# Research on the Optimization of Construction Schedule of Super High-rise Prefabricated Buildings

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**Abstract:** An optimization model was established for the standard floor construction period against the current management situation of the super high-rise assembly construction schedule with manpower usage, material consumption and machinery usage as main reference variables, so as to prevent from affecting the construction schedule. And the best linear relationship of the minimum duration was obtained to optimize the construction schedule through the LINGO programming operation. Moreover, the feasibility of the optimized model is verified to be more reasonable than the traditional method over the resource allocation in combination with the engineering cases. Evidently, the optimized model can shorten the construction period.

**Keywords:** Super high-rise; Prefabricated buildings; Construction schedule; Optimization

## 1 Introduction

People have set out to find breakthroughs in building height with the constantly improving urbanization rate in recent years. And construction engineering has also developed towards the large-scale and super high-rise direction along with the continuous development of the engineering industry in China, promoting the development of China's super high-rise prefabricated buildings. With prefabricated buildings as the development direction of the building industry, the super high-rise prefabricated building is an extensive construction process that changes the traditional super high-rise building.

In such a context, the optimized construction schedule for prefabricated buildings is one of the research hotspots in recent years. Various schedule optimization methods have been proposed from manpower research according to the differences in the setting and emphasis of the research problem.Bian et al. optimized the construction schedule of the standard floor of prefabricated buildings according to the construction schedule of the standard floor of the prefabricated buildings of the scheduled target of the construction period by compiling the construction schedule using the time scale network method after the WPS project decomposition. And the construction schedule was optimized according to the principle of minimum cost, so that the construction unit can accomplish the construction task as scheduled with the lowest construction cost[1]. Chen established an SD schedule risk model to propose countermeasures and suggestions for the key risks before analyzing the causal relationship between the schedule risks of prefabricated construction with the social network analysis method[2]. Han et al. sought for the problems of prefabricated buildings in the construction of super high-rise buildings according to the characteristics of prefabricated buildings[3]. Targeted the fine construction management

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of prefabricated buildings, Kou et al. discussed the fine management of prefabricated buildings in the construction process to strengthen the relationship between construction and management after analyzing the management advantages and specific applications of applying BIM technology in prefabricated buildings from the aspects of construction cost, quality, safety and schedule[4]. Tang et al. researched the implementation of the super high-rise building of Nanning China Resources Center[5] using intelligent building technologies such as BIM and information technology. Wang et al. established a prediction model for the plane volume of the prefabricated building construction site, the plane inventory of the construction site, and the construction schedule after effectively correlating the inventory of main parts of the prefabricated building construction and the construction schedule by managing the plane of the construction site by building a model[6]. Wang et al. established a resource-constrained project scheduling model and programmed it with JAVA language to quickly and accurately obtain the schedule and resource-constrained schedule, constrained resource distribution, and the optimized schemes of resources and construction period[7]. Xie enriched the research achievements in the field of prefabricated construction schedules by introducing the management thought of key chain projects and formulated the prefabricated monomial and polynomial critical chain on-site construction schedule[8] in combination with the AHP entropy weight method.Zhao introduced BIM technology to update the establishment and information of the BIM model of prefabricated buildings in real time, analyze the construction schedule of prefabricated buildings, and manage the production and installation schedules of prefabricated parts[9]. Zheng discussed that the construction schedule can be effectively improved through the establishment of an information management platform progress using modern technical methods, and the schedule control means aided by data analysis with the case analysis method to deal with the management problem in the schedule of prefabricated buildings[10]. Zhang established a sound construction schedule management strategy after analyzing the problems in the process of construction schedule management of prefabricated buildings from the theory of schedule management of prefabricated buildings[11].

This paper studied the construction schedule in the construction stage by combining prefabricated buildings and super high-rise buildings. To be specific, a standard floor construction progress optimization model was established using the linear programming method and then applied to optimize the use of manpower, material consumption, and machinery in the installation process of laminated slabs of the standard floor, the cast-in-situ construction of the main structure, and the installation of the ALC interior wall. After that, the construction period can be optimized.Please refer to the second part of the article for the specific establishment of the model, and the parameter range is based on actual engineering cases.

