

Identifying time wastage of prefabricated building hoisting operations based on the MODAPTS and field measurement method: a case study in Nanjing, China

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Abstract. The assembly efficiency of prefabricated buildings significantly depends on the productive time taken to complete the hoisting operations of components. Therefore, the on-site measurement of the effective time needed for component assembly is crucial for identifying time wastage and improving construction efficiency. This study utilizes MODAPTS (Modular Arrangement of Predetermined Time Standards) and the stopwatch time method to determine the effective working hours of the assembly process. The component hoisting process is broken down into the following five operations, hooking & slinging, hoisting to the operating surface, adjusting the position, removing the load hook, and backing up. A case study of a Nanjing project showed that the average times for five assembly operations of steel components were 227, 279, 760, 160, and 94 seconds. The time variation in crane arm movements is more stable than that of component adjustments during connection operations. Human factors like phone usage, exiting the operation area, along with hoisting point design and production mistakes, greatly reduce hoisting operation efficiency. The results of this study can not only effectively identify the time waste in the assembly process, but also lay a foundation for standardized hoisting operations and calculation of standard working hours in the prefabricated construction industry. In addition, these results will help optimize the construction organization plan at the early decision-making stage and improve the efficiency of resource use, thus shortening the construction period and reducing the construction cost.

1 Introduction

Within the evolving architecture industry, prefabricated construction has emerged as a solution for shortening construction periods, enhancing construction efficiency, and mitigating environmental impacts [1]. Prefabricated construction refers to the type of building where various pre-manufactured components are assembled on-site [2]. The assembly process, encompassing the hoisting, positioning, connecting, and installing of prefabricated components, stands as the core of prefabricated construction activities and is pivotal for ensuring construction quality [3]. Due to the lack of unified assembly process standards and operational norms in China, construction practices heavily rely on the experience of construction teams, leading to significant variability in the assembly process, diminished work efficiency, and uncontrollable working hours. Therefore, the assembly process is arbitrary, with low work efficiency, and difficult to control the working time. Determining the effective working hours for the assembly process is critically important for construction enterprises aiming at scientific and efficient construction organization, progress management, and labor planning [4,5,6]. To enhance production efficiency, methods for determining effective working hours have been widely applied in the manufacturing industry. These methods include time studies, stopwatch

timing, work sampling, synthetic method analysis estimation, and Predetermined Motion Time Systems (PMTS), which are key tools for improving the work efficiency of any manufacturing process [7,8]. Among these, stopwatch timing, which involves repeated observation and recording of operation sequences followed by statistical analysis, is a common measurement technique. The Modular Arrangement of Predetermined Time Standard (MODAPTS), as one of the most popular PMTS methods, is extensively used to evaluate the standard time operators should take to complete their assigned tasks [9].

According to Jin et al. (2008), the Modular Arrangement of MODAPTS has been proven to be an effective method for estimating the appropriate time required to execute specified tasks [10].

This study integrates MODAPTS with stopwatch timing, comparing real-time data against predicted effective data to determine effective working hours for component assembly, propose optimization strategies, and enhance construction efficiency. The findings also establish a foundation for setting standard working hours in prefabricated construction. It will facilitate the construction manager to optimize the construction organization plan.

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2 Methodology

2.1 Stopwatch method

The stopwatch time measurement method takes the process operation as the measurement object repeatedly observes and records the operation time according to the process sequence, and analyses it statistically to get the average working time. The standard operation steps of the method are 1) to select skilled and qualified operators as the time measurement objects; 2) to collect the technical data of the operation site; 3) to divide the operation unit; 4) to determine the time measurement method and the number of observations; 5) to eliminate the abnormal values; 6) to formulate the average working hours.

The number of observations calculated by the Error Boundary Method as shown in Eqs. (1).

$$N = \left\{ 40 \left[n \sum_{i=1}^n T_i^2 - \left(\sum_{i=1}^n T_i \right)^2 \right]^{1/2} / \sum_{i=1}^n T_i \right\}^2 \quad (1)$$

where T_i is the observation time. \bar{T}_i is the average observation time of the hoisting process of each component.

2.2 MODAPTS method

The MOST actual operation method is to break an operational process into several sub-operations and assign standard time values to each sub-operation. These standard time values are called Time Metric Units (TMU) and are expressed in MODs, where 1 MODs is equal to 0.129 seconds. The MODAPTS obtains the predicted time values by analysing the body movements required to complete a specified task and summing up these TMU.

MODAPTS classifies operator motions into three types: movement tasks, terminal tasks, and auxiliary tasks. Movement tasks involve motions by fingers, hands, arms, shoulders, and the trunk. Terminal tasks are categorized into "Get" actions, using codes G0 (low-control object acquisition), G1 (simple grasping), and G3 (complex grasping), and "Put" actions, with codes P0 (simple placement), P2 (defined position placement), and P5 (complex placement with multiple feedbacks). Auxiliary tasks, which don't involve direct use of the motor system like walking or bending, include codes like F3 for foot actions, B18 for bending, S30 for sitting and standing, W5 for walking, and C3 and C4 for circular hand and arm movements.

