System Dynamics Modeling of the Supply Chain Performance of Prefabricated Construction Based on the Stakeholder Analysis

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Abstract. The supply chain performance of prefabricated construction plays an important role in the development of prefabricated construction. In this paper, in order to improve the supply chain performance of prefabricated construction and identify its factors, the indicators system for the supply chain performance of prefabricated construction based on the stakeholders’ perspective on the three dimensions of schedule, cost, and quality was built. Based on the indicators system, the system dynamics simulation model of supply chain performance of prefabricated construction was established. This study provides a dynamic performance management tool for prefabricated construction supply chain stakeholders.

1. Introduction

The construction industry is the pillar industry of the national economy, which not only promotes economic growth but also creates many job opportunities. However, due to the increasing labor costs and prominent environmental problems in the traditional construction industry, the resource-saving and environment-friendly prefabricated construction have been popularized and applied in many countries.

Prefabricated construction (PC) refers to a building made of prefabricated components assembled on the site[1], including design, manufacturing and transportation, construction and assembly, operation and other stages. Therefore, more nodal enterprises are involved in the supply chain of prefabricated construction, which increases the complexity of the supply chain. Prefabricated components require a high degree of coordination among stakeholders at the beginning of the design phase to ensure close coordination of labor, materials, and equipment. However, in China, prefabricated construction supply chain has problems such as low degree of information sharing, participants’ insufficient attention to supply chain performance, and design units' lack of collaborative work experience, which will aggravate the fragmentation and discontinuity of supply chain, have a negative impact on supply chain performance, and ultimately harm the interests of stakeholders.

It is very important for the sustainable development of prefabricated construction to improve supply chain performance. Said believes supply chain management is key to the successful delivery of prefabricated construction. The introduction of stakeholder theory into the study of prefabricated building supply chain performance is more conducive to the successful delivery of projects[2]. According to the characteristics of prefabricated construction, stakeholders’ interest needs, conflicts and compromises are specifically analyzed to achieve the optimal performance of supply chain and change the status quo of fragmentation.

This paper identifies the factors affecting the performance of prefabricated construction supply chain
from the perspective of stakeholders and constructs a performance indicators system. The system dynamics model of performance indicators was established by using the method of system dynamics.

2. Stakeholder-Based Performance Indicator System for PC supply chain

From the perspective of stakeholders and based on the whole life cycle of prefabricated construction supply chain, this paper studies the performance of prefabricated building supply chain, as shown in Figure 1.

![Figure 1. Performance evaluation of prefabricated building supply chain](image)

2.1. Stakeholder identification

Li[3] believes that the monitoring and control of the design, production and construction process of PC are of great strategic significance for responding to the dynamic aspects of the construction industry. Therefore, this paper selects the construction unit, designer, component factory, raw material supplier and general contractor as stakeholders to construct the system dynamics model. Table 1 shows the performance drivers of PC stakeholders.

| Stakeholders          | Performance drivers                                      |
|-----------------------|----------------------------------------------------------|
| Construction Unit     | Successful delivery of the project, High profit, Customer satisfaction |
| Designer              | Standardized design, Accurate drawings, Timely           |
| Component Factory     | Order response speed, Timely delivery, High quality       |
| General Contractor    | Delivery on schedule, Assembly quality, Project payment received |

2.2. Prefabricated construction supply chain

As a functional network chain structure, it realizes the information sharing among prefabricated building stakeholders through the supply chain. It also allocates reasonable resources and reduces conflicts of interest. This paper believes that prefabricated construction supply chain refers to a functional network chain structure in which the stakeholders of PC are formed into a whole by controlling the capital flow, information flow and product flow, with the construction unit as the core and through four stages of design, manufacturing, assembly and delivery, as shown in Figure 2.
2.3. Prefabricated construction supply chain performance indicator system

Construction project management objectives include cost, schedule, quality, stakeholder engagement and customer satisfaction. Referring to Chen Ying's definition of supply chain performance, the performance of PC supply chain is defined as the collaborative efficiency, operation effect and overall efficiency among all stakeholders of the supply chain, focusing on the cost, schedule and quality of PC supply chain. Based on the demand of customers, this paper lists some indicators of construction units and other stakeholders (Figure. 3).

3. System dynamics model of PC supply chain performance

The system dynamics method is suitable to study the dynamic relationship between the system behavior and the actual behavior due to the numerous and complicated factors affecting the supply chain performance of PC.

3.1. Model hypothesis

(1) Only Consider the main causal relationship between the indicators;
(2) Only the design, manufacturing and construction stages are considered, not the project operation and maintenance stage;
(3) Full information and smooth communication among stakeholders.

3.2. Causal analysis
From the perspective of performance content, the model includes three subsystems: project cost, project schedule and project quality. From the perspective of stakeholders, the model includes four subsystems: construction unit, designer, general contractor, and component factory. According to the feedback principle of system dynamics, the logical relationship between the factors influencing the performance of prefabricated building is analyzed, and the causal loop diagram is drawn.

3.2.1. Construction unit subsystem
The construction unit plays a dominant role in the supply chain of PC, and the customer demand is the starting point of the entire project operation. As shown in Figure 4, management ability is the core competitiveness of the construction unit, and good economic ability can support the supply chain to complete the whole life cycle. Government support policies for PC will encourage more developers to invest in prefabricated projects.

3.2.2. Designer subsystem
In the design stage of PC, the information feedback and cooperation among design units, component factory and general contractor are more frequent. As shown in Figure 5, improving the level of integrated design and component standardization is conducive to improving the production speed of components, the pass rate of construction and assembly, and ultimately reducing costs, thus improving the overall performance of the supply chain.

3.2.3. Component factory subsystem
As shown in Figure 6, the on-time delivery rate of prefabricated components determines the schedule of
the general contractor. The qualified rate of prefabricated components not only affects the construction quality, but also the installation rate. Unqualified components will cause rework, resulting in delays and additional costs.

3.2.4. General contractor subsystem
The hoisting and connection of components will affect the project schedule and project quality. Strengthening the input of information technology and staff training can reduce the information barrier, improve the assembly technology maturity of workers, and improve the project schedule and project quality (Figure 7).

3.3. Stock flow chart
The causal loop diagram uses "+" and "+" to reflect the positive and negative feedback relationship between variables. In order to study the quantitative relationship between supply chain performance influencing factors, this paper constructs a dynamic stock flow diagram of prefabricated construction supply chain performance system (Figure 8).
Figure 8. Prefabricated construction supply chain performance stock flow diagram

4. Conclusion
The prefabricated construction supply chain performance is an important part of ensuring the smooth delivery of the PC through supply chain management. This paper introduces stakeholder theory, clarifies the performance drivers of stakeholders in the PC supply chain. From the perspective of stakeholders, this paper constructs the performance indicators system of prefabricated construction supply chain from three dimensions of project cost, project schedule and project quality, and establishes the dynamic simulation model of supply chain performance system. This study provides a dynamic performance management tool for prefabricated construction supply chain stakeholders. Subsequently, system dynamics simulation can be carried out to explore the main indicators that affect the performance of prefabricated construction supply chain.

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