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Research on Project Resource Allocation and Lean Procurement Strategy Based on System Dynamics

Ting Chen [1,*], Beiping Tan [2]

1. College of Management, Sichuan University of Science & Engineering, Zigong 643000, China
2. College of Civil Engineering, Sichuan University of Science & Engineering, Zigong 643000, China
[*]Corresponding Author

ABSTRACT. *Dynamic cost control of construction projects has been a hot topic in the construction industry. Therefore, the idea of lean procurement cost management is combined with dynamic procurement system. First of all, it discusses the characteristics of the relevant elements of the procurement system and analyzes the relationship between variables. Next, make a casual loop diagram of lean procurement system, and introduce two policy variables, namely, the material inventory days and the early-warning value. Finally, the dynamic simulation model of system dynamics is established to simulate and analyze the impact of inventory days and early warning value changes on project cost and construction period, and optimize resource allocation strategy. The model can be used to analyze the impact of different strategies on cost performance and schedule performance, and optimize the procurement plan in theory.*

KEYWORDS: *Resource allocation; Lean procurement; System dynamics; Earned value method; Cost control*

1. Introduction

Due to the large amount of working capital occupied by construction projects, and the slow capital turnover and long cycle, improper decision-making will result in waste of capital time value and increase of opportunity cost. In order to realize the sustainable development of the industry, construction enterprises need to optimize the decision-making and control the cost in each stage of project implementation. The idea of lean cost management is to achieve cost saving by controlling the use of resources and allocating resources appropriately in each link. Based on this, the introduction of lean cost management can optimize the enterprise's resource

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allocation strategy, reduce the waste of capital, and realize the sustainable development of the industry.

Material consumption accounts for about 70% of the total project cost in the construction project cost. Improper procurement of materials will result in a large amount of inventory costs and a large amount of additional costs. Therefore, inventory is the source of waste, because inventory is too much, and the retention time is too long, will lead to a decline in capital turnover rate and loss of capital time value. In addition, countries such as the United States and Japan have achieved good benefits in controlling project costs by optimizing procurement strategies. However, the current research on material procurement in the construction process only focuses on the horizontal allocation and rough overview of various resources [1][2][3][4], and there are few studies on the mechanism of the specific procurement plan on the project cost and schedule. Meanwhile, the analysis of the characteristics of the project itself is ignored. System dynamics has significant advantages in the study of complex, dynamic and nonlinear problems [5]. Therefore, the system dynamics is used to build a simulation model to analyze the mechanism of the internal factors in the procurement system, comprehensively analyze the strategic benefits of the project material procurement, and calculate the inflection point of resource allocation, so as to provide some reference for the actual engineering material procurement and project cost control.

1 Model boundary and lean sourcing causality diagram

1.1 System boundary setting

The system boundary [6][7] is the basis to determine the variables, the properties of variables and the relationship between variables in the model and to enhance the effectiveness of the model. The purpose of the model is to explore the mechanism of the factors related to the procurement of engineering materials and optimize the procurement scheme. Therefore, the model constructed only considers the factors that have an impact on the procurement activities. The main body of the model includes material procurement, construction material consumption, construction costs and construction schedule. Meanwhile, in order to guarantee the stability and independence of the model, the following restrictions are set:

(1) In order to analyze the mechanism of the procurement system in detail and optimize the procurement strategy, the model takes the steel with large demand and high cost in the whole process of the project as the specific research object, and the rest of the resources meet the corresponding schedule requirements.

(2) The model does not consider the influence of uncertain natural factors such as weather on the construction schedule. The target construction period shall be determined according to the construction procedure.

(3) In order to avoid the influence of construction period on the model parameters, the model parameters are based on the short-term project design with

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construction period within one year. Because the short-term material unit price changes little, so the material unit price does not consider the adjustment coefficient.

1.2 Cause-and-effect diagram of lean procurement system

The system dynamics model is dynamic mainly through causality diagram and feedback system [8]. Therefore, Vensim PLE was used to draw a causal diagram of lean procurement, including three subsystems of material inventory, cost performance and schedule performance, as shown in Figure 1.

In the material inventory subsystem, the construction schedule of the project depends on the availability of resources and the operability of the process [9].The delay effect caused by the arrival of labor and capital is not considered, so the actual construction speed only considers the limitation of stock materials and construction procedures. As the next process cannot be carried out before the completion of the previous process, the maximum construction speed is limited by the construction process. At the same time, the actual construction speed and the planned construction speed have a negative feedback effect on the material inventory, which forms a causal loop of the material inventory subsystem. The material inventory system describes the supply and consumption of materials and at the same time reflects the real-time inventory of the project and the actual construction speed. In addition, cost performance and schedule performance are introduced into the lean procurement system to evaluate the benefits of material procurement plan [10].In the cost performance system, when the cost performance is greater than or equal to 1, the project is implemented according to the original procurement plan. When the cost performance is less than 1, the procurement plan will be adjusted to control the cost within the budget. In the same way, the schedule performance system will be designed. Finally, the three subsystems are composed into a dynamic system of material lean procurement to control cost.

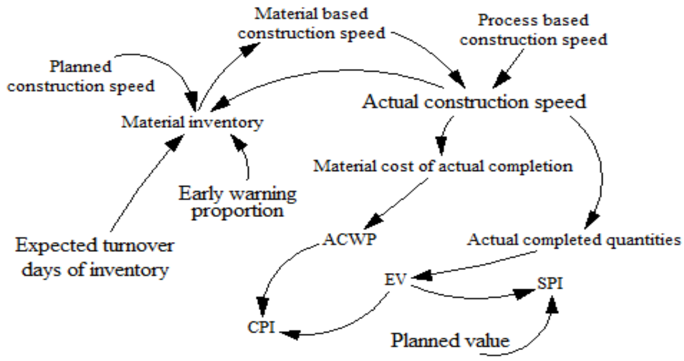

Figure. 1 Causality diagram of lean procurement

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2 Simulation model and scheme optimization of lean material procurement system

2.1 Lean material procurement system stack -- flow diagram

The causal loop diagram only qualitatively describes the characteristics of the model and cannot quantitatively reflect the essential relationship between variables [11].In order to clearly reflect the interaction mechanism between variables, Vensim PLE was used to establish the system dynamics stack -- flow diagram, as shown in Figure 2. The model contains a total of 31 variables, among which 4 are state variables, 5 are rate variables, 14 are auxiliary variables and 8 are constants.

