# Time Cost Optimization of Assembly Building Installation Phase Based on Particle Swarm Optimization

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**Abstract:** This paper combines the theory of resource-constrained project scheduling to analyze the cost influencing factors during the installation phase of prefabricated buildings, and establishes a resource-constrained scheduling model with the goal of minimizing the installation time to achieve the optimization of time cost during the installation phase.

## 1. Introduction

With the acceleration of urbanization and the improvement of environmental protection awareness, prefabricated buildings play an increasingly important role in the construction industry[1]. Prefabricated construction has the advantages of high efficiency, energy saving and environmental protection, but it also faces the problem of high cost[2]. Therefore, optimizing the cost control of prefabricated buildings is of great importance for improving the competitiveness of prefabricated building enterprises[3].

Anvari[4] solved the resource scheduling problem of production, transportation and installation departments based on multi-objective genetic algorithm to minimize time and cost; Fang[5] used genetic algorithm to model construction logistics, combined construction plan and logistics schedule, and deduced the best construction plan according to the lowest construction logistics cost. Zhang[6] established an elastic cost trade-off optimization model based on multi-objective particle swarm optimization algorithm to save transportation cost during construction. Zou[7] used BIM and finite element simulation to optimize the cost of prefabricated building construction; Wu[8] proposed an improved wolf pack algorithm to solve the transportation problem of a certain prefabricated component, and built a transportation vehicle scheduling optimization model to minimize transportation cost.

Scholars mainly study the transportation problems in the construction process. As the key work in the whole construction process, the installation period determines the time limit for the construction of the production stage and the transportation stage. The decision of the prefabricated construction schedule will affect the length of the installation period. Therefore, it is necessary to study the time cost of the installation stage.

This paper establishes a resource-constrained scheduling model with the goal of minimizing the installation time. Taking an office building project set up by a prefabricated steel structure enterprise in Guilin as an example, the particle swarm optimization algorithm is used to solve the time optimization problem in the installation phase of prefabricated buildings.

## 2. Installation phase mathematical model creation

### 2.1 Model assumptions

(1) The main work of the prefabricated component installation stage is the hoisting of the prefabricated component. In order to carry out the hoisting work smoothly and on schedule, it is necessary to ensure that all resources are in place prior to the start of standard layer construction. This requires that all activities and required resources are in place before the project begins.

(2) Prefabricated components are manufactured and tested in the manufacturing plant before being transported from the prefabrication plant to the construction site. Unlike traditional cast-in-place construction, which is heavily influenced by the local climate, the installation phase of prefabricated components in prefabricated buildings is relatively less influenced by the local climate. In addition, the construction of standard floors has the characteristic of repeatability. To simplify calculations, the construction efficiency of each floor can be considered the same, and the installation time can be expressed as the product of the installation time and the number of installation layers of each floor. Assuming that the construction environment is normal, the work efficiency of the tower crane and the construction personnel on each standard layer is the same.

### 2.2 Model building

Suppose a project consists of $m$ tasks, with the mathematical expression $P=\{1, 2, \ldots, m\}$. The virtual tasks at the beginning and end of the project are task 1 and $m$, respectively, which represent the order of adjacent tasks.

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There are a total of $R$ renewable resources in these work activities, and the number of these resources is limited. Among them, the capacity limit of the $k$ resource is $R_k$ ($k$=1, 2, ... , $R$). All work is subject to the constraints of its immediate work, also known as FS constraints. Immediate work refers to the work that immediately precedes the work and must be started before the work begins. In addition, the sum of the consumption of the $k$ renewable resource for each task cannot exceed the capacity limit $R_k$ of the resource at any time. The time required for work $i$ in the project is $d_i$ ($i$=1, 2, ..., $m$) and the consumption of the $k$ renewable resource is $r_k$.

During the installation phase, a project scheduling model was established to meet the resource constraints and minimize the installation time. By reasonably arranging the sequence of various tasks in the project, the shortest construction schedule with installation period $S_m=\sum d_i$ was obtained. The specific mathematical expression is as follows:

$$\text{objective}: \quad \min S_m \tag{1}$$

$$\text{s.t.} \quad S_i + d_i \le S_j \ , \quad \forall i \in P_j \tag{2}$$

$$\sum_{i \in A_t} r_{ik} \le R_k \tag{3}$$

$$t = 0, 1, ..., S_m \tag{4}$$

$$S_i \ge 0 \, , i = 1, 2, ..., m \tag{5}$$

Where, the start time of activity $i$ is represented by $S_i$, the execution time of activity $i$ is represented by $d_i$, all the compact activities of activity $j$ are represented by $P_j$, all activity sets in execution at time t are represented by $A_t$, and the unit time usage of activity $i$ for the $k$ resource in the execution process is represented by the constant $r_{ik}$.

