A multi-objective optimization method for aerospace product research and development process based on particle swarm optimization algorithm and critical path algorithm

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Abstract. In order to realize the multi-objective management objectives in the production cycle of aviation products, this paper combines particle swarm optimization algorithm and critical path optimization algorithm to carry out multi-objective optimization on the research and development process of aviation products. First, calculate the start time of each process by the critical path method and construct the initial population. Then construct the fitness function. Finally, particle swarm optimization is used for optimization, and through continuous iteration, the optimal combination that can achieve multi-objective optimization is obtained. Through the optimization experiment on the research and development process of aviation products, the global optimal research and development process calculated in this paper can shorten the production period by 32.4% and reduce the cost by 41.1%. Therefore, the multi-objective optimization scheme based on hybrid optimization algorithm proposed in this paper has theoretical and practical significance for the model management of the whole life cycle of aviation products.

1. Introduction

At present, China’s rapid development of the aviation product development conditions and manufacturing ability, based on the model of product whole life cycle of a digital design technology theory framework, model definition method and management is more and more thorough, the aviation group of many varieties of small batch production and pre-research products increased demand, the product model management [1] targets at the same time also more and more. Aviation products belong to complex products [2], and their research and development process is complicated. Therefore, advanced optimization technology is needed to support the research and development process management of aviation products [3], so as to realize multiple management objectives of complex product model.

Then many scholars continuously put forward new optimization algorithms, such as: branch and bound method, genetic algorithm, simulated annealing algorithm optimization algorithms such as [4], but these optimization algorithm is applied to the actual production process, is more complex and difficult to understand, such as genetic algorithm to design the individuals in the population crossover, mutation, selection and a series of operations, to select a set of optimal solutions. In this paper, the population intelligence algorithm which is more successful than other optimization algorithms is selected: particle swarm optimization algorithm [5], which was invented by Dr. Eberhart and Dr.
Kennedy in 1995. PSO algorithm originated from the study of foraging behavior of flying birds. When the flock is hunting, when a bird finds food not far away, it will fly to the food site, which will cause other birds around it to follow in the same direction until the whole flock lands and finds the food. This is a natural information-sharing mechanism. In the process of cognition and searching, individuals will remember their own flight experience. At the same time, it also learns from other excellent individuals. When it finds that some other individual flies better, it will learn from it and make appropriate adjustments to itself so that it can fly in a better direction. The particle swarm optimization algorithm only needs the individuals in the population to update their own speed and position to find the globally optimal solution.

The optimization of product research and development process and resource scheduling [6] are the key to the goal of product lifecycle management. Therefore, the objective of this paper is to study the multi-objective intelligent optimization algorithm for the life cycle management of trainer aircraft 'rear fuselage'. By adjusting the task execution sequence in the process of product development, rework and repeated development are minimized, development cycle is shortened and development cost is reduced. To achieve this goal, this article USES the critical path optimization method (nearing completion after the non-critical path of human resources to use on the critical path, thus shortening the duration of the critical path), the critical path of aviation product development project is optimized, and using the optimization design of fitness function of particle swarm optimization algorithm, and finally using particle swarm optimization algorithm in the fitness function under the constraint of global optimization operation, finally to obtain the optimal start time and achieve the goal of multiple optimization research and development process.

2. Establishment of optimization method

2.1. Optimized object

Generally, the Activity on Vertices (AOV) diagram is used to represent the relationships among the various activities in the project [7]. When describing the criss-crossing relationships between transactions, the nodes are used to represent the transactions, and the edges are used to represent the activities (that is, the relationships between the transactions and the information accompanying these relationships). The research and development process of aviation products in this paper is divided into 20 transactions. According to the relationship between the precursor and the successor of the transactions in the research and development process, the project flow chart of this topic is constructed as shown in figure 1.

![Figure 1. AOV diagram of aviation product research and development process.](image)

2.2. Optimization algorithm design

2.2.1. Constructed particle swarm. In the particle swarm optimization algorithm, each particle represents a possible solution to a problem. The main purpose of this project is to find a group of activity sequences that can minimize the total duration and cost. Suppose there are n project activities, using a1, a2... An represents the activity number, for example, forming the sequence ST(a1)- ST (a3)- ST (a2)- ST (a4)- ST (a5)- ST (a6)- ST (a7)- ST (a8)- ST (a12)- ST (a9)- ST (a10)- ST (a13)- ST (a11)- ST (a14)- ST (a15)- ST (a16)- ST (a17)- ST (a19)- ST (a18)- ST (a20)- ST (a22)- ST (a21)- ST
(a24)- ST (a23)- ST (a25) -ST (a28)- ST (a26)- ST (a27)-ST(a28) (where ST is short for start time), the sequence is a solution (a particle in the particle swarm).