## 2 Establishment of an Optimized Construction Schedule Model

The basic assumption of the optimized construction schedule model is presented below:

Manpower, material consumption, and the quantity of machinery used were used as the main reference variables affecting the schedule. The optimized construction period model of the standard floor was established to constrain the manpower, materials, and machinery used in the construction of the laminated slab, the cast-in-situ construction of the main structure, and the installation of the ALC interior wall of the authentic project（The standard floor refers to the residential floor with the same layout）. The construction schedule of the whole project is determined by the main works on the main route. The sum of the activity time of the main work is the construction period of the super high-rise prefabricated building and also the optimized objective of the construction period of the project. First, the construction process is assumed as an uninterrupted process, that is, it cannot be stopped once the activity starts. Basic assumptions for the establishment of the optimized model are proposed as below:

a. Also, the daily resource supply can maintain the construction activities, with manpower, materials, and the quantity of machinery s used not exceeding the daily resource supply in the construction process of the standard floor of the project. Besides, the sum of daily resource consumption shall not be more than all resource limits in the construction plan in the construction process of the standard floor.

b. It shall be guaranteed in the construction process of prefabricated parts that the amount of manpower used is proportional to that of materials consumed, and that the quantity of machinery used is proportional to the amount of manpower used.

c. The only critical path of the project remains the critical path after optimization.

d. The project objectives such as safety and quality shall not be affected in the process of schedule and resource optimization.

A specific construction schedule model is established below:

The project schedule optimization model is described as follows: A standard floor is composed of n construction activities i03D 1, 2, --, and n. The project time ranges 05B0 and *si*02B1 05D05D are specified as per the process of the main route of the construction period planning. The project involves resources of machinery $j_i$, manpower $p_i$ and material $r_i$, of which the daily quantity of Kth resource is $R_k$. The amount of resource k required by activity *i* during execution is $R_{ik}$. Note that the consumed amount of resource in an activity shall be within the total amount of the resource at any time. The duration of each activity i is $d_i$. The construction of a laminated slab is a fictitious activity marking the activity's beginnings, with zero time and resources required. The starting and ending time of activity i is $s_i$ and $s_{i+1}$, respectively, then $s_i + d_i = s_{i+1}$. All parameters are assumed to be non-negative integers since it is assumed that the construction activity of the standard floor cannot be stopped once it starts. Two preconditions shall be fulfilled at the same time for the objective of an optimized schedule, as shown below: time constraints and project resource constraints are set between the construction processes of the standard floor to achieve the minimum construction period $\mathrm{Min}s_{i+1}$ of the standard floor.

The model is established as below:

Targeted schedule optimization: $\min = s_{i+1}$

Time constraints between activities: $s_i + d_i = s_{i+1}$

Project activity started from zero hour: $s_1 = 0$

The linear function between the activity time and the usage amounts of manpower, materials and machinery: $d_i = a_i - b_i r_i - c_i p_i - e_i j_i$

The time interval between construction activity i of the laminated slab and construction activity 2 of the main structure of the standard floor: $t_i \le d_i$

Spatial constraints on the quantity of manpower used for the project activity *i*: $p_i^{'} \le p_i \le p_i^{"}$

Spatial constraints on the machinery of the project activity *i*: $j_i^{'} \le j_i \le j_i^{"}$

Sum of the total quantity of manpower constraining the quantity of manpower used in the project activity *i*: $\sum_{i=1}^{n} p_i \le P$

Sum of the total quantity of machinery constraining the quantity of manpower used in the project activity *i*: $\sum_{i=1}^{n} j_i \le J$

Spatial constraints on the material usage amount $r_i$ for the project activity *i*: $r_i^{'} \le r_i \le r_i^{"}$

Resource constraints of the material usage amount r*1* in the construction process *1* of the laminated slab and the material usage amount *r2* in the main structure construction 2 of the project: $g^{'} r_1 \le r_i \le g^{"} r_2$

Spatial constraints on the quantity $p_i$ of manpower and the material usage amount $r_i$ for the project activity *i* can be expressed as: $v_i r_i \le p_i \le h_i r_i$

Spatial constraints on the quantity $j_i$ of machinery and the quantity $p_i$ of manpower for the project activity *i* can be expressed as: $f_i p_i \le j_i \le k_i p_i$

The quantity $p_i$ of manpower, the material usage amount $r_i$ and the quantity $j_i$ of machinery are guaranteed as non-negative integers: $p_i, r_i, j_i \ge 0$

## 3 Cases Application

The case is located in the T2 Building of the HD Project in Hangzhou, Zhejiang, China, with a height of 125m and a floor height of 3.10m. The underground and ground buildings cover areas of roughly 1827.53 ㎡ and 23266.43 ㎡, respectively. The number of floors: 34 floors, with 6-31 floors constructed by prefabricated parts.

