Research on Optimization of Production and Transportation Management of Prefabricated Buildings

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Abstract. In order to effectively solve the problems of high construction cost of prefabricated buildings, insufficient resources, and insufficient collaborative management and control capabilities. This paper conducts research on the factors affecting the construction cost of prefabricated buildings and the optimization of process management, analyzes the factors affecting the construction cost of prefabricated buildings, the hierarchical structure and the action path, constructs a lean construction process management framework system for prefabricated buildings, establishes an optimization model for the construction process management of prefabricated buildings, and proposes an integrated process management collaborative mechanism for prefabricated building projects. The research results are helpful to identify the factors affecting the construction cost of prefabricated buildings, clarify the ideas and methods for optimizing the construction process management, and maximize the benefits of the construction process. It provides a theoretical basis and important support for improving the optimization of the construction process management, collaborative management and lean construction of prefabricated buildings, and has important practical guiding significance for accelerating the industrialization of construction in my country.

Keywords: Collaborative control; lean construction; framework system; transportation management; integrated process management.

1. Introduction

With the continuous development of my country's economy, society and science and technology, the construction industry is also constantly innovating and changing. From the initial manual construction to the current industrial manufacturing, the professional technology of the construction industry is constantly innovating and improving, and prefabricated buildings have received widespread attention and recognition due to their many advantages such as lean design, factory production and assembly construction. Prefabricated components are the most important components and smallest units of prefabricated buildings. Their design management is crucial. The quality of the design results directly affects the subsequent production, transportation and on-site construction, and also determines the overall quality and benefits of prefabricated buildings. The production and transportation process of prefabricated components is often affected by many factors such as the degree of specialization, production scale, loading and transportation scheme of the prefabricated component factory. Production -Transportation Scenario Description

1.1 Production Inventory Process

Prefabricated components for assembled buildings are produced in production workshops in an assembly-line production mode [1]. The main processes include cleaning and assembling molds and dies, hanging steel cages, burying embedded parts, pouring and vibrating concrete, curing in curing kilns, demoulding and placing components, and finished product inspection and repair; the third stage is to transport the prefabricated components to the prefabricated component factory yard for temporary inventory maintenance after numbering them. Its basic production process is shown in figure 1.

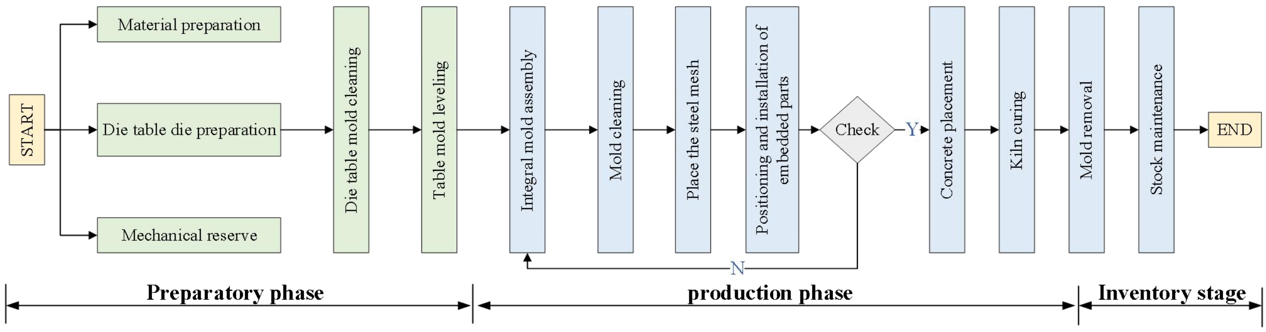

Fig. 1 Inventory process of prefabricated components for prefabricated buildings

1.2 Transport Scheduling Process

The transportation scheduling problem of prefabricated components for assembled buildings is a special vehicle scheduling problem with a time window. The prefabricated component factory produces and processes prefabricated components according to the order requirements issued by the construction site, and then is responsible for the logistics transportation scheduling of prefabricated components [2]. The main process of transportation scheduling of prefabricated components for assembled buildings is shown in figure 2.

