Factor Analysis of Scheduling Challenges in Prefabricated Construction Projects

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Abstract. This study investigates the critical factors influencing the scheduling of prefabricated construction projects, a domain increasingly prioritized for its potential in addressing sustainability challenges in the construction industry. Drawing on factor analysis, the research identifies and quantifies key processes that impact project schedules, spanning design, production, transportation, and assembly stages. A comprehensive indicator system comprising 17 core processes was developed, and statistical analyses, including reliability and validity tests, confirmed the robustness of the data. The findings highlight that the design stage exerts the most significant influence on project schedules, emphasizing the importance of high-quality design outputs and effective coordination with downstream processes. Factor analysis revealed four primary influencing factors: technology and methods, project management competence, experience in similar projects, and design support. These factors collectively explain 83.54% of the variance in schedule performance. This study contributes to the literature by offering actionable insights for optimizing scheduling strategies in prefabricated construction projects. Practical recommendations include adopting advanced design technologies, enhancing project management training, leveraging lessons from similar projects, and prioritizing early-stage design quality. By addressing these factors, the prefabricated construction industry can achieve greater efficiency, reduce delays, and advance sustainability goals.

Keywords: prefabricated construction, schedule management, factor analysis, project efficiency, sustainable construction

1 Introduction

Prefabricated construction, an emerging method in the building industry, offers potential solutions to sustainability challenges. However, it presents unique scheduling difficulties, including the need for coordination across geographically dispersed production sites, complex logistics for transporting components, and precision in on-site assembly. Delays in any stage, such as manufacturing or transportation, can disrupt the overall project schedule. Furthermore, integrating advanced technologies, such as robotic assembly and Building Information Modeling (BIM), demands effective scheduling frameworks to minimize inefficiencies.

W. Nie et al. (eds.), *Proceedings of the 2024 6th International Conference on Hydraulic, Civil and Construction Engineering (HCCE 2024)*, Atlantis Highlights in Engineering 37,
https://doi.org/10.2991/978-94-6463-726-7_45

While prefabricated construction shows promise, its adoption remains limited in many regions, often due to stakeholders focusing on regulatory compliance rather than technological innovation [1]. This has prevented the industry from fully capitalizing on its efficiency and sustainability advantages. Identifying the critical factors influencing project scheduling is essential to optimizing prefabricated construction processes and improving overall outcomes [2].

Existing research has explored various factors affecting scheduling in prefabricated construction, yet few studies provide a comprehensive view across all stages. Rolfsen and Sherehiy [3] applied Gantt charts for resource allocation and project oversight. Soldatenko et al. [4] used probabilistic methods to predict project reliability, while Wang et al. [5] employed Design Structure Matrix (DSM) to optimize information flow. Zhang and Lu [6] highlighted BIM's role in reducing delays by enhancing coordination.

However, these studies focus on individual factors such as production efficiency or assembly accuracy without considering their interdependencies across design, production, transportation, and assembly stages. Büyüközkan and Çifçi [7] stressed the need for an integrated approach to address these complexities. This study aims to fill these gaps by using factor analysis to identify and analyze the relationships among key scheduling factors across all project stages.

2 Methodology

2.1 Factors Influencing

Factor analysis is a multivariate statistical method that reduces a large set of influencing variables into a smaller number of interpretable common factors while minimizing information loss[8]. The mathematical model is expressed as follows:

$$X = AF + e \tag{1}$$

where X represents the observed variables, F denotes the common factors, A is the factor load matrix, and e represents unique factors not explained by the common factors. In multi-indicator analyses, discrepancies in scale and magnitude among variables can distort results. Variables with higher numerical values may have disproportionate influence, while those with lower values may be undervalued. To mitigate this issue, standardization is performed to eliminate variability across variables. The process includes:

- Constructing a matrix of influencing factors and raw data.
- Standardizing the data to eliminate differences in magnitude and scale.
- Calculating the correlation matrix and its eigenvalues.
- Determining the number of factors based on cumulative variance contribution rates.

For the k -th principal component (y_k), the variance contribution rate is defined as:

$$\eta_k = \frac{\lambda_k}{\sum_{i=1}^{m} \lambda_i} \tag{2}$$

where λ_k is the variance of the k -th principal component. The cumulative variance contribution rate is expressed as:

$$\eta_{cumulative} = \frac{\sum_{k=1}^{k} \lambda_i}{\sum_{i=1}^{m} \lambda_i} \tag{3}$$

- Rotating the factors to identify common factors more clearly.
- Calculating factor scores and composite scores:

$$F_k = \sum_{k=1}^{k} \mu_k x \tag{4}$$

where F_k is the k -th common factor, μ_k represents the factor score coefficients, and x denotes the variables.

Factor analysis is well-suited for this study as the scheduling of prefabricated construction projects involves complex, interrelated processes influenced by multiple factors. This method enables the extraction of independent and significant common factors, providing a systematic approach to analyzing their impact on project schedules.

2.2 Data Collection and Variables

Data for this study were collected through structured surveys and expert interviews. Twenty professionals with extensive experience in prefabricated construction were selected, including project managers, design engineers, and site supervisors[9].

Each core process was assessed using a 5-point Likert scale, where:

1 = Minimal Influence, 5 = Critical Influence

Variables were selected based on their relevance to scheduling, supported by industry standards and prior research. The mean scores from expert evaluations were used for factor analysis.

2.3 Conducting Factor Analysis

Factor analysis was performed using SPSS 28.0, following these steps:

- Data Standardization: All variables were standardized to eliminate scale effects.
- Correlation Matrix: Strong correlations indicated potential factor clusters.

- Factor Extraction: Principal Component Analysis (PCA) was used, with factors selected based on eigenvalues > 1 and cumulative variance > 80%.
- Factor Rotation: Varimax rotation was applied to improve interpretability.
- Factor Scoring: Composite factor scores were calculated for each factor.

