Research on the Benefit Calculation Method of Prefabricated Residential Building EPC Project from a Supply Chain Perspective

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Abstract. In the subcontractor selection for prefabricated residential EPC project, it is still difficult for the general contractor to solve the problems of design-construction phase separation and realizing the maximum team potential, the research of project benefit calculation method has become the first problem to be solved. This study uses the literature induction method to extract the details of the benefit indicators, and a coupled model of the participant-benefit system has been constructed with the relative error of 2.66% based on the theory of system theory. The project benefits of the residential build-ing A project has been calculated to be 132,500 yuan. The sensitivity results show that the design unit's qualification level is most suitable when it is moderately above average.

Keywords: Prefabricated building, Project benefits, Subcontractor selection decisions, System dynamics

1 Introduction

In the current application of EPC model, there are still problems such as separation of design and construction and poor cooperation between enterprises[1]. How to make use of the advantages of EPC projects to optimize the benefits of prefabricated residential projects has become an important content of current research. From a global perspective, subcontractors that meet the current optimal decision may not be able to form the best team combination for the project, so it is difficult to achieve the overall maximization of EPC project benefits. Therefore, it is very important to study the influence path of subcontractor's decision on project benefit, and project benefit measurement becomes the first problem to be solved. In this paper, a comprehensive benefit calculation model for prefabricated housing projects is constructed, in order to quantify the project benefits of prefabricated buildings under the influence of systematic decision making and guide subcontractors to make decisions.

In order to seek ways to maximize benefits, scholars at home and abroad have adopted a variety of benefit evaluation methods to conduct in-depth research from three dimensions: economy, environment and society. Due to the complexity and vastness of the comprehensive benefit system, some scholars choose to focus on the single benefit

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of the two dimensions of economy and environment, or the coupling relationship between them. In terms of research methods, commonly used methods include life cycle assessment and cost-benefit analysis[2]. Yimeng Tia et al. used life cycle assessment (LCA) to compare the environmental trade-offs between prefabricated and traditional cast-in methods[3]. Kaicheng Shen evaluated the change rate of construction cost and environmental benefit through the framework of cost-benefit analysis (CBA)[4]. Shuqiang Wang et al. used fuzzy gray correlation projection to study the benefits from four aspects: assembly rate, cost, construction period and carbon footprint[5].

Research generally recognizes the advantages of PB in saving energy, reducing environmental pollution, improving construction efficiency and quality, and points out that the long-term economic benefits of prefabricated buildings are still considerable. However, most of these studies did not consider the influence relationship between comprehensive benefit drivers, while linkage effect is more significant in EPC projects[6], which has not been paid enough attention in existing studies. However, the System dynamics method can capture the complexity of many factors and their interactions in SC, and provide a comprehensive perspective for project benefit analysis. Liu Mengkai et al. developed a cost estimation model that covers the design, component production, and construction subsystems[7]; Chen Wei et al. established a component quality chain management model for prefabricated building design, production, transportation, and assembly stages[8]; Zhang Yuebin et al. applied system dynamics to the construction safety field and built a dynamic regulatory evolutionary game model[9]. These studies delve deeply into the dynamic performance and complex interrelationships of factors affecting cost, quality, safety, etc., and lay a theoretical foundation for applying system dynamics to the comprehensive assessment of the economic benefits of prefabricated buildings. At the same time, these studies provide a clear line of thought and method for dividing the subsystems of comprehensive benefit assessment.

2 System Dynamics Method

System Dynamics (SD) is a research method based on the theory of system thinking, which integrates the feedback structure and behavior of the internal factors of the system into the computer simulation model. The tool used is Vensim PLE software. The application steps of system dynamics are as follows:

Step 1: Identify research objectives and questions

Step 2: Identify key variables and entities in the system

Step 3: Draw a causal loop diagram that shows the causal relationship between variables

Step 4: Draw a stock flow chart to show the relationship between stock and flow

Step 5: Collect data and assign values to parameters in the model

Step 6: Write equations that describe the behavior of the system

Step 7: The system dynamics software Vensim was used to construct the model, and its validity was tested

Step 8: Simulation and analysis results

Step 9: Apply model results to guide actual decisions

In a causal diagram, the interactions between variables, whether enhancing or inhibiting, are visually represented by arrows, the direction of which clearly indicates the affected variable. Based on the basis of causality diagram, inventory flow diagram further details the characteristics and interactions of stock (such as inventory goods) and flow (such as sales volume) in the system, and shows the calculus relationship between variables in a graphical way. In addition, auxiliary variables and constants are included in the system, which are introduced to enhance the accuracy and stability of the model. Auxiliary variables are often used to describe intermediate variables in a decision making process, while constants represent quantities that remain constant over a specific period of time.