### 3.1 Optimized construction period for laminated slab

The standard floor area of the building is 750.53 ㎡. After realizing the loss problem at the construction site, the floor space of the laminated slab under construction is 687.8 ㎡, with the same laminated slab adopted for installation. The installation process of the laminated slab is composed of the installation of the laminated slab and the pouring of reinforced concrete. The construction period for installing a laminated slab is 2 days in authentic engineering. Concrete pouring is performed after the installation of the laminated slab. After that, curing shall be carried out. The next construction process is permitted only when the concrete strength of the laminated slab reaches 1.2N/mm$^2$. The installation period for the composite slab is 3.5 days since a 1.5-day curing time is required after concrete pouring. According to the table, the data standardizations of materials, manpower, and machinery for the construction of laminated plates are presented below.

Standardizations of manpower, various materials, and machinery in the installation process of laminated slab of the standard floor were obtained from past construction experience and the cost calculation of individual buildings of several similar projects. On this basis, the mathematical optimization model is calculated. The manpower is standardized as 226 yuan/m$^2$, with a fluctuation range of 5%. The material is standardized as 2766 yuan/m$^2$, with a fluctuation range of 10%. The machinery is standardized as 54.5 yuan/m$^2$, with a fluctuation range of 10%.

Meanwhile, the standardization of manpower and materials is between (1/14, 1/11), or $\frac{1}{14}r_1 \le p_1 \le \frac{1}{11}r_1$.

And the standardization of machinery and manpower is between (1/8, 1/3), or $\frac{1}{8}p_1 \le j_1 \le \frac{1}{3}p_1$.

The construction period for installing the laminated slab is 3.5 days, with a fluctuation of 10%.

The construction period function of the laminated slab construction process is:

$$d_1 = a_1 - b_1 r_1 - c_1 p_1 - e_1 j_1$$

**Table 1** Optimized Construction Period of Laminated Slab

| Construction date | Manpower data standardization | Material data standardization | Mechanical data standardization |
|---|---|---|---|
| 4 | 147 | 1979 | 38.5 |
| 3.875 | 163 | 2117 | 40.4 |
| 3.75 | 181 | 2332 | 45.6 |
| 3.625 | 206 | 2520 | 50.8 |
| 3.5 | 226 | 2766 | 54.5 |
| 3.375 | 247 | 2932 | 67.3 |
| 3.25 | 264 | 3113 | 72.3 |
| 3.125 | 283 | 3211 | 88.1 |
| 3 | 306 | 3410 | 97.8 |

By linearly fitting the function, the function of the construction period for installing the laminated slab of the standard floor can be determined as:

$$d_1 = 5.039 - 0.0018r_1 - 0.0004p_1 - 0.0027j_1$$

### 3.2 Optimized construction period for the main structure

A system combining advanced production technologies intelligent climbing frame and aluminum mold is adopted in the construction of the main structure of the standard floor in the project, contributing to saving labor costs and shortening the construction period by 3.5 days. According to the table, the data standardizations of materials, manpower, and machinery for pouring the main structure are presented below.

The manpower is standardized as 409 yuan/m2, with a fluctuation range of 5%. The material is standardized as 1319.8 yuan/m2, with a fluctuation range of 10%. The machinery is standardized as 71.71 yuan/m2, with a fluctuation range of 10%.
Meanwhile, the standardization of manpower and materials is between (1/14, 2/3), or $\frac{1}{4}r_2 \le p_2 \le \frac{2}{3}r_2$.

And the standardization of machinery and manpower is between (1/8, 1/3), or $\frac{1}{8}p_2 \le j_2 \le \frac{1}{3}p_2$

The construction period for the main structure is 3.5 days, with a fluctuation of 10%.

The construction period function of the main structure is:

$$d_2 = a_2 - b_2 r_2 - c_2 p_2 - e_2 j_2$$

**Table 2** Optimized Construction Period of Cast-in-place Concrete

| Construction date | Manpower data standardization | Material data standardization | Mechanical data standardization |
|---|---|---|---|
| 4 | 278 | 1075.7 | 55.5 |
| 3.875 | 318 | 1135.4 | 59.4 |
| 3.75 | 356 | 1194.9 | 63.6 |
| 3.625 | 383 | 1259.9 | 67.8 |
| 3.5 | 409 | 1319.8 | 71.71 |
| 3.375 | 430 | 1377.5 | 75.3 |
| 3.25 | 465 | 1434.2 | 79.8 |
| 3.125 | 500 | 1498.8 | 84.1 |
| 3 | 535 | 1553.3 | 87.8 |

By linearly fitting the function, the function of the construction period for the main structure of the standard floor can be determined as:

$$d_2 = 6.077 - 0.000027 r_2 - 0.0014 p_2 - 0.0095 j_2$$

### 3.3 Optimized construction period for installing ALC prefabricated interior wall

Installing the ALC prefabricated interior wall of the main structure of this project with the mechanical arm can improve the efficiency of interior wall installation, requiring 4-day for completing construction and installation. Data standardizations of materials, manpower, and machinery for the installation of ALC prefabricated interior walls are presented below.

