

Intelligent scheduling optimization of prefabricated components for assembly buildings

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Abstract. Prefabricated construction, as an emerging architectural model, has the characteristics of fast construction process and flexible design, and has been widely used in the field of architecture in China. As the core component of prefabricated buildings, the schedule of prefabricated components directly affects the progress and quality of the project. This study extends the volume of prefabricated components from a single building to a group of buildings, designs and solves an intelligent scheduling scheme model based on project construction schedule and procurement plan, and proposes two reference building group scheduling schemes and their applicable conditions. Genetic algorithm is used to optimize vehicle scheduling and transportation paths to achieve intelligent scheduling of prefabricated components in prefabricated building groups, ensuring project progress and quality.

Keywords: Assembled buildings; Prefabricated components; Scheduling optimization; GA

1. Introduction

As an emerging construction mode, assembly building is developing rapidly under the strong support of the state [1]. Assembly building is to divide the building structure into several units according to its spatial layout, force characteristics, etc., and each unit is prefabricated in the factory and then transported to the construction site for assembly [2]. The assembly building model is characterized by fast building process, high building quality, low environmental impact, and flexible design. Prefabricated components, as the core component of assembly building, play an important role in influencing the progress and quality of the project. Therefore, scheduling optimization has become one of the effective means to improve the production management level, shorten the market response time, reduce the production cost and improve the production efficiency [3].

Research on prefabricated building scheduling, both domestic and international, mainly includes the following aspects: Wang Leyuan [4] established a vehicle scheduling model for a PC component factory serving multiple construction sites in a one-to-many mode, and solved this model by improving the basic artificial fish swarm algorithm. Zhang Huimei [5] constructed a joint optimization model for production scheduling of prefabricated components and preventive maintenance of equipment, and designed a multi-objective backbone particle swarm optimization algorithm (BB-MOPSO) to solve this model. Xu Mingxiao [6,7,8] established a multi-objective production scheduling optimization model with the goal of minimizing production completion time and minimizing penalty costs. Wang Heping have constructed and solved a mathematical model for the multi space collaborative scheduling problem under multiple factor constraints, with the goals of project duration, cost, and robustness [9]. Sheng Longwei [10] Optimize the transportation process by selecting component transportation routes and optimizing logistics scheduling algorithms.

The above literature review shows that in terms of scheduling optimization of prefabricated components, existing research mainly focuses on the scheduling optimization of prefabricated components in individual buildings, while there is relatively little research on the optimization of

scheduling management of prefabricated components between building clusters. Therefore, this study will design and solve an intelligent scheduling model based on the construction schedule and procurement plan by calculating the volume of prefabricated components, and obtain the optimal scheduling plan for the building complex. Genetic algorithm will be further optimized to ensure the progress and quality of the project.

2. Project Overview

2.1 Project General Information

The engineering case study project for this study is a general contracting project for Phase 1 of the Trinity Cloud City project in a city. Firstly, the single building 3# building was studied, and then it was expanded to the first phase of the group of buildings. Among them, the first phase of the project consists of seven single buildings, focusing on the study of the 3# building with a floor area of about 1,237.30 square meters, a building height of 79.15 meters, 25 floors above ground, two floors below ground, with a floor height of 3.15m, and the number of residential households is 100.

2.2 Component work volume statistics

First of all, the number of prefabricated components of the single building is counted, and on the basis of the detailed list of components of the single building, it is summarized and integrated, expanded, and applied to other floors in accordance with the principle of taking the same components for the same type of floors, and finally obtained the quantity of prefabricated components of the group building, and obtained the summary table of the quantity of prefabricated components of the group building, as shown in Table 1.

