, \( l = 1, 2, \ldots, h \)
\( J \) ----------- The order set to which the task belongs. Tasks in the same order have the same priority \( \omega_j \)
\( \Omega_p \) ----------- A collection of processors that can be used in the phase \( h \) of task \( j \)
\( m_p \) ----------- Total number of processors available for phase \( h \) of task \( j \)
\( p_{ih} \) ----------- The time required for phase \( h \) of task \( j \) to be processed by processor \( i \)
\( s_j \) ----------- The beginning time of process preparation for phase \( h \) of task \( j \)
The ending time of process preparation for phase $h$ of task $j$

Estimated completion time for task $j$

Actual completion time of task $j$

Maximum completion time for all tasks

$$ T_e = \sum_{j=1}^{n} h_j $$

Total number of phases for all tasks

$$ x_{ph} = \begin{cases} 1 & \text{Select processor } i \text{ in phase } O_{ph} \\ 0 & \text{other cases} \end{cases} $$

$$ y_{phd} = \begin{cases} 1 & \text{Phase } O_{ph} \text{ is processed before phase } O_{phd} \\ 0 & \text{other cases} \end{cases} $$

### 3.4. Scheduling model

#### 3.4.1. Objective function

Considering the actual production needs of complex equipment manufacturing enterprises, it requires high punctuality for tasks. Therefore, this paper adopts the model of two-level planning. After a decision is made in an upper layer, the best solution is given from the lower level to the upper layer on the premise of satisfying its own best interests. The main objectives are as follows:

1. **Minimum delay**
   
   $$ f_1 = \min(\max_{j,h} T_j) $$

   $$ T_j = \max(A_j - d_j, 0) $$

   Maximum delay indicator, it represents the non-negative difference of the completion time $A_j$ and delivery date $d_j$ of task $j$.

2. **Lowest production cost**

   $$ f_2 = \min \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{h=1}^{b} A_{ph} \times x_{ph} \times p_{ph} $$

   $A_{ph}$ is the wage of processors.

#### 3.4.2. Constraints

1. The constraint of the order of the phase of each task

   $$ \begin{cases} S_{ph} + x_{ph} \times p_{ph} \leq A_{ph}, i = 1, 2, L, m; j = 1, 2, L, n; h = 1, 2, L, h_j \\ A_{ph} \leq S_{j(h+1)}, j = 1, 2, L, n; h = 1, 2, L, h_j - 1 \end{cases} $$

2. The constraint of task completion time

   $$ A_{ph} \leq C_{max}, j = 1, 2, L, n; h = 1, 2, L, h_j $$

3. At one time, a processor can only handle one phase of a task

   $$ \begin{cases} S_{ph} + p_{ph} \leq S_{ph} + L(1 - y_{phd}), i = 1, 2, L, m; j = 1, 2, L, n; h = 1, 2, L, h_j \\ A_{ph} \leq S_{j(h+1)} + L(1 - y_{phd}), k = 0, 1, 2, L, n; h = 1, 2, L, h_j - 1; l = 1, 2, L, h_j \end{cases} $$

4. A task can only be executed by one processor at a time

   $$ \begin{cases} \sum_{j=1}^{n} x_{ph} = 1, j = 1, 2, L, n; h = 1, 2, L, h_j \\ \sum_{j=1}^{n} \sum_{h=1}^{b} y_{phd} = x_{ph}, i = 1, 2, L, m; k = 1, 2, L, n; l = 1, 2, L, h_k \\ \sum_{j=1}^{n} \sum_{h=1}^{b} y_{phd} = x_{ph}, i = 1, 2, L, m; j = 1, 2, L, n; h = 1, 2, L, h_i \end{cases} $$
5 The value of each variable is positive

\[ S_{ij} \geq 0, A_{ij} \geq 0, j = 1, 2, \ldots, n; h = 1, 2, \ldots, h_i \]  

(7)

4. Process task scheduling based on genetic algorithm

For the task scheduling problem, domestic and foreign scholars have proposed a variety of solving algorithms, such as neural network [12-13], tabu search algorithm [14-15], genetic algorithms [16-17], ant colony optimization algorithm [18-19] and particle swarm optimization algorithm [20-21]. Among them, genetic algorithms are widely used because of their good robustness and parallel search capabilities.

Compared with the traditional optimization algorithm, the genetic algorithm can find the global optimal solution of the optimization problem. The optimization result is independent of the initial condition, and the algorithm is independent of the solution domain. It has strong robustness and is suitable for solving complex optimization problems. Considering the dynamics, complexity and uncertainty of complex equipment manufacturing process tasks, this paper uses genetic algorithm to solve the process task scheduling problem. The algorithm flow is shown in Figure 1.

![Algorithm flow of genetic algorithm](image)

**Figure 1.** The algorithm flow of genetic algorithm.

**Step 1: Individual coding**

The chromosome coding method uses a certificate code, and each chromosome represents the processing order of the task. When the total number of tasks to be processed is \( n \) and the processing phase of task \( n_i \) has a total of \( m_j \), the individual is represented as an integer string of length \( 2 \sum n_i m_j \).

The first half of the chromosome represents the execution order of all tasks, and the second half represents the processor number of each phase. For example:

\[ [2 4 3 1 1 2 3 4 2 1 3 3 2 2 1 3] \]

The individual expressed the order in which four tasks involving two phases are performed by three processors. Among them, the first eight digits indicate the processing order of the task.

- Task 2→4→3→1→2→3→4→
- 9 to 16 digits represent the processors who handle the tasks.

