Research on Multi-objective Project Scheduling Model Based on Multi-skilled Workers

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Abstract. There are many kinds of skills for the workers in the project group, but the present scheduling methods do not consider that the workers have different proficiency in different skills. In this paper, a scheduling model of human resources project is established, which takes the worker’s skill proficiency into account and the project duration and labor cost are considered as the optimization objectives. The improved non-dominated sorting genetic algorithm (NSGAII) is used to solve the model. The simulation results show that the model can significantly improve the scheduling efficiency of the project team, and managers can make scheduling decisions according to preference in a series of solutions.

1. Introduction
Human resource is the key factor of enterprise development, and labor scheduling is the core of human resource management. With the increase of workers’ access to knowledge and skills, it is a normal phenomenon for workers to master multiple skills. Multi-skilled worker[1] refers to a worker who has multiple skills at different levels. The presence of multi-skilled workers helps organizations to respond to changes in the external environment, also has increased the number of personnel options in the project activities, as well as the complexity of personnel scheduling. In 1998, Burleson et al[2] put forward the multi-skilled human resource strategy problem in the construction industry and solved it with the skill helper strategy. However, the search space of the solution in this method is relatively small. Neron[3] proposed a multi-skill employee scheduling problem in project management, calling it a multi-skill project scheduling problem (MSPSP). Neron pointed out that MSPSP is a classic resource-constrained project scheduling problem. The degree problem[4] is an extension of (RCPSP), and in reference[5] taking the duration of the project as the optimization objective, the single-objective project scheduling problem of multi-skilled personnel with different levels is studied, but in fact, this kind of scheduling is usually a multi-objective optimization problem considering both time and cost. Li Ming collates the relevant literature to deal with the problem of multi-skilled workers in literature[6] with different model algorithms for different objectives. At present, the methods of solving multi-objective scheduling model can be divided into heuristic algorithm[7] and intelligent algorithm[8]. Compared with heuristic algorithm, NSGAIL[9] in intelligent algorithm is congested because of the use of fast undominated ordering. The comparison and elitist strategy make the individuals distribute uniformly in the population, the computational complexity is lower, and the sampling space is larger. Therefore, considering the workers' mastery of many kinds of skills, according to the influence of skill proficiency on compensation and duration, this paper sets up a multi-objective project scheduling model based on multi-skill workers, taking the time limit and labor cost as the optimization goal. Using NAGAIL algorithm and combined with this model, the corresponding chromosome coding is designed to solve the problem.
2. Model building
The project includes m activities, n workers, the activities j most allow the participation of the L workers, the number of skills required to complete the project and the number of skill types and skilled workers required for each activity is a fixed value, and the activity time is correspondingly prolonged if the worker's skills are not well-known.

\[ G = (A, E, d) \] for project activities network, of which: \( A = \{ A_1, A_2, \ldots, A_m \} \) represents a set of project activities, \( A_1 \) is the starting node, \( A_m \) is the end node. \( d_j \) (1≤j≤m) indicates the duration of \( A_j \); \( E \) represents the set of activity relationships, if it exists (\( A_i, A_j \))∈E, then \( A_i \) is the predecessor activity of \( A_j \).

The objective functions that need to be optimized at the same time are as follows:
1) Salary cost function
\[ C = \min \sum_{i=1}^{n} \sum_{j=1}^{m} d_{jk} \cdot c_k \cdot PS_{ik} \]

2) Construction period function
\[ T = \min \sum_{j=1}^{h} d_j \quad (j \in H) \]

Constraint condition:
Temporal constraints: \( t_i - t_i \geq d_i, (A_i, A_j) \in E; \)
Resource constraints: \( \sum_{j \in A_i} r_{jk} \leq R_k; \)
\( l_j \leq L_j. \)

In which each letter means as follows:
\( j, k \) separate representation worker, activity, skills, 1≤i≤n, 1≤j≤m, 1≤k≤s;
\( d_{jk} \) indicates the time it takes worker i to finish activity j with k skills;
\( c_k \) indicates unit time remuneration of skill k;
\( PS_{ik} \) indicates worker i proficiency degree in skill k, 0≤PS_{ik}≤1;
\( d_j \) indicates the completion time of activity j;
\( H \) indicates all activities on critical paths, 1≤h≤H;
\( t_i \) indicates the start time of \( A_i; \)
\( r_{jk} \) indicates the number of workers with k skills required for activity j;
\( R_k \) indicates the number of workers with k skills;
\( A_t \) represents all active sets in t period;
\( l_j \) indicates activity j arranges the number of workers;
\( L_j \) indicates that activity j allows the maximum number of workers to be arranged.