3 Case study

3.1 Case description

This case study is located in Nanjing, Jiangsu Province (Figure 1). The project's main structure comprises 44 prefabricated components, categorized into three types of vertical components and three types of horizontal components. The assembly team, consisting of one

assembly group leader, one crane operator, one signal worker, and five assemblers, is responsible for the installation of components. The group leader oversees determining the assembly sequence, coordinating workers, and judging the orientation and positioning of components, while the team members handle positioning and unhooking tasks flexibly (Figure 2).



Fig. 1. The architectural rendering and actual site photos.

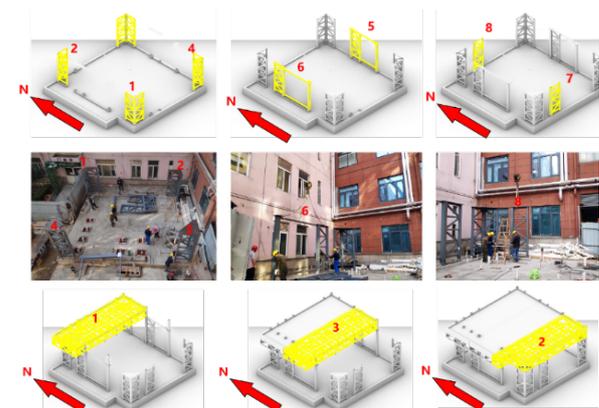


Fig. 2. Schematic diagram of component types and on-site installation sequence.

3.2 Building components hoisting process analyses

The workflow and tasks of the assembly personnel are detailed in Table 1, where each process starts immediately after the previous one ends. The hoisting sequence consists of five actions: rigging & slinging,

lifting to the work surface, adjusting the position, disassembling the hook, and backing up. Rigging and lifting time spans from when the component is securely hung until connected by the assembler. Hoisting to the workface time is from hooking completion to the component reaching an operable surface. Position adjustment time is needed from hooking completion to reaching the operable position. Unhooking time is the duration from when lifting is no longer needed until the hook is removed. The hook return time covers from the hook's removal to when the rigging is ready for the next lift.

Table 1. The MOD schedule for structural component assembly processes.

Task No.	Hoisting Process	MODs	Labour Force
1	Rigging & Slings	M2G1 B17P2A4 M5G3 F3A4+60	1~2
2	Hoisting to the operating surface	-	0(Crane)
3	Adjusting the position	L(p-6)/4*B17P5+1 20	4~6
4	Removing the load hook	B17P2A4+60	1~2
5	Hooking back up	-	0(Crane)

Note: Tasks No. 2 and 5, which are performed by the crane, are excluded from the MOD analysis scope. For Task No. 1 and 3, the average time for workers to move to their operating positions is calculated as 60s and 120s, respectively.

4 Results and discussion

4.1 Building components hoisting operation time analysis

Figure 3 presents the time fluctuations for five critical hoisting operations of steel structural components, based on real-time measurements conducted on-site by the research team. The average completion times for the five basic operations of hoisting the 44 components were recorded as 227s, 279s, 760s, 160s, and 94s, respectively, with the "Adjusting position" process taking the longest and the "Reconnecting" process the shortest. The total hoisting times for "Column," "Frame-1," "Frame-2," and "Floor Panel" were 748s, 1193s, 912s, and 3173s, respectively, indicating that the installation time for horizontal components, such as floor panels, exceeds that of vertical components. The complexity of operations increases with the component's size and the number of connection points, especially at the junctions of vertical and horizontal components. Further analysis revealed that the standard deviations for the "Rigging & Slings" and "Adjusting position" processes were notably high at 148.5s and 489.5s, respectively. The fluctuation in time increases

with the growing diversity of components and the number of floors. However, as crane operators' proficiency increases, the time for "Hoisting to operating surface" "Removing the load hook," and "Hooking back up" becomes more stable, with the standard deviation of 46.5s, 1.5s, and 20s, respectively. These findings suggest that tasks performed solely by assembly workers or the crane tend to be relatively stable and less influenced by external factors, primarily depending on operational skill. In contrast, tasks requiring human-machine coordination, such as position adjustment, are significantly affected by external variables, including component type, spatial positioning, and the proficiency of assembly personnel.