Table 1 Summary of cluster building components

Unit: pcs

Prefabricated component types	Total number of components in the cluster							
	1#	2#	3#	4#	5#	6#	7#	Total sum
laminated panels	576	576	864	576	576	864	684	4716
stairs	64	64	96	64	64	96	76	524
exterior walls	112	112	176	112	112	176	136	936
interior walls	392	392	616	392	392	616	476	3276

3. Intelligent Scheduling Model for Prefabricated Building Components

3.1 Scheduling model underlying assumptions

- (1) Assume that each vehicle can be loaded with only one component at a time.
- (2) Assume that there is no path selection problem. The driving distance from the component factory to the group building and between the group buildings is known, and the driving paths of all transportation vehicles are also planned in advance, without considering the driver's short rest time, real-time traffic conditions and traffic control and other factors.
- (3) Assuming that all transportation vehicles in the component factory are of the same type, and the maximum load capacity of the vehicles is the same.
- (4) Assuming that the loading and unloading operations of the transportation vehicles are carried out one by one, the loading time of each vehicle is the same, and the unit loading cost of prefabricated components in the component plant is the same as the unit unloading cost at the construction site.
- (5) It is assumed that the component plant has continuous production and supply capability, there is no shortage of goods, and the demand for goods from each construction unit is clear.

3.2 Model parameters and constraint settings

The parameter symbols and their meanings involved in constructing the mathematical model for this study are shown in Table 2.

Table 2 Parameter symbols and their meanings

Parameter	Definition
UT_{jk}	Unloading time of transport vehicle k at site j
N	Number of transportation vehicles available for redeployment
I, J	Transportation vehicle number, $i=1,2,3,\dots,n$; Individual building number, $j=1,2,3,\dots,m$
K_j	Total number of transportation trips to single building j
K	Trip number assigned to monolithic building j , $k=1,2,3,\dots,K_j$
L	Nominal load capacity of transport vehicles
Q_j	Total number of component requirements for single building j
B_j	Number of components required for a single building on a transport vehicle j
D_{oj}	Distance from component plant O to single building j
(ES_j, LF_j)	Soft time-window constraints to be satisfied for transportation of components required for single building j
R_i, g_i	Vehicle load factor; Actual vehicle weight
DT_{oj}	Time required for transportation vehicles to deliver PC components from component factory O to site j
RT_{oj}	Time required for transportation vehicles to return empty from monolithic building j to component plant O
ST_{jk}	Point of departure from the prefabricated building plant of the k th vehicle assigned to the single building j
AT_{jk}	Point of arrival at the site of the k th vehicle assigned to single building j
BT_{jk}	Point in time when the k th vehicle arrives at the monolithic building j to unload and leave the site
FT_{jk}	Point in time when the k th vehicle returns from the single building j to arrive at the PC component plant
I_{jk}	Difference between the time of departure of the k -1st transportation vehicle from the single building j and the time of arrival of the k th vehicle
E_{jk}	Difference between the k th vehicle arrival time and the earliest required delivery time ES_j for a single building j
L_{jk}	Difference between the k th vehicle arrival time and the latest required delivery time LF_j for a single building j
Z_{ijk}	Calculation factor for the k th movement of components of a single building j to be transported by vehicle i

Vehicle scheduling has the following process in sequence:

(1) The number of trips K_j required at site j is equal to the number of pieces demanded divided by the number of components that can be loaded on each vehicle:

$$K_j = \frac{Q_j}{B_j} + 1, \quad \frac{Q_j}{B_j} \in INT. \quad (1)$$

(2) The time for the k th vehicle to arrive at the construction monolithic building j is equal to the sum of the time required for the k th vehicle to depart from the prefabrication plant at the point in time and the distance traveled, that is:

$$AT_{jk} = ST_{jk} + DT_{oj}. \quad (2)$$

(3) If the k th vehicle arrival time of construction unit building j is earlier than the k -1th vehicle departure time, there is a wait. The length of the waiting time is:

$$I_{jk} = BT_{jk-1} - AT_{jk}. \quad (3)$$

If $I_{jk} > 0$, then you need to wait; conversely you don't need to wait.

(4) Depending on whether or not there is a need to wait, the time at which the k th vehicle of construction unit building j leaves the site can be deduced:

$$BT_{jk} = \begin{cases} ST_{jk} + DT_{oj} + UT_{jk} + I_{jk}, I_{jk} > 0 \\ ST_{jk} + DT_{oj} + UT_{jk}, I_{jk} \leq 0 \end{cases} \quad (4)$$

(5) The k th vehicle arrives at construction monolithic building j at a time that does not satisfy the length of the construction monolithic building j time window constraint:

$$\begin{cases} E_{jk} = ES_j - AT_{jk} \\ L_{jk} = AT_{jk} - LF_j \end{cases} \quad (5)$$

If $E_{jk}, L_{jk} > 0$, then penalty costs are incurred; conversely they are not incurred.