The manpower is standardized as 138 yuan/m2, with a fluctuation range of 5%. The material is standardized as 529.6 yuan/m2, with a fluctuation range of 10%. The machinery is standardized as 43.5 yuan/m2, with a fluctuation range of 10%.

Meanwhile, the standardization of manpower and materials is between (1/14, 2/3, or $\frac{1}{4}r_3 \le p_3 \le \frac{2}{3}r_3$.

And the standardization of machinery and manpower is between (1/8, 1/3), or $\frac{1}{8}p_3 \le j_3 \le \frac{2}{3}p_3$

The construction period for installing ALC prefabricated interior walls is 3 days, with a fluctuation of 10%.

Construction period function of ALC prefabricated interior wall installation

$$d_3 = a_3 - b_3 r_3 - c_3 p_3 - e_3 j_3$$

**Table 3** Optimized Construction Period of ALC Prefabricated Interior Wall Installation

| Construction date | Manpower data standardization | Material data standardization | Mechanical data standardization |
|---|---|---|---|
| 3.5 | 103 | 453.1 | 28.7 |
| 3.375 | 109 | 464.1 | 32.8 |
| 3.25 | 118 | 487.9 | 38.5 |
| 3.125 | 127 | 513.3 | 40.4 |
| 3 | 138 | 529.6 | 43.5 |
| 2.75 | 146 | 584.5 | 48.9 |
| 2.625 | 153 | 671.3 | 54.2 |
| 2.5 | 160 | 730.5 | 60.3 |

By linearly fitting the function, the optimized construction period for mounting the ALC prefabricated interior wall of the standard floor can be determined as:

$$d_3 = 5.079 - 0.0107 r_3 - 0.0006 p_3 - 0.007 j_3$$

### 3.4 Optimized Construction Period Value

The best coordination of materials, manpower, and machinery at each stage was determined using the software based on the calculation of the mathematical model of the standard floor of the project. Then the optimized construction period for each stage can be fitted. The sum of the optimized construction period values at each stage is the optimized construction period value for the construction of the standard floor of the project. The minimum objective function of the construction period for constructing the standard floor is established from the manpower, materials, and machinery- construction period functions in the above three stages:

$$\begin{aligned}\mathrm{Min}s_4 &= s_1 + d_1 + d_2 + d_3 \\ &= 5.039 - 0.0018r_1 - 0.0004p_1 - 0.0027j_1 + 6.077 - 0.000027r_2 \\ &- 0.0014p_2 - 0.0095j_2 + 5.079 - 0.0107r_3 - 0.0006p_3 - 0.007j_3\end{aligned}$$

According to the calculation results of the model, the manpower, material, and machinery for the installation of the laminated slab of the standard floor are standardized as 306 yuan/m2, 3410.99 yuan/m2, and 97.8 yuan/m2, respectively; the manpower, material, and machinery for the construction stage of the main structure of the standard floor are standardized as 535 yuan/m2, 1553.3 yuan/m2, and 87.8 yuan/m2, respectively; the manpower, material, machinery for the installation of the ALC interior wall of the standard floor are standardized as 160 yuan/m2, 640 yuan/m2, and 53.33 yuan/m2, respectively. The optimized construction period of the standard floor at the construction stage is 8.606 days after the optimization of manpower, materials, and machinery. The construction period for compiling the general grid chart is 10 days, with 1.394 days shortened.

## 4 Conclusions

The T2 building is a 31- storey building. Its planned period for the construction activities of the building was 345 days, which was optimized to 310.15 days after optimizing the schedule with the optimized model. Evidently, the construction time of the T2 building can be shortened by 34.85 days as a whole, effectively saving construction time.An optimized construction and installation schedule model is established in this paper for the standard floor by proposing the factors of manpower, materials, and machinery based on the current situation of the construction schedule management of the authentic super high-rise prefabricated building project. The best linear relationship of the minimum construction period is acquired from programming and calculation with LINGO. The optimized schedule model for super high-rise prefabricated buildings is conducive to effectively saving resources and avoiding waste after calculation. In this way, resources can be efficiently utilized to lower costs in addition to optimizing the schedule. The optimized model is more efficient and reasonable than the traditional network chart construction. Moreover, the optimized schedule model can shorten the construction schedule of prefabricated buildings according to the calculation result of the actual resource conditions and cost conditions at different prefabricated building construction sites according to the constraints required by the optimized model.

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