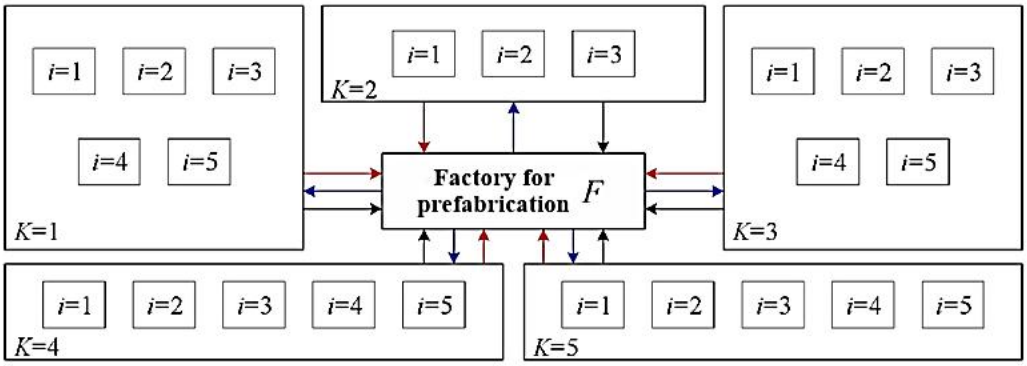

Fig. 2 Scheduling process of prefabricated components for prefabricated buildings

1.3 Problem Analysis and Description

In order to meet the growing demand for the supply of prefabricated components for prefabricated building projects, prefabricated component factories with certain production capacity and scale are built around cities. If the process that has been started cannot be completed within normal working hours, it can be interrupted or suspended until the next working day to continue production. Among them, P1~P4 and P7 are interruptible processes [3]. P5~P6 and P8 are non-interruptible processes. For example, after the concrete pouring is completed at the construction site, maintenance should be carried out immediately. The production and processing duration of the prefabricated component workshop is shown in figure 3.

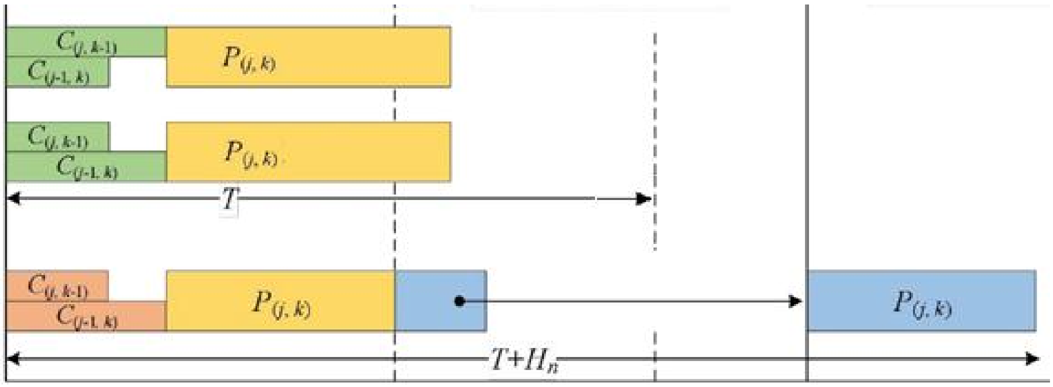

Fig.3 Schematic diagram of the duration of prefabricated component production

Prefabricated components will face road traffic congestion and traffic control during logistics transportation, which will inevitably have a certain impact on transportation time. Therefore, regarding the relevant research on road traffic impedance, the Federal Highway Administration of the United States proposed a new road resistance function model (BPR road resistance function model), which quantitatively expresses road traffic impedance and is a relatively typical research method. In the transportation of prefabricated components, the calculation formula of the road traffic impedance function is as follows:

$$t = t_0\left[1 + \alpha \cdot (\frac{m}{n})^{\beta}\right] \quad (1)$$

t: Represents the normal road driving time (min), the road driving time when the traffic volume of the road section is zero (min);

m: Indicates the traffic volume of motor vehicles on the road section (vehicles/h);

n: Represents the actual traffic capacity of the motor vehicle on the road section (vehicles/h);

α / β : Represents the undetermined coefficient. Among them, the Federal Highway Administration of the United States α takes 0.15 in the allocation and β takes 4.0.