(6) Point in time when the k th vehicle of construction monolithic building j returns to the component factory

$$FT_{jk} = BT_{jk} + RT_{oj} \quad (6)$$

(7) Calculation factor for the k th truckload of prefabricated components of construction unit building j to be transported by vehicle i

$$Z_{ijk} = \begin{cases} 0, & \text{Transportation} \\ 1, & \text{Not transporting} \end{cases} \quad (7)$$

(8) The formula for the actual load factor of vehicle i is

$$r_i = \frac{g_i}{L} \quad (8)$$

In this study, the following three assumptions are made for the precast yard situation:

- 1) The amount of precast components stacked on-site for one standard floor;
- 2) Half of the precast component volume of one standard floor is stacked on-site;
- 3) No stacking on-site and on-demand callout.

3.3 Component scheduling program design

Taking the standard floor as an example and assuming it is in the supply phase, a study of vehicle scheduling in the cluster building was initiated and the statistics of prefabricated component demand in the cluster building are shown in Table 3 below.

Table 3. Incoming prefabricated components for cluster buildings

Types	2#	4#	3#	6#	1#	5#	7#	Number of components carried on a single vehicle
laminated panels	36	36	36	36	36	36	36	12
walls	36	36	36	36	36	36	36	12
staircases	4	4	4	4	4	4	4	4

Based on the above table of prefabricated component requirements, the following three modes of vehicle transportation to the cluster building are considered:

- (1) Each vehicle delivers only a specific building, i.e., no vehicles are reused;
- (2) Vehicles are reused, lapped, and grouped in accordance with the following Table 4 Option I program: where a component within the group may be completed by the reuse of a single vehicle;
- (3) Vehicles are reused, overlapped, and grouped according to the Option II scheme in Table 4.

Table 4, Option of cluster building arrangements

	Group 1	Group2	Group3	Group4
combo 1	2, 4, 3, 6	1, 5	7	/
combo 2	2, 4	1, 5	3, 6	7

Nine options were derived in conjunction with the limitations of the component yards in the project:

Option 1: No stacking on-site, on-demand, each vehicle to deliver only a specific building, i.e.

Option 2: No stacking on site, reuse vehicles, carry out overlaps and follow Option 1 into groups;

Option 3: No stacking on site, reuse vehicles, carry out overlaps and follow Option 2 into groups;

Option 4: on-site stacking of a standard layer of prefabricated components half of the amount , each vehicle only distribution of a specific building, that is, not reuse of vehicles;

Option 5: Stacking half of the precast volume of one standard floor on site to ensure construction supply, reuse of vehicles, overlapping, and grouping according to Option 1.

Option 6: On-site stacking of half the amount of prefabricated components of a standard floor to ensure construction supply, reuse of vehicles, lapping, and grouping in accordance with Option 2.

Option 7: On-site stacking of one standard layer of prefabricated components to ensure construction supply, with each vehicle delivering to a specific building only, i.e., no reuse of vehicles;

Option 8: Stacking of one standard floor of precast units on site to ensure construction supply, reuse of vehicles, overlapping, and grouping in accordance with Option 1.

Option 9: The amount of prefabricated components stacked on site for one standard floor to ensure construction supply, reuse of vehicles, overlapping, and grouping according to combo 2.

4. Intelligent Scheduling Model Solving for Precast Components

4.1 Component Scheduling Path Objective Optimization

The overall flow of the genetic algorithm is shown in Fig. 1. On this basis, the path optimization objective of scheduling is introduced.