**Step 2: Fitness calculation**

The fitness value of the chromosome is the time to complete all tasks, and the fitness formula is as follow:

\[ fitness(i) = time \]  

(8)

\( time \) refers to the time to complete all tasks. The shorter the time to complete all tasks, the better the chromosome.

**Step 3: Selection**

The selection operation uses the roulette method to select a chromosome with better fitness, and the individual selection probability is as follow:
\[ pi(i) = \frac{\text{Fitness}(i)}{\sum_{i=1}^{n} \text{Fitness}(i)} \quad (9) \]

\[ \text{Fitness}(i) = 1 / \text{fitness}(i) \quad (10) \]

\[ pi(i) \] indicates the probability that the chromosome is selected each time.

**Step 4: Cross operation**

The population acquires new chromosomes through cross-operation, which drives the entire population forward. The cross operation of this paper uses the integer cross method. Firstly, two chromosomes are randomly selected from the population, and then the positions are randomly selected for intersection.

**Step 5: Variation operation**

The population has obtained a new individual through a variation operation, thereby promoting the entire population forward. The mutation operator first selects the variant individuals from the population, then selects the variant positions \( pos1 \) and \( pos2 \), and finally swaps the phases and corresponding processors in \( pos1 \) and \( pos2 \).

As shown in the example below, the intersections are two and four.

\[
[2 2 1 3 2 2 3 3 1 1 2 1 2 1 2 2 2] \rightarrow [2 3 1 2 2 2 3 3 1 1 2 1 2 1 2 2 2]
\]

**5. Example**

As to the above scheduling method of process tasks, it is necessary to validate the feasibility and effectiveness of proposed method in this section. Under the guidance of the aforementioned scheduling method, the case and the comparative analysis are carried out.

Firstly, before the start of scheduling, the relevant parameters of the genetic algorithm are set, and the initial values of the scheduling problem are assumed, as shown in Table 1.

| Name                      | Value |
|---------------------------|-------|
| Population size           | 40    |
| maximum number of iterations | 50 |
| cross probability         | 0.6   |
| mutation probability      | 0.1   |
| Number of process tasks   | 9     |
| Number of subtasks        | 6     |
| Number of processors      | 5     |

Then, the initial value is set. Set the collection of processors to \( P = (P_1, P_2, P_3, P_4, P_5) \), the collection of process tasks to \( T = (T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9) \), and and the collection of subtasks to \( T = (T_{i1}, T_{i2}, T_{i3}, T_{i4}, T_{i5}, T_{i6}) \). The optional processors at each phase of each task and the corresponding processing time are shown in Table 2 and Table 3.

Moreover, in order to obtain the calculated scheduling result more intuitively, this paper uses Matlab to program the genetic algorithm and bring the data in Table 2 and Table 3 into the code. The algorithm search process and the schedule Gantt are shown in Figure 2.

It can be seen from Figure 2 that the minimum completion time of the obtained scheduling scheme is 29 minutes.
Table 2. The optional processors at each phase of each task.

| T_1 | T_2 | T_3 | T_4 | T_5 | T_6 | T_7 | T_8 | T_9 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| T_{i1} | P_5 | P_4 | P_3 | P_3 | P_2 | P_4 | P_3 | P_1 | P_5 |
| T_{i2} | P_5 | P_4 | P_3 | P_3 | P_2 | P_4 | P_3 | P_1 | P_5 |
| T_{i3} | P_4 | P_4 | P_3 | P_3 | P_2 | P_4 | P_3 | P_1 | P_5 |
| T_{i4} | P_5 | P_4 | P_3 | P_3 | P_2 | P_4 | P_3 | P_1 | P_5 |
| T_{i5} | P_5 | P_4 | P_3 | P_3 | P_2 | P_4 | P_3 | P_1 | P_5 |
| T_{i6} | P_5 | P_4 | P_3 | P_3 | P_2 | P_4 | P_3 | P_1 | P_5 |

Table 3. The processing time of each phase of each task (Unit: minute).

| T_1 | T_2 | T_3 | T_4 | T_5 | T_6 | T_7 | T_8 | T_9 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| T_{i1} | 10 | 14 | 7 | 8 | 13 | 10 | 9 | 14 | 10 |
| T_{i2} | 8 | 6 | 12 | 5 | 6 | 4 | 6 | 10 | 11 |
| T_{i3} | 9 | 11 | 15 | 6 | 9 | 11 | 12 | 8 | 7 |
| T_{i4} | 5 | 11 | 9 | 7 | 5 | 8 | 11 | 5 | 6 |
| T_{i5} | 7 | 5 | 3 | 7 | 4 | 7 | 9 | 6 | 8 |
| T_{i6} | 12 | 3 | 4 | 9 | 12 | 3 | 8 | 5 | 5 |

Figure 2. The Gantt chart of scheduling result.
6. Conclusions
In this paper, the characteristics of complex equipment manufacturing tasks were systematically analysed, and a process task scheduling model that considers the maturity of the processor was presented. Then, a process task scheduling algorithm based on genetic algorithm was used, which is suitable for solving discrete problems such as shop scheduling problems. The proposed method was validated to be feasible and effective for achieving the optimal scheduling of process tasks in complex equipment manufacturing, through example studies and algorithmic analyses and comparisons. The research results of this paper will provide a theoretical and technical support for process task scheduling. In the future, we will focus on the further optimization and improvement of scheduling algorithm to continuously improve the application effect and scope of the method.

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