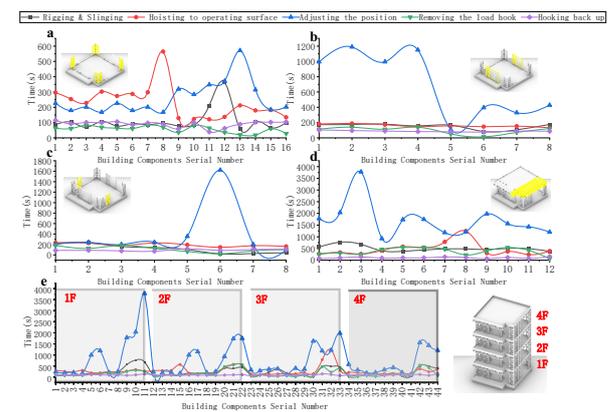


Fig. 3. Time distribution of different hoisting processes for each component.

4.2 Stopwatch method and MODAPTS method application comparison analysis

As illustrated in Figure 4, the actual durations of three key operational phases exceeded the MODAPTS predictions by 250%, 485%, and 150%, respectively. Such significant discrepancies highlight the complexity of the construction work environment, revealing the gap between the ideal conditions assumed by MODAPTS predictions and the realities of actual construction scenarios, especially in contexts requiring coordination between construction personnel and cranes. A further detailed examination of the operational records reveals the primary reasons for time wastage at different stages (Table 2). During the rigging & slings phase, major causes of time wastage included unorganized collaboration among workers, making phone calls during operations, and leaving the workstation arbitrarily. In the position adjustment phase, inaccurate component tolerances, improper arrangement of hoisting points, and difficulty with aerial posture adjustments were the main contributors to construction inefficiency. Reflecting on these insights, creating standard operating procedures for future construction projects should include addressing the identified causes of time wastage described above. Reducing the variability in the duration of these tasks allows for standardized human-machine collaboration, significantly enhancing the hoisting operational efficiency.

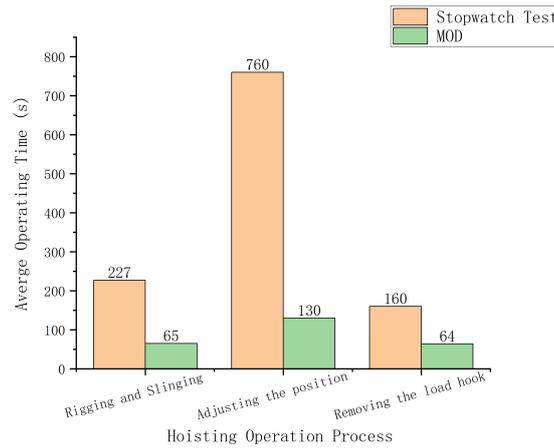


Fig. 4. The average measurement time and MOD of the component hoisting process.

Table 2. The MOD schedule for structural component assembly processes.

Hoisting Process	Time Waste Identification	Improvement
Rigging & Slings	<ol style="list-style-type: none"> 1. Disorganized collaboration 2. Arbitrary leaving of workstations 3. Interruptions such as answering phone calls 	
Hoisting to operating surface	<ol style="list-style-type: none"> 1. Skill level of crane operators 2. Disorder in steel component yard organization 3. Unstable arrangement and posture 4. Narrow space for crane boom movement 	<ol style="list-style-type: none"> 1. Boost training to enhance team coordination. 2. Organize components by lift order. 3. Refine sling positions and component tolerances.
Adjusting the position	<ol style="list-style-type: none"> 1. Component manufacturing errors 2. Unstable aerial posture of components 3. Handheld equipment not prepared in advance 4. Arbitrary leaving of workstations 	<ol style="list-style-type: none"> 4. Ready equipment beforehand. 5. Expand crane operating space.
Removing the load hook	<ol style="list-style-type: none"> 1. Disorganized collaboration 2. Arbitrary leaving of workstations 	
Hooking back up	<ol style="list-style-type: none"> 1. Skill level of crane operators 2. Narrow space for crane boom movement 	

5 Conclusion

To identify time wastage of the prefabricated building hoisting operations and enhance lifting efficiency, a case study of a project in Nanjing, China was conducted. In this project, the average completion times for the five basic hoisting operations of the 44 components were recorded as 227s, 279s, 760s, 160s, and 94s, respectively. The analysis of the operational procedures during assembly showed that the fluctuation of the crane boom movement time was small compared to the human-machine interaction process (Adjusting the position). Human factors such as answering the phone, randomly leaving the workstation, and operational errors had a significant impact on the lifting operation. Optimizing the design of component sling positions and tolerances would improve the efficiency of the adjustment position operation. In conclusion, based on the MODAPTS and on-site stopwatch measurement methods, it is possible to effectively identify sources of time wastage in the hoisting process, guiding the optimization of hoisting procedures. This study also lays the foundation for standardizing hoisting operations and determining the standard work hours for prefabricated construction. In addition, it is important to remain cautious about the broader implications of this study.

Component lifting times may vary depending on factors such as the level of the construction operator's expertise and the choice of the structural system selected. Therefore, further research can continue to explore the identification and reduction of wasted lifting time for various building types and precast component types to further improve resource efficiency in the construction process.

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