This model is based on the following assumptions:
1) Each worker can only participate in one activity at the same time;
2) Active tasks cannot be interrupted.

3. Algorithm design

3.1. Algorithm flow
1) Randomly generated initial population \( P_0 \), the scale is \( N_p; \)
2) The corresponding objective function value is obtained by parallel scheduling algorithm based on improved topological sorting, then the initial population is ranked according to the dominance level and the crowding distance.
3) Let the current evolutionary algebra \( d=1; \)
4) Selection of better populations from parent populations \( Q_1; \)
5) Use differential evolution algorithm[10] to cross and mutate the parent species to obtain a new population \( Q_2; \)
6) Combining two populations \(Q=Q_1 \cup Q_2\), calculate the value of the objective function and do an undominated sort for \(Q\) (Refer to step 2); selection of better \(N_p\) individuals based on Elite retention Strategy, gain generation population \(P_t\);
7) Let \(d=d+1\), if \(d<\text{Gmax}\), turn to step 3; else, step 8;
8) Save the running result and output the multi-objective function image, according to the preference of the decision maker, the gantt graph of the corresponding scheduling plan is outputted, and the algorithm terminates.

3.2. Coding program

The characteristics of multi-objective project scheduling model based on multi-skilled workers, the 3D coding method shown in figure 1 is designed. Among them, a complete chromosome consists of three parts: priority coding, participating worker coding and specific worker numbering. The priority is expressed as a random number between 0 and 1, and the smaller the value is, the more priority is given to the task arrangement; the number of workers involved represents the number of workers involved in the activity, which is randomly generated as an integer, and is not greater than the maximum number of workers who are restricted by the activity; the specific worker number represents the worker number involved in the activity and randomly generates the corresponding integer.

| Priority coding | 0.1 | 0.3 | 0.5 | ... | 0.6 |
|-----------------|-----|-----|-----|-----|-----|
| Number of workers involved | 3   | 2   | 3   | ... | 1   |
| Specific worker number | 4   | 5   | 8   | 3   | 9   |
|                     | 2   | 7   | 9   | ... | 6   |

\[ J_1 \quad J_2 \quad J_3 \quad \ldots \quad J_n \]

Fig. 1 Chromosome coding

3.3. Crossover and variation

Random crossover method is used for cross operation. Two chromosomes were selected and the breakpoints were randomly generated. The chromosomes were divided into several segments of genes and then combined accordingly. The specific operation is shown in figure 2.

Fig. 2 Crossover operator

The mutation operation was carried out in reverse mutation mode. Two adjacent gene sites were randomly selected on the paternal cogeneration chromosomes. The corresponding gene values of the
two genes were reversed and the other gene values were copied to the offspring in sequence in order to generate the progeny chromosomes. The operation was shown in figure 3.

![Fig. 3 Mutation operation](image)

3.4. Select
To maintain the diversity of the population based on the optimal non-dominated ordering and crowding distance of Pareto. Calculate each individual’s non-domination level and crowded distance. Individuals with low non-dominance level and large aggregation distance have a higher probability of entering their offspring, the selection operation is based on this, the non-dominated solution generated in the running process of the algorithm is stored in the elite reservation pool by using the elite retention strategy in NSGA-II. After several iterations, a series of optimal solutions are obtained, and the individuals with better relative indexes are selected according to the preference of the decision makers.