In the calculation of project benefits, system dynamics shows its unique advantages: it can fully describe the complex relationship and feedback mechanism among the factors affecting the benefits, and measure the project benefits more systematically and comprehensively. At the same time, dynamic simulation capabilities can grasp the real-time status and change trends of construction progress and risks, especially in project schedule management. In addition, the flexibility of the system dynamics model allows parameters to be adjusted to simulate benefit levels in different situations, identifying key factors and providing strong support for project decisions.

3 Project Benefit Calculation Model

3.1 Factor Identification

Table 1. Benefit influencing factors and their literature sources

Factors	Literature source																				Frequency
	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[24]	[25]	[26]	[27]	[28]	[29]	
Design level	√	√		√	√	√	√	√	√	√		√	√			√					12/20
Structural function of component				√	√			√	√								√	√		√	7/20
Material and equipment properties			√	√		√	√	√					√		√				√		8/20
Production technology			√	√	√	√	√		√	√	√	√	√	√	√	√	√		√	√	16/20
Subcontractor qualification						√								√	√						3/20
Enterprise cooperation experience				√													√		√	√	4/20
Whole process management level			√		√		√	√	√				√						√		7/20

Cooperation degree	√		√			√	√		√	√			√			√	√	√	√	√	12/20
Number of design changes		√							√			√				√		√			5/20
Internal management	√				√	√	√			√	√	√	√		√				√	√	11/20
Production experience	√			√	√			√	√	√	√			√	√						9/20
Operator proficiency										√	√	√						√			4/20
Safe operation	√										√					√		√			4/20
Safe production	√										√					√	√	√			5/20
Climatic and geographical conditions	√						√						√					√			4/20
Capital turnover rate			√										√		√			√			4/20
Risk coping ability			√				√														2/20

The iron triangle of "time-cost-quality" and other indicators such as safety and economy are often used to measure different aspects of project performance. This study considers quality, cost, schedule, security and their associated risks as key components of project benefits. In order to ensure the scientific selection of benefit influencing factors, a detailed literature investigation was carried out based on the research achievements of scholars[10-29], and the collated results were shown in Table 1.

3.2 Causal Relationship between Factors

Within the enterprise, the enterprise qualification is the basis of the enterprise's ability level such as the design level and the internal management level, which in turn affects the quality and cost of the products or services provided. In addition, in the process of enterprise cooperation, the quality of products or services pro-vided by enterprises will be transmitted along the logistics chain and have an impact on downstream enterprises. Consider the computability and system completeness of key variables, relate quality, safety and schedule and cost so that they are on the same order of magnitude, and use the ratio to reflect the benefit level of the project. Risk is a random value generated by the normal distribution function, the range is (0,1), and its mean is related to the risk influencing factors. The model also contains some auxiliary variables such as a, p and so on. Figure 1 shows the inventory flow diagram of influencing factors of project benefits.