In addition, formula (1) indicates that the objective function is to minimize the duration. Formula (2) is the tight pre-activity constraint relationship between activity $i$ and $j$. Activity $i$ is the tight pre-activity of activity $j$, which indicates that work $j$ can only start after all tight pre-activities are completed. Formula (3) represents the resource constraint of the activity, which means the resource consumption of the activity being performed in a given time period must not exceed its limit $R_k$; Formula (4) represents time-consuming discrete variables; Formula (5) indicates that all activity start times are non-negative.

## 3. Case study

### 3.1 Case components

Take the office building project as an example for analysis. The project has 5 floors above ground and is a prefabricated steel structure building. It is divided into two units, with one unit on each floor as the construction flow section, and the two unit flow sections are constructed alternately. The main goal of the installation phase is to optimize the construction scheduling sequence of the installation process under resource constraints of workers such as construction machinery (tower cranes), measurement, and templates, in order to obtain the shortest installation period that meets resource constraints, that is, to solve the resource constrained project scheduling problem with the minimum chemical period as the objective function. The main resources provided at the construction site include 1 tower crane, 2 surveyors, 6 lifting machines, 6ordinary workers, 5steel reinforcement workers, and 5 grouting workers. Organize the machine and human resource supply table, as shown in Table 1.

**Table 1** Machine and human resources supply table

| Number | Resource | Quantity |
|---|---|---|
| C1 | Tower crane | 1 |
| C2 | Welder | 2 |
| C3 | Slinger | 8 |
| C4 | Ordinary worker | 6 |
| C5 | Riveter | 6 |
| C6 | Grouter | 4 |

The goal of the installation phase is to minimize the construction period of the standard layer as much as possible. Based on the requirements of the construction period and one's own operational capabilities, the main job numbers, job durations, and required resource allocation are shown in Table 2.

**Table 2** Work resource requirements table

| Number | Procedure | Duration(d) | Resource | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | C1 | C2 | C3 | C4 | C5 | C6 |
| 1(13) | Embedded bolt acceptance of civil foundation | 0.5 | 0 | 0 | 0 | 3 | 0 | 0 |
| 2(14) | Find the centerline of the column | 0.5 | 0 | 0 | 2 | 0 | 0 | 0 |
| 3(15) | Steel column installation | 1.5 | 1 | 0 | 5 | 1 | 0 | 0 |
| 4(16) | Inter column support installation | 1 | 0 | 1 | 3 | 1 | 0 | 0 |
| 5(17) | Steel beam installation | 1 | 1 | 0 | 4 | 1 | 0 | 0 |
| 6(18) | Initial and final tightening of high-strength bolts | 1 | 0 | 0 | 0 | 0 | 6 | 0 |
| 7(19) | Frame bulk correction | 0.5 | 0 | 0 | 2 | 1 | 0 | 0 |
| 8(20) | Purlin installation | 0.5 | 0 | 2 | 1 | 3 | 0 | 0 |
| 9(21) | Piecemeal installation | 0.5 | 0 | 0 | 0 | 2 | 0 | 0 |
| 10(22) | Stair installation | 0.5 | 0 | 0 | 0 | 2 | 0 | 1 |
| 11(23) | Wall panel installation | 1.5 | 1 | 0 | 4 | 1 | 0 | 0 |
| 12(24) | Caulking and grouting | 0.5 | 0 | 0 | 0 | 0 | 0 | 4 |

### 3.2 Algorithm duration calculation

The PSO algorithm is used to solve the resource constraint scheduling model established during the installation phase using MATLAB 2018b programming. The purpose of the solution is to optimize the installation scheduling sequence of the installation phase under the resource constraints of tower cranes, welding, lifting, riveting, and grouting workers, and ultimately obtain the shortest installation period that meets the constraints. Particle swarm population size is 80, individual variation range is (-3,3), velocity variation range is (-1,1), inertia weight is 0.9, learning factor c1 is 1.49445, c2 is 1.49445 (usually c1=c2), and the shortest construction time is 8.5 days after 100 iterative calculations. The output Gantt chart for the installation phase schedule is shown in Figure 1.