In this paper, according to the duration of each activity are shown in table 1, and cost, the use of critical path algorithm to determine the earliest start time of each activity, as well as the late start time, the earliest start time and start time is used to determine the latest sequences of each activity in the process of the position, the earliest start time and the difference between the latest start time transformation range of start time for each activity.

The earliest start time and the latest start time of each activity are shown in table 2 (for the convenience of calculation, the starting time of the activity is set to 0) [8]. According to table 2, the critical path of the project can be determined as follows: ST (a1) - ST (a2)- ST (a5)- ST (a7)- ST (a9)-ST (a11)- ST (a13)- ST (a15)- ST (a16) - ST (a18)- ST (a22)- ST (a23)- ST (a25)- ST (a26)- ST (a27).

### Table 1. Activity number, expected cost and expected duration.

| Activity | SN | LC | Person | CP | Activity | SN | LC | Person | CP |
|----------|----|----|--------|----|----------|----|----|--------|----|
| a1       | 102| 20 | 10     | 15 | a15      | 304| 54 | 10     | 35 |
| a2       | 103| 50 | 20     | 10 | a16      | 308| 66 | 11     | 20 |
| a3       | 104| 40 | 5      | 8  | a17      | 309| 45 | 9      | 23 |
| a4       | 105| 10 | 2      | 7  | a18      | 310| 25 | 5      | 10 |
| a5       | 106| 24 | 3      | 9  | a19      | 311| 13 | 10     | 6  |
| a6       | 107| 20 | 12     | 31 | a20      | 312| 16 | 4      | 5  |

Note: In this table, SN represents activity number, LC represents labor cost, and CP represents construction period.

### Table 2. The earliest and latest start times of activities.

| Activity | Earliest start time | Latest start time | Activity | Earliest start time | Latest start time |
|----------|---------------------|-------------------|----------|---------------------|-------------------|
| a1       | 0                   | 0                 | a15      | 181                 | 181               |
| a2       | 15                  | 15                | a16      | 216                 | 216               |
| a3       | 0                   | 17                | a17      | 216                 | 223               |
| a4       | 15                  | 27                | a18      | 239                 | 239               |
| a5       | 25                  | 25                | a19      | 236                 | 243               |
| a6       | 25                  | 105               | a20      | 249                 | 256               |
| a7       | 34                  | 34                | a21      | 254                 | 261               |
| a8       | 34                  | 75                | a22      | 249                 | 249               |
| a9       | 69                  | 69                | a23      | 264                 | 264               |
| a10      | 102                 | 102               | a24      | 264                 | 333               |
| a11      | 117                 | 117               | a25      | 306                 | 306               |
| a12      | 56                  | 143               | a26      | 337                 | 337               |
| a13      | 152                 | 152               | a27      | 394                 | 394               |
| a14      | 117                 | 165               | a28      | 337                 | 409               |

2.2.2. Adaptation function. In order to optimize the performance of the results in all aspects, the adaptive function used contains multiple optimization objectives, such as equation 1, where $X =$
(x₁, x₂, ... xₙ) represents the activity. In equations 2 to 5, C(X) represents the cost, T(X) represents the construction period, R(X) represents the labor cost, G(X) represents the cost of relevant materials, and α represents the average labor cost coefficient, while Nₓᵢ represents the number of people involved in the ith activity, and gₓᵢ represents the material cost required for the ith activity.

\[
\begin{align*}
\text{min } F(X) &= C(X) + T(X) \\
C(X) &= R(X) + G(X)
\end{align*}
\]

In the aviation product in actual production process [9], some activities can be happened at the same time, such as activity a₁ and a₃ can occur at the same stage, but the production process of AOV diagram, each transaction to happen when the next activity, must ensure that the precursor of affairs of all activities to be completed, so the said time limit the function of T (X) as the equation 5. tₓᵢ, each activity period, the values of 0-1, ρ said each of the critical path activities, shorten the construction period of proportion coefficient value is 0-1, γ said in the critical path of new personnel work period, the proportion of time limit for a project, The value is 0-1, I(xᵢ,j) represents the jth number of new personnel in the ith activity, and m represents the number of new personnel in the critical path.

\[
T(X) = \sum_{i=1}^{n} (t_{x_i} - \rho_i t_{x_i})
\]

\[
R(X) = \alpha(\sum_{i=1}^{n} N_{x_i})T(X) + \sum_{j=1}^{m} \sum_{i=1}^{n} (\gamma_{ij} t_{x_i} I(x_i,j))
\]

\[
G(X) = \sum_{i=1}^{n} g_{x_i}
\]

2.2.3. Design particle property update. In the particle swarm optimization algorithm, the particle has only two properties: speed and position. The speed represents the speed of movement and the position represents the direction of movement. The particle velocity can be dynamically adjusted according to the optimal position of particle history and the optimal position of population history. The optimal solution sought by each particle individually is called the individual extreme value, and the optimal individual extreme value in the particle swarm is the current global optimal solution. Through continuous iteration, update speed and location, the optimal solution that satisfies the termination condition is finally obtained.