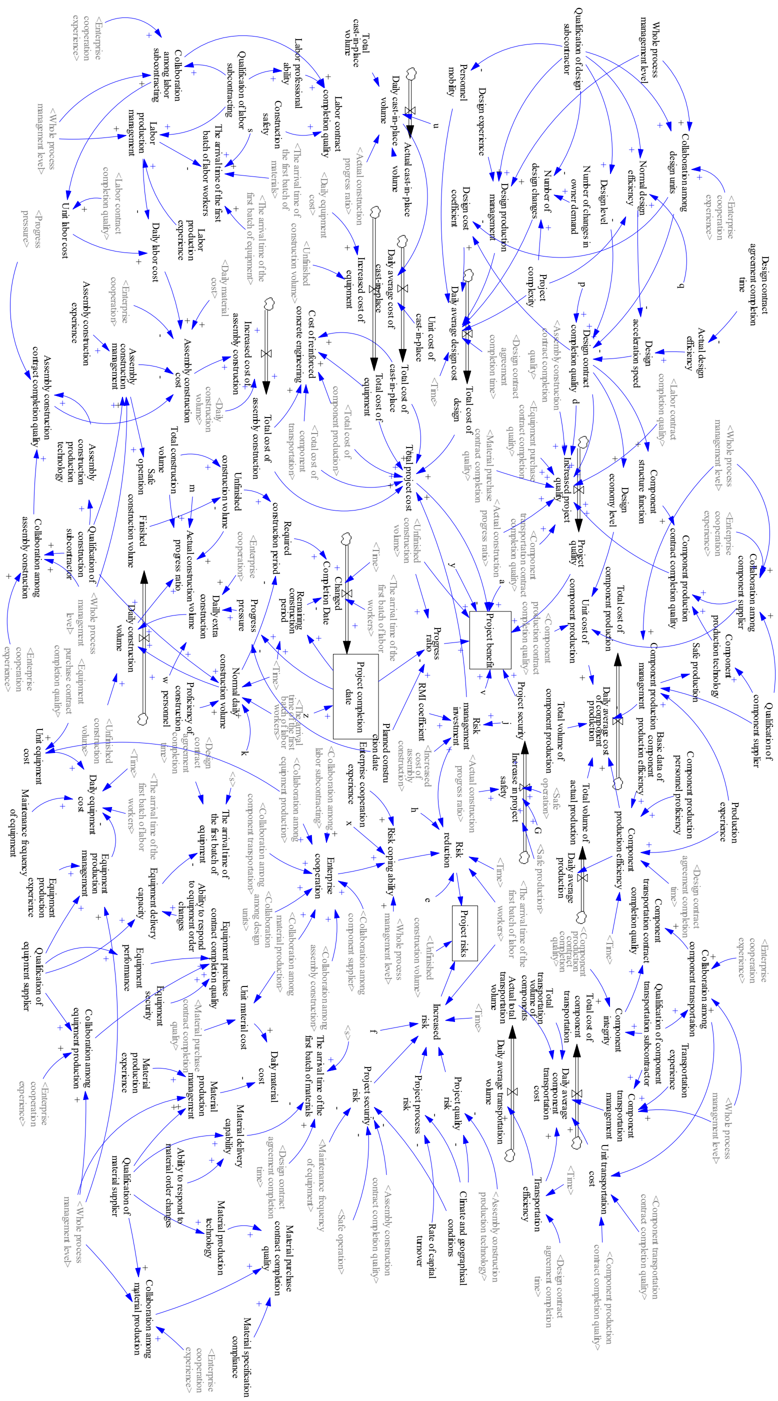

Fig. 1. Inventory flow diagram

3.3 Model Checking

To ensure the accuracy and structural rationality of the model, the validity of its project cost component is verified. The verification data is derived from the case study in Xu Jingxin's 'Analysis of Cost Factors in Prefabricated Concrete Building Structures Based on Budget Quotas'. The costs of various prefabricated com-ponents are shown in Table 2.

Table 2. Reinforced Concrete Project Cost Table[30]

Name of component	Component Quantity (m^3)	Unit cost of component (Yuan/m^3)	Cost (Million yuan)
Prefabricated compo-nent	2716.9	3640.18	9.89
Cast-in-place concrete element	4273	1330.0	5.68
Total cost	15.57million yuan		

The Vensim model takes the collated data as input, and presents the final results in Figure 2.

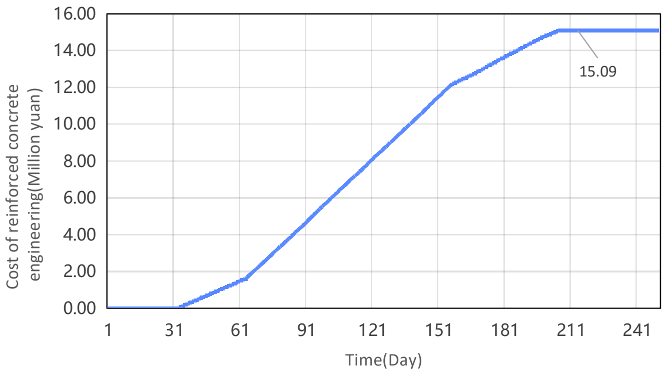

Fig. 2. Cost of reinforced concrete engineering

The results indicate that the cost of the prefabricated reinforced concrete engineering is 15.09 million yuan. Compared to the case study figure of 15.51 million yuan, the relative error is -2.66%. The relative error of the system does not exceed 10% and is within the allowable range of error[31]. The model is found to be reasonably accurate, and the analysis suggests that the errors mainly stem from the selection of model pa-rameters, the simplification of the model for actual scenarios, and other such reasons.