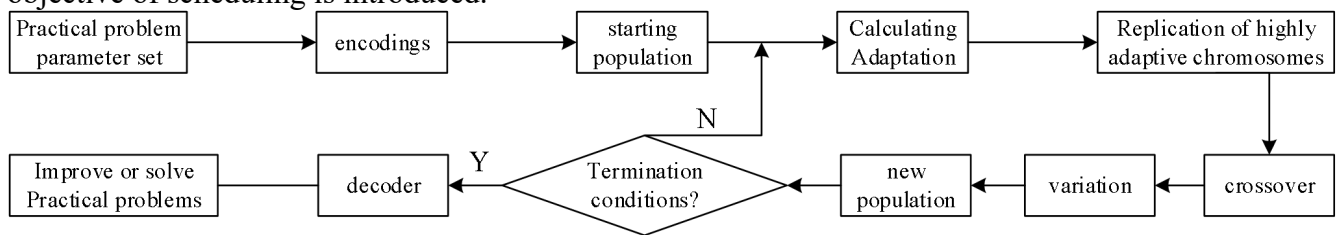


Fig. 1 Steps of genetic algorithm to solve the problem

First of all, genetic algorithm is used to solve the optimal path of transport vehicle scheduling for assembled prefabricated components, which is a combinatorial optimization problem based on the order and time schedule of each construction site corresponding to the transportation distance at the minimum time, and the solution space corresponds to the discrete integer domain space, so the overall idea is to establish a mapping relationship by means of coding in genetic algorithms, and indirectly produce the order of transport vehicles by decoding the individual positional states and calculating the value of the objective function.

4.2 Schematic modeling solution

(1) Solution of the on-demand program

Options one, two and three are available. At this time, the vehicle needs to arrive at the scene at the same time for the component crane loading and unloading, so this type of situation is basically the same as a dedicated vehicle dedicated building.

(2) Half yard program solution

Options IV, V and VI are available. Option 4 considers the designation of vehicles and buildings, with one vehicle for each of the different buildings designated to be delivered to the corresponding cluster yard at different times; Option V vehicles are reused, carried out in overlaps, and in groups according to combination two. Among them, each group of cluster buildings is equivalent to a single building inside the dedicated vehicle delivery, respectively, consider prefabricated walls, prefabricated laminated panels, prefabricated stairs crane loading and unloading vehicles; Program six consider the site is not stacked, on-demand dispatch, vehicle reuse, lap to carry out, and in accordance with the combination of one. Based on its characteristics, on-demand dispatching requires that each type of component within a group can be kept in supply at one time.

(3) Full yard program solution

Options VII, VIII and IX are available. The difference between full and half field is in the requirements for on-site staging and other construction aspects, and has no impact on the vehicle scheduling options themselves.

4.3 Discussion and analysis of results

When considering the on-site prefabricated components as they are used to ensure construction supply, there are options 1, 2 and 3, which require 20 vehicles;

When considering on-site stacking of half the amount of prefabricated components for a standard floor to ensure construction supply, there are Scenarios IV, V, and VI, with Scenario IV requiring 7 vehicles for the dedicated building, Scenario V using 4 vehicles for Lap Combination I, and Scenario VI using 12 vehicles for Lap Combination II.

Specifically, there is a schedule of vehicle dispatch requirements as shown in table 5.

Table 5. Results of the cluster component scheduling program

	On-demand scheduling	Standard level half yard	Standard level full yard
Designated car and building	20	7	7
Combo 1	20	4	4
Combo 2	20	12	12

As can be seen from the table:

(1) Safely, a sufficient number of vehicles need to be arranged to ensure that the construction of the complex is carried out properly at the time of maximum demand;

(2) The number of vehicles can be effectively reduced through the overlapping relationship of vehicle scheduling and by combining the conditions of the on-site stackable yard;

(3) The standard number of layers for on-site stacking requires judgment in relation to construction site requirements.

On-demand scheduling requires too much real-time on-site, component plant, exclusion. Designated vehicles and construction increase vehicle utilization and greatly increase costs, ruled out. After screening, either Option 5 or Option 8 can be selected depending on site yard restrictions. If the material yard and the actual situation require a large number of standard layer components, choose option eight, and vice versa, choose option five.

5. Summary

Based on the actual engineering cases, this study counts the number of prefabricated components of a single building, expands on this basis, and applies it to other floors according to the principle of taking the same components for the same type of floors, and finally obtains the volume of prefabricated components for a group of buildings.

Combined with the project construction schedule, procurement plan, vehicle transportation mode, the limitations of component yard, time window constraints and other factors, the basic assumptions and constraints of the model are constructed, and the intelligent scheduling model scheme is designed, which contains 9 different scheduling schemes for the cluster building.

The advantages and disadvantages on the use of vehicles are compared, two kinds of building group scheduling schemes available for reference and their applicable conditions are derived, and the genetic algorithm is used to optimize the scheduling and transportation paths of the vehicles, and the final result is that there is no optimization space for the paths due to the limitations of the loop paths in this project.

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