3 Research and Analysis of Schedule Influencing Factors Using Factor Analysis

3.1 Indicator System

Based on a literature review and expert input, the 17 core processes were categorized into four stages: design, production, transportation, and assembly. These processes were evaluated for their influence on project schedules in Table 1.

Table 1. Degree of Influence of Core Processes on Prefabricated Construction Projects

First-Level Indicators	Second-Level Indicators
Design Stage (A)	A1: Project Planning A2: Scheme Design A3: Preliminary Design A4: Construction Drawing Design A5: Component Detailed Design
Production Stage (B)	B1: Material Procurement B2: Component Production Planning B3: Component Manufacturing B4: Component Storage
Transportation Stage (C)	C1: Grouped Transportation Planning C2: Route and Vehicle Selection
Assembly Stage (D)	D1: Site Layout D2: Lifting Plan D3: Equipment Selection D4: Lifting Positioning D5: Vertical Grouting D6: Horizontal Connections

These processes were assessed using a 5-point Likert scale to determine their impact on scheduling, and highly influential processes were prioritized for further analysis.

3.2 Descriptive Statistics of Sample Data

The descriptive statistics for the 17 core processes are presented in Table 2. The results indicate that all processes scored above 2.90 on average, signifying their relevance to scheduling. Processes such as "Material Procurement" (B1) and "Component Detailed Design" (A5) emerged as highly influential, with mean scores exceeding 3.70.

Table 2. Detailed descriptive statistics

Indicator	Mean	Standard Deviation	Skewness	Kurtosis
A1	3.58	1.049	0.141	-1.252
A2	3.41	1.034	0.344	-1.048
A3	3.58	1.109	0.079	-1.382
A4	3.65	0.930	0.031	-0.951
A5	3.68	0.917	0.273	-1.151
B1	3.76	0.992	-0.350	-0.895
B2	3.50	1.093	0.244	-1.298
B3	3.22	1.147	0.502	-1.177
B4	3.51	0.802	0.692	-0.476
C1	3.63	0.926	0.242	-1.035
C2	3.53	0.828	0.595	-0.616
D1	3.56	0.986	0.379	-1.118
D2	3.60	1.027	0.101	-1.195
D3	3.68	0.827	0.512	-1.076
D4	3.38	1.163	0.306	-1.377
D5	2.92	1.228	0.867	-0.969
D6	3.47	0.980	0.329	-0.958

3.3 Factor Extraction and Rotation

Principal component analysis (PCA) was used to extract the most significant common factors from the 17 core processes. Four common factors were identified, explaining 83.543% of the total variance, which meets the standard of 80% typically required in factor analysis. The results are summarized in Table 3.

Table 3. Principal component analysis results

Component	Initial Eigenvalue	Variance (%)	Cumulative Variance (%)
1	7.077	41.627	41.627
2	3.464	20.377	62.004
3	2.006	11.798	73.802
4	1.656	9.741	83.543

A varimax rotation was applied to these factors to make their interpretation clearer and to identify clusters of highly correlated indicators. The rotated factor matrix is shown in Table 4.

Table 4. The rotated factor matrix

Component	Clustered Indicators	Factor Description
1	D4, B3, D5, D6, A1	Technology and Methods
2	C1, B2, D2, C2	Project Management Competence
3	D1, B4, D3, A5	Experience in Similar Projects
4	A4, B1, A3, A2	Design Support

3.4 Analysis of Influencing Factors

Based on the results from factor rotation, the four identified common factors were named and analyzed as follows:

(1) Technology and Methods

The technology and methods factor is significant across the design, production, and assembly stages. During early-stage project planning, decisions regarding the prefabrication rate, building characteristics, structural types, and quality management strategies must align with the overall project strategy. In the assembly stage, prefabricated components require more precise handling compared to cast-in-place construction. The accuracy of lifting and the stability of the equipment during the process directly impact the project timeline.

(2) Project Management Competence

Effective project management requires seamless integration of planning, coordination, leadership, and control. Competent project managers are crucial in ensuring that different stages—such as production and transportation—are synchronized. This coordination reduces delays caused by logistical issues, such as mismatched workflows or supply shortages.

(3) Experience in Similar Projects

Experience in similar projects plays a critical role in avoiding inefficiencies and unforeseen challenges. Experienced project teams are more capable of anticipating potential risks and devising appropriate solutions early in the design and production phases. For example, experienced designers understand the constraints of manufacturing and assembly processes and can design components that are easier to fabricate and install.

(4) Design Support.

As the upstream phase in construction, the design process significantly impacts the entire project. Early-stage design decisions—such as the choice of prefabrication methods, component design, and material specifications—affect subsequent stages, including production and assembly.

4 Conclusions and Recommendations

This study identifies and analyzes four key factors influencing the scheduling of prefabricated construction projects: Technology and Methods, Project Management

Competence, Experience in Similar Projects, and Design Support. These factors collectively explain 83.54% of the variance in project scheduling performance.

The findings highlight the significant impact of the design stage, with processes such as "Component Detailed Design" and "Construction Drawing Design" playing a critical role in determining overall project timelines. Technology and Methods, particularly advanced tools like BIM and automated manufacturing, were found to enhance scheduling efficiency by reducing errors and improving coordination. Project Management Competence plays a central role in integrating the various stages of the project, while Experience in Similar Projects helps to anticipate and mitigate delays by leveraging lessons from previous projects. The Design Support factor emphasizes the importance of timely procurement and effective coordination between design and production teams.

These findings provide a comprehensive understanding of the critical factors that shape the scheduling of prefabricated construction projects, offering valuable insights for improving project management practices in this field.

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