4 Model Application

4.1 Case Overview

The existing PRB project A is currently out for bids, which is situated in the city center of a location in Hubei Province. The tender encompasses the project's design, reinforced concrete works, and other related scopes, with a budget allocated at 15 million. The project timeline stipulates a 1-month design period, a 1-month period for the production of components including component curing, and an 8-month construction period. With an assembly rate of 75%, the estimated volume of components required is 3500 m^3.

According to the 'Hunan Province Engineering Survey and Design Fee Guidance Standard (2023),' the design cost coefficient is calculated to be 257.47 mil-lion yuan. Based on the 'Hubei Province Assembled Construction Project Consumption Quotas and Full-Cost Base Price List (2018)' and the 'Jiangsu Province Prefabricated Concrete Construction Quotas (2017),' the labor cost for one cubic meter of prefabricated components is 233.81 yuan/m^3, the material cost is 99.05 yuan/m^3, the machinery cost is 9.23 yuan/m^3 , and the unit price for vertical transportation at 904.53 yuan/m^3. And Transportation costs are priced based on market prices.

4.2 Case Simulation Result

To clearly display the daily status of the project, the unit of time for the model is set to day, with a start and end period ranging from 0 to 400, and a time step of 1. The results being shown in Figure 3.

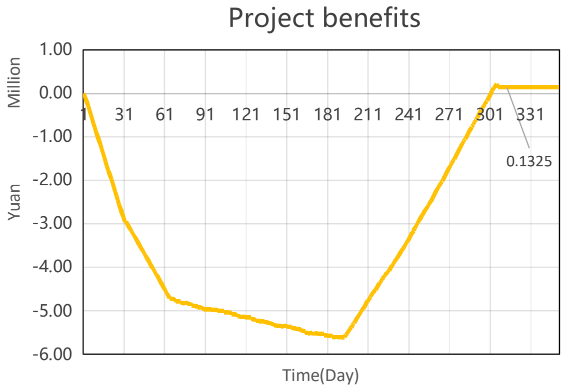

Fig. 3. Case simulation result of project benefit

It is estimated that the benefit of the PRB project A project is 132,480 yuan, and the ratio of the total project cost is only 0.89%, which is far lower than the theoretical maximum ratio of 33.51%, indicating that the benefit level of the project is relatively low. After the project started, the total project cost experienced different growth rates during the design phase, the component production and transportation phase, and the assembly construction phase. The quality level and safe-ty level of the PRB project begins to appear in the formal construction stage of the project, and gradually improves with the continuous progress of the project. The Contractor completed the project one day after the contract time. Because of the time overrun, the project's benefits decrease by 83,700 yuan, after which they remain constant.

5 Sensitivity Analysis

To further enhance project benefits, a study has been conducted on the individual effects of four types of uncertainty factors: collaboration degree of subcontractor units (SUCD), Whole process management level(WPML), the qualification of design subcontractor(DSQ), and the qualification of construction subcontractor(CSQ).

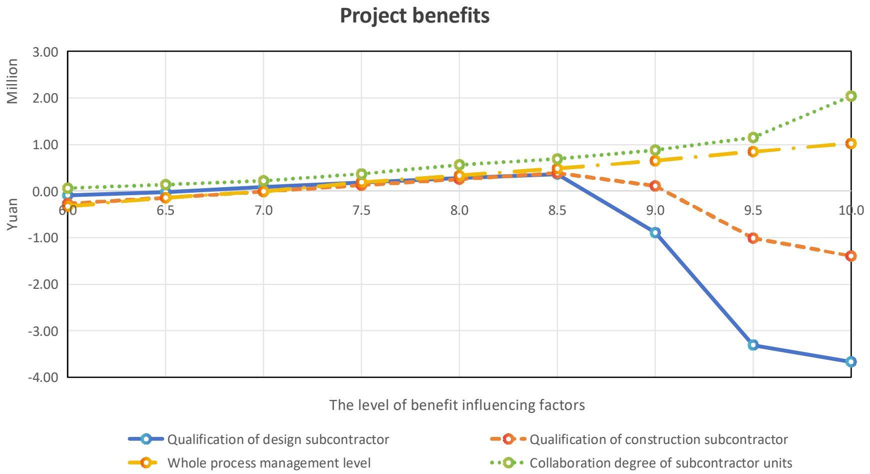

Fig. 4. Sensitivity analysis of project benefits

As shown in Figure 4, the SUCD and WPML have always played a positive role in promoting project benefits. However, the impact of DSQ and CSQ on project benefits first promotes and then diminishes. When the level of four types of factors is between 6.0 and 8.5, SUCD, WPML, DSQ, CSQ respectively increases the project benefits by 626,000 yuan, 812,000 yuan, 454,000 yuan, and 655,000 yuan, and WPML results in the largest increase in project benefits. But when each factor is at the level of 8.5, SUCD creates the highest project benefits, reaching 691,000 yuan.