4. Numerical simulation and results
The algorithm is implemented in MATLAB programming language. The algorithm parameters are set as follows: population size = 300, cross probability 0.8, mutation probability 0.05, evolutionary algebra 200. This paper model and its algorithm are applied to the project of Z Construction Company. There are 19 activities in the project and 12 workers in the project team. 8 kinds of skills are required to complete the project. Table 1–3 shows the relevant information of the task during the implementation of the project.

| Task number | Project task logic constraint | Activity time | Required number of workers | Skill type |
|-------------|-------------------------------|---------------|---------------------------|-----------|
| 1           |                               | 5             | 3                         | 3         |
| 2           | 1                             | 8             | 2                         | 1         |
| 3           | 1                             | 10            | 3                         | 5         |
| 4           | 2                             | 4             | 1                         | 2         |
| 5           | 4                             | 7             | 4                         | 6         |
| 6           | 3                             | 3             | 2                         | 2         |
| 7           | 3                             | 11            | 4                         | 3         |
| 8           | 4                             | 8             | 2                         | 4         |
| 9           | 5, 6                          | 6             | 2                         | 7         |
| 10          | 7                             | 10            | 4                         | 6         |
| 11          | 8                             | 8             | 3                         | 5         |
| 12          | 9, 10                         | 9             | 5                         | 2         |
| 13          | 11, 12                        | 3             | 1                         | 8         |
| 14          | 13                            | 5             | 3                         | 4         |
| 15          | 13                            | 8             | 2                         | 1         |
| 16          | 14                            | 4             | 1                         | 5         |
| 17          | 15, 16                        | 9             | 3                         | 6         |
| 18          | 8                             | 7             | 3                         | 8         |
| 19          | 17, 18                        | 3             | 1                         | 7         |
We obtained a group of Pareto solutions as shown in Fig 4, and selected some representative solutions as shown in Table 4.

**Fig. 4 Multi-objective Pareto**

| Tab. 2 Project team workers and their skill proficiency |
|---------------------------------|-----|-----|-----|-----|-----|-----|-----|
| Worker | Skill | 1   | 2   | 3   | 4   | 5   | 6   |
| 1      | 0    | 0   | 0.6 | 0   | 0   | 1   | 0   |
| 2      | 1    | 0.7 | 0.5 | 0   | 0   | 0   | 0   |
| 3      | 0    | 1   | 0.9 | 0   | 0.6 | 0   | 0   |
| 4      | 0    | 1   | 0   | 0   | 0   | 0.8 | 0   |
| 5      | 0    | 0   | 1   | 0   | 0.6 | 0   | 0   |
| 6      | 0.5  | 0   | 0.7 | 0   | 0   | 1   | 0   |
| 7      | 0    | 0.6 | 0   | 1   | 0   | 0   | 0.6 |
| 8      | 0    | 0   | 0   | 1   | 0   | 0.7 | 0   |
| 9      | 0    | 0   | 0   | 0   | 1   | 0   | 0.7 |
| 10     | 0    | 0   | 0   | 0   | 1   | 0.8 | 0   |
| 11     | 0    | 0   | 0   | 0   | 0   | 0   | 1   |
| 12     | 0.9  | 0   | 0   | 0   | 0   | 0   | 1   |

| Tab. 3 Skill salary |
|---------------------|-----|-----|-----|-----|-----|-----|-----|
| Skill               | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
| Unit hourly rate    | 18  | 25  | 15  | 24  | 28  | 20  | 35  |

We obtained a group of Pareto solutions as shown in Fig 4, and selected some representative solutions as shown in Table 4.
Tab. 4 Partial solution set

|   | 1   | 2   | 3   | 4   | 5   | 6   |
|---|-----|-----|-----|-----|-----|-----|
| Salary cost / yuan | 8305 | 8434 | 8428 | 8590 | 8783 | 9082 |
| Construction period / h | 153.9 | 131.3 | 133.7 | 114.3 | 105.5 | 100.3 |

The first set of solutions in Table 4 is selected to give the corresponding Gantt chart of worker scheduling, as shown in figure 5, in which the label on the horizontal road represents the activities of the worker during this period.

5. Conclusion

Consider that the worker has a variety of skills, and the skill proficiency has an impact on the remuneration and duration of the case, the multi-objective project scheduling model based on multi-skilled workers is established. The improved non-dominated sorting genetic algorithm is applied and the corresponding chromosome coding is designed to solve the problem. The multi-objective optimization of time limit and labor cost is realized; the problem of multi-skilled worker scheduling is solved by the method of information technology, and the utilization efficiency of workers’ skills is improved; the simulation results show that the multi-skilled workers can reduce the project cost and shorten the duration by rational deployment. Project managers can make decisions based on preferences in a series of solutions.

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