3. Results analysis

In the second stage of the hybrid optimization algorithm, the fitness function of the population including the critical path optimization algorithm was firstly calculated, and the duration of the optimal particle in the initial population was found to be 498.0 days, the cost was 8.185 million yuan, and the fitness was 1316.5. 50 rounds of population optimization operation, eventually found from the seventh round of the global optimal particle back no longer changes, changes in the duration of the first 8 rounds, artificial cost and fitness as shown in figure 3, can be found on the critical path optimization algorithm and particle swarm optimization algorithm, the time limit for a project and cost has been constantly optimized, after the optimization experiment finally obtain the optimal particle period for 380 days, the cost is 6.365 million yuan, fitness is 1016.5. The final starting time of each activity for each stage is shown in table 3 (0-17 represents the starting time of the range of values between 0 and 17 containing boundary integers, and so on. Values with a range in the figure all mean this).
Figure 2. Changes in the starting time of non-critical activities in the optimization process.

Figure 3. Duration, cost and fitness of the optimization process.

Table 3. Start times of each activity in each stage.

| Activity | The first stage | The second stage | The third stage | Activity | The first stage | The second stage | The third stage |
|----------|----------------|-----------------|----------------|----------|----------------|-----------------|----------------|
| a1       | 0              | 0               | 0              | a15      | 181            | 181             | 181            |
| a2       | 15             | 15              | 15             | a16      | 216            | 216             | 216            |
| a3       | 0-17           | 16              | 16             | a17      | 216-223        | 223             | 223            |
| a4       | 15-27          | 22              | 19             | a18      | 239            | 239             | 239            |
| a5       | 25             | 25              | 25             | a19      | 236-243        | 242             | 242            |
| a6       | 25-105         | 25              | 40             | a20      | 249-256        | 254             | 256            |
| a7       | 34             | 34              | 34             | a21      | 254-261        | 261             | 261            |
| a8       | 34-75          | 61              | 41             | a22      | 249            | 249             | 249            |
| a9       | 69             | 69              | 69             | a23      | 264            | 264             | 264            |
| a10      | 102            | 102             | 102            | a24      | 264-333        | 264             | 264            |
| a11      | 117            | 117             | 117            | a25      | 306            | 306             | 306            |
| a12      | 56-143         | 104             | 136            | a26      | 337            | 337             | 337            |
| a13      | 152            | 152             | 152            | a27      | 394            | 394             | 394            |
| a14      | 117-165        | 149             | 135            | a28      | 337-409        | 387             | 388            |
In the second stage, particle swarm optimization algorithm is used for optimization, and each particle continuously updates its speed and position of each dimension [10]. For example, each particle is a combination sequence containing the starting time of each activity in the project. The project contains a total of 28 activities, so the dimension of each particle is 28. Experiments, each particle only 4, 6, 8, 12, 14, 20, 28 update the speed and position, as shown in figure 2, the a4, a6 and a8 non-critical activity namely, a12, a14, a20, a28 the start time of change in the experimental process, the non-critical activities and all of the start time of key activities are unchanged.

4. Conclusion

In order to obviously realize the optimization of multiple objectives such as project duration and cost, this paper designs a hybrid optimization algorithm, namely, particle swarm optimization algorithm is used to find the global optimal particle according to the fitness function containing the critical path optimization method, which is the starting time of the optimal research and development process. The critical path optimization algorithm used in the experiment is mainly for the purpose of using the human resources in the non-critical path on the critical path after the completion of the non-critical path, so as to shorten the construction period of the critical path. The particle swarm optimization algorithm mentioned in the experiment is to find the particle with the lowest labor cost on the basis of finding the particle with the shortest time limit. In this paper, the global optimal particle found by using hybrid optimization algorithm can shorten the project duration by 32.4% and labor cost by 41.1%, thus achieving multi-objective optimization. It has theoretical and practical significance for the management of product lifecycle model and has broad application prospect.

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