After the level of the four factors exceeds 8.5, project benefits increase about twice as fast as WPML under the influence of SUCD. The reason is that through close communication between enterprises and effective resource allocation, the number of design changes and transaction costs are reduced, so as to obtain high-er project benefits. When the level of the four factors is between 8.5 and 10, the increase of DSQ and CSQ leads to the decrease of project efficiency. With the increase of DSQ and CSQ, the quality safety level and design economy level of the project are also improved, but the production and transportation requirements of the components are higher, resulting in indirect and direct cost fluctuations of the project. The increase rate of total cost is increasing rapidly, resulting in the decline rate of project benefit from slow to fast. Due to the dominance of DS, DSQ determines the design height of the project, influences the production of components and the construction of the project, and has a greater influence than CSQ.

For PRB project A, the theoretical maximum expected benefit could reach 2.55 million yuan, which is an increase of 2.42 million yuan compared with the original plan. Project A has enhanced corporate synergy, effectively reducing misunderstandings and conflicts during the project implementation process, and avoid-ed the wastage or shortage of resources, thus safeguarding its quality and sched-ule. It can be observed that Project A has an efficiency growth rate reaching as high as 1725%. This achievement fully proves that proper subcontractor decision making plays a crucial role in improving project benefits.

From the results of the sensitivity analysis, it is evident that DSQ exerts the most complex influence on project benefits, and an upper medium level is most suitable. USCD has the most pronounced positive impact on project benefits. Higher levels of USCD can significantly reduce delays, rework, and additional costs that stem from communication issues, thereby enhancing overall project benefits.

When selecting a subcontractor, a number of key factors must be considered, including qualifications, experience, cost-effectiveness and degree of collaboration. In order to ensure that the project can achieve the best results, it is essential to select a moderately qualified subcontractor. In particular, if the subcontractor's qualifications are too high, it may lead to an unnecessary increase in project costs; If the qualification is too low, it may barely meet the basic requirements of the project. Therefore, the ideal choice is to select a subcontractor with intermediate and superior qualifications on the basis of meeting the necessary qualifications for the project. In the bidding process, it is recommended to adopt a systematic bidding method and select subcontractors who meet the minimum qualification requirements and have medium and superior qualifications through uniform standards and procedures. In addition, the scope and objectives of the subcontractor's work should be clearly defined in the contract, including specific requirements in terms of quality, safety, etc., and the subcontractor's work should be inspected regularly to ensure that these requirements are met. At the same time, the general contractor needs to establish an effective communication mechanism with the subcontractor to encourage both sides to speak freely and express their needs and challenges, so as to coordinate each other's expectations and jointly develop scientific and reasonable design and construction plans.

6 Conclusions

To address the challenge of how to make subcontractor decisions to maximize project benefits, this study combines the method of system dynamics, establishes a model for benefit calculation in a systematic decision-making mode and SC perspective. Here are the research conclusions:

(1) A budget model for the overall process project benefits is constructed. The model is built using the method of system dynamics and validated for effective-ness, with a relative error of -2.66%. Simulations are conducted using the verified parameters, and the project benefits for PRB project A is calculated to be 132,480 yuan, which is an average level.

(2) The key factor affecting project benefits is identified as DSQ, which should be at an upper medium level.

7 Limitations and Future Research

The method proposed in this study is applicable for estimating the overall bene-fits of EPC project, but the criteria for parameter selection and standardization tailored to the characteristics of each project still require further research.

The close integration of subcontractor selection process and supply chain management is the key to improve project efficiency. In the future, supply chain management theory can be applied to production, transportation, and construction scheduling problems in the model, such as demand forecasting, inventory control, and transportation optimization, so as to achieve the optimal allocation of resources and further improve project benefits. Through comprehensive consideration of all aspects of the project cycle, improve and standardize the model parameters, so as to make more scientific and reasonable subcontractor decisions and follow-up management measures.

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