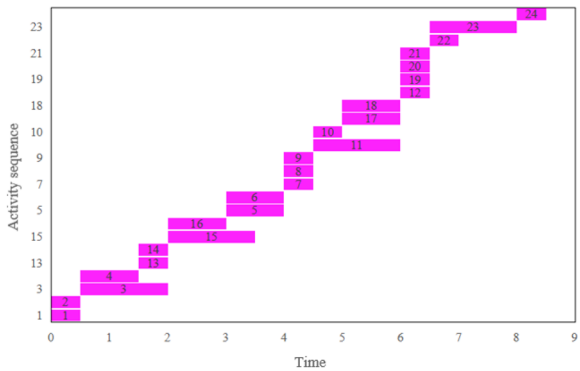


**Figure 1** Schedule Gantt chart

**Table 3** Standard floor installation phase work schedule

| Time(d) | Work arrangement |
|---|---|
| 1 | a. Embedded bolt acceptance of civil foundation<br>a. Find the centerline of the column<br>a. Steel column installation<br>a. Inter column support installation |
| 2 | a. Steel column installation<br>a. Inter column support installation<br>b. Embedded bolt acceptance of civil foundation<br>b. Find the centerline of the column |
| 3 | b. Steel column installation<br>b. Inter column support installation |
| 4 | b. Inter column support installation<br>a. Steel beam installation<br>a. Initial and final tightening of high-strength bolts |
| 5 | a. Frame bulk correction<br>a. Purlin installation<br>a. Piecemeal installation |
| 6 | a. Wall panel installation<br>b. Steel beam installation<br>b. Initial and final tightening of high-strength bolts |
| 7 | a. Caulking and grouting<br>b. Frame bulk correction<br>b. Purlin installation<br>b. Piecemeal installation |
| 8 | b. Stair installation<br>b. Wall panel installation |
| 8.5 | b. Caulking and grouting |

The progress and work schedule of the project in the installation phase can be obtained by combining the Gantt chart of the progress arrangement and the minimum working days, as shown in Table 3, where a and b represent two units. From the table, we can know that the installation period of a standard floor is 8.5 days, and the daily work tasks can be reasonably planned under the resource constraints of the project. For example, the work arrangement of the first day is to carry out the acceptance of the embedded bolts of unit a, find the center line of the column, install the steel column and the support between the columns; the work arrangement of the second day is to install the steel column of unit a and the support between the installation columns. At the same time, the acceptance of the embedded bolt of unit b is also carried out. Similarly, the daily work schedule can be clearly seen, considering 8.5 days as a cycle of installation work on a standard floor until all floors of the project have been installed.

In the above schedule, when the installation time of a standard floor is 8.5 days, C3 is the most used resource. To better understand the meaning, Figure 2 shows the utilization of C3 lifters as the main resource. Where, the horizontal coordinate represents the construction period, and the vertical coordinate represents the number of C3 resources. The "3,5" in the figure indicates that work number 3 requires five C3 resources.

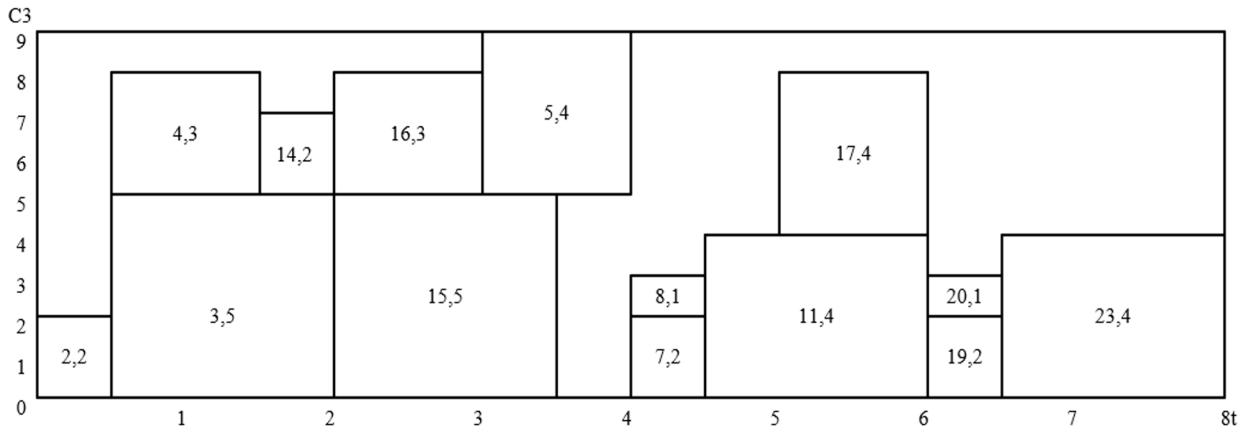


**Figure 2** Usage diagram of C3

From the analysis in Figure 2, it can be concluded that the demand for the use of lifting resources is relatively high on the third and fourth days. In order to ensure the smooth progress of subsequent work and save time and cost during the installation phase, it is necessary to manage the usage time and quantity of such resources reasonably during this period. In other words, managers need to pay more attention to C3 resource management during this period, which will help them find key points and organize installation more efficiently, avoiding project delays caused by untimely resource supply and increasing unnecessary installation costs in a timely manner.

## 4. Conclusion

This paper studies the optimization of time cost in the installation phase of prefabricated buildings through the rational scheduling of resources. In the installation stage, a resource-constrained project scheduling model is established with the goal of minimizing the work time. Combined with the actual case of the office building, the PSO algorithm is used to solve the model, and the shortest installation time is 8.5 days. At the same time, the construction scheduling scheme with the shortest assembly cycle and the corresponding utilization of main resources under the resource constraint is formulated, so that the resources can be optimally arranged in the scheduling plan, and a feasible idea for the time-cost optimization of the assembly phase of prefabricated buildings is provided.

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