2. Production-Transportation Model Building

2.1 Resource Constraint Analysis

The mold constraints in the production process of prefabricated components are shown in figure 4. Taking the workshop production process of the composite plate as an example, the molds are required in the seven processes from mold assembly to mold removal. There are three sets of quantitatively designed molds, and four composite plates of the same type are produced in sequence on the same assembly line. Due to the limited number of molds, the mold will not be released until the first composite plate completes mold removal, and the fourth composite plate can enter the first process to perform the production task. In addition, in order to ensure the continuous operation of the assembly line machinery and equipment and the uninterrupted production process of prefabricated components, each process of the second composite plate must wait until each process of the first composite plate is completed before production and processing can be carried out. In this way, the production process repeats the workshop production tasks of prefabricated components on the assembly line [4].

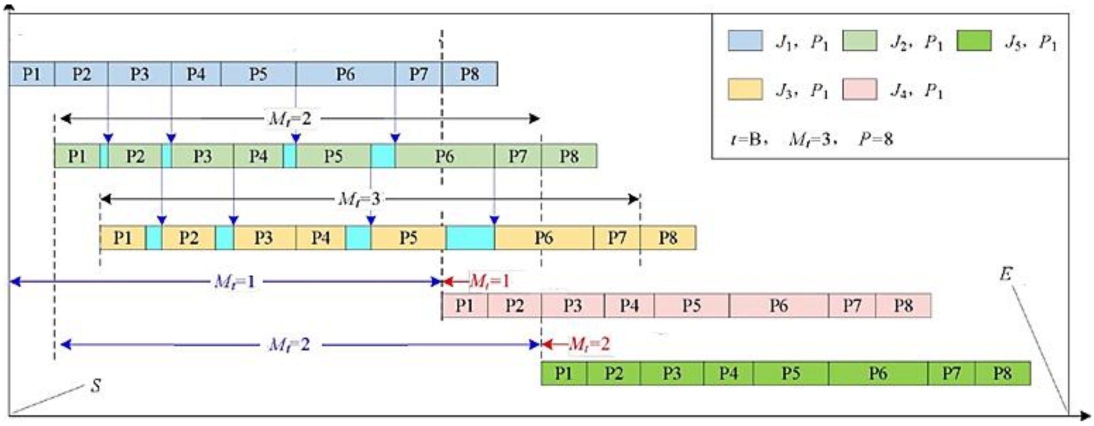

Fig.4 Mold constraints in the production process of prefabricated components

The production of prefabricated components can be completed after the prefabricated components go through the first 7 processes on the assembly line in the production workshop. If the prefabricated components are being processed in one of the processes, the prefabricated components in front have not been processed yet, and they need to wait for the processing of the previous process to be completed before entering the next process; if the lean production level of the prefabricated component factory is not high, it will wait for a long time in the production process, resulting in a waste of resources. Therefore, it is necessary to reduce the idle waiting time cost of the production line of prefabricated components for orders [5]. The calculation formula is as follows:

$$f(x_1) = min\beta_1 \cdot \sum_{i=1}^{I} \sum_{k=1}^{M=8} [E(J_{i,m_i}, N_{i,k}) - S(J_{i,1}, N_{i,k}) - \sum_{j=1}^{m_i} P_{j,k}] \tag{2}$$

β1 : Represents the unit time cost coefficient of the prefabricated component waiting for production in the production process of the assembly line;

$E(J_{i,m_i}, N_{i,k})$ — means that in the th production line, there are prefabricated components to be produced, and the completion time of the last prefabricated component t in the th process;$im_t m_t k$

$S(J_{i,1}, N_{i,k})$ — indicates that in the production line, there are prefabricated components to be produced, and the start time of the first prefabricated component in the process;$im_t k$

$\sum(P_j, k)$ — Indicates the cumulative production time of the prefabricated components to be produced in the process in the th assembly line.$im_t k$

2.2 Transport Scheduling Model Construction

According to the transportation process of prefabricated components of prefabricated buildings, the prefabricated component factory has a transport vehicle available for dispatch [6]. The secondary components of the prefabricated building project are transported according to the transportation dispatch plan formulated in advance. The transport dispatch vehicle departs from the component factory and then returns to the prefabricated component factory. The vehicle transportation dispatch time nodes are shown in figure 5.

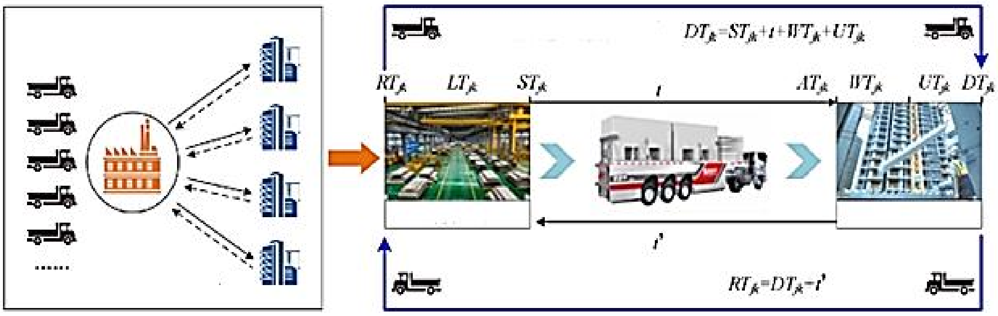

Fig.5 Vehicle scheduling process and timing for prefabricated components

3. Production-Transportation Empirical Analysis

After completing the splitting and in-depth design of the prefabricated components of the assembled single building, the types and quantities of prefabricated components are counted in turn according to the floors that need to be hoisted and constructed (the fourth floor is the first floor prefabricated components), and the demand details of the prefabricated components (composite panels, prefabricated stairs, prefabricated shear walls) of the single building are obtained, and statistical summary is performed on this basis. The types and details of the prefabricated components of the assembled building project group buildings are obtained in turn [7].

Tab.1 Prefabricated component details for prefabricated building complexes

Type	8# (17)		9# (25)		10# (17)	
	Standard	Single	Standard	Single	Standard	Single
Shear wall	16	224	25	550	16	224
Superimposed plate	26	388	48	1092	26	388
Staircase	2	28	4	88	2	28

3.1 Design of production-transportation optimization method

When loading and transporting prefabricated shear walls, they need to be stacked using a leaning rack or an insertion rack. The wall panels should be placed symmetrically with the exterior facing outwards, with 2-4 panels stacked each time, and the upper part of the components should be isolated with wooden pads. When loading composite panels, they should be stacked flat, and the interlayer pads should be aligned up and down [8]. The number of stacked layers of composite panels should not exceed 6, and the number of prefabricated staircases should not exceed 3. The loading and transportation of prefabricated components is shown in figure 6.

Fig.6 Schematic diagram of prefabricated component transportation

3.2 Optimization results analysis

In order to improve the transportation efficiency of prefabricated components of assembled buildings, reduce logistics and transportation costs, and achieve instant delivery without affecting the progress of engineering construction [9]. Based on the lean transportation theory, this paper takes the prefabricated component factory as the research subject, conducts a scientific and reasonable analysis of factors such as the demand plan, transportation plan, and transportation distance of prefabricated components, establishes a mathematical model with the minimum cost of prefabricated component transportation scheduling as the goal, and uses GA, PSO and SA optimization algorithms to optimize the decision-making and simulation test of the transportation scheduling plan, and obtains the iterative convergence comparison curve of the transportation scheduling of prefabricated components of assembled buildings, as shown in figure 7.

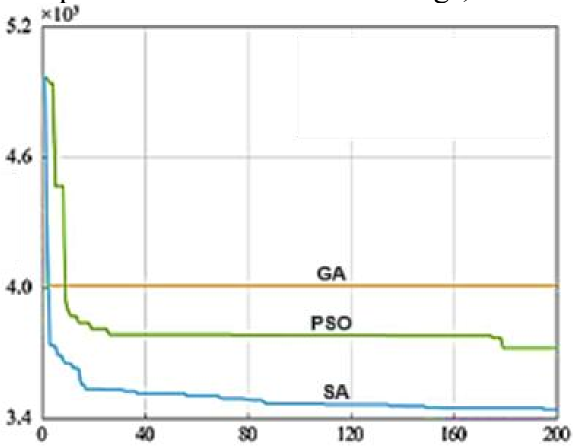

Fig. 7 Iterative convergence curves for prefabricated component transportation scheduling

As can be seen from figure 8, in the convergence curve of transport scheduling of prefabricated components for assembled buildings, when the iterations reach 12 and 180, the SA and PSO algorithms converge to the lowest cost of 3632 and 3700 yuan respectively, while the GA algorithm converges to the lowest cost of 3494 yuan when iterates to 192. Compared with the PSO and SA algorithms, the GA algorithm requires a longer calculation process, but has a better convergence effect than the other two algorithms [10].

In order to complete the transportation scheduling task of the standard floor prefabricated components of the prefabricated building complex, the loading and transportation scheme with the lowest transportation scheduling cost and the best scheme for the prefabricated components of the complex was obtained through experimental simulation. Among them, the optimized production-transportation process management scheme plays an important role in improving resource utilization efficiency and reducing production and transportation costs.

4. Conclusion

Based on the core concepts of lean production and lean construction, mathematical models of prefabricated component production inventory and construction scheduling were constructed respectively. In order to further improve the global convergence of the algorithm, the proposed model algorithm was simulated and tested for effectiveness and reliability by changing parameters such as mutation operator, mutation probability, learning factor and inertia factor in the process of comprehensive application of multiple optimization algorithms, and combined with specific engineering cases. Through the empirical analysis of engineering cases, the reasonable effectiveness of the algorithm was verified, and the scientificity and efficiency of the research were confirmed. This simulation technology can provide a scientific, reasonable and easy-to-express analysis method for the production-transportation process management optimization and lean production-transportation of prefabricated components of prefabricated buildings, which has important guiding significance for improving the lean management of similar engineering construction projects. On the premise of meeting the demand and supply of prefabricated components at the construction site, it not only reduces the transportation scheduling cost of prefabricated component factories, accelerates the capacity transformation of prefabricated component factories, and promotes the optimization and upgrading of the prefabricated building supply chain industry chain, but also enables the high-quality development of the construction industry with the service concept of lean and industrialization, and provides scientific and reasonable decision-making solutions for the lean production and lean transportation of prefabricated buildings.

References

[1] MAFFEI GL, MAFFEI M. Interpreting specialized buildings[M]. Florence: Altralinea Edizioni, 2018.

[2] PEZZETTI Laura Anna. Layered Morphologies and Latent Structures-Reading Decoding and Rewriting to Enhance Historic Rurban Landscape [M]. Shanghai: Tongi University Press, 2019.

[3] RAMSAY J. Editorial: cultural landscapes in the 21st century–issues and opportunities[J].Landscape research, 2015, 40(06): 649-654.

[4] Stanik N, Aalders I, Miller D. Towards an indicator-based assessment of cultural heritage as a cultural ecosystem service-A case study of Scottish landscapes[J]. Ecological Indicators, 2018(95):288-297.

[5] Ferretti V, Comino E. An integrated framework to assess complex cultural and natural heritage systems with Multi-Attribute Value Theory[J]. Journal of Cultural Heritage, 2015,16(05):688-697.

[6] Vuoto A, Funari FM, Lourenço B P. On the use of the digital twin concept for the structural integrity protection of architectural heritage[J]. Infrastructures,2023,8(05).

[7] Historic Environment Scotland. Historic Land-use Assessment of Scotland, 1996-2015[R]. Historic Environment Scotland, 2018.

[8] MOON O. Hahoe: The Appropriation and Marketing of Local Cultural Heritage in Kore[J]. Asia Anthropology, 2012,4(01):1-28.

[9] Mazzanti M. Cultural heritage as multi-dimensional, multi-value and multi-attribute economic good: toward a new framework for economic analysis and valuation[J]. Journal of Socio-Economics, 2002(31):529-558.

[10] CATALDI G, MAFFEI GL, VACCARO P. Saverio Muratori and the Italian school of planning typology[J]. Urban morphology, 2002, 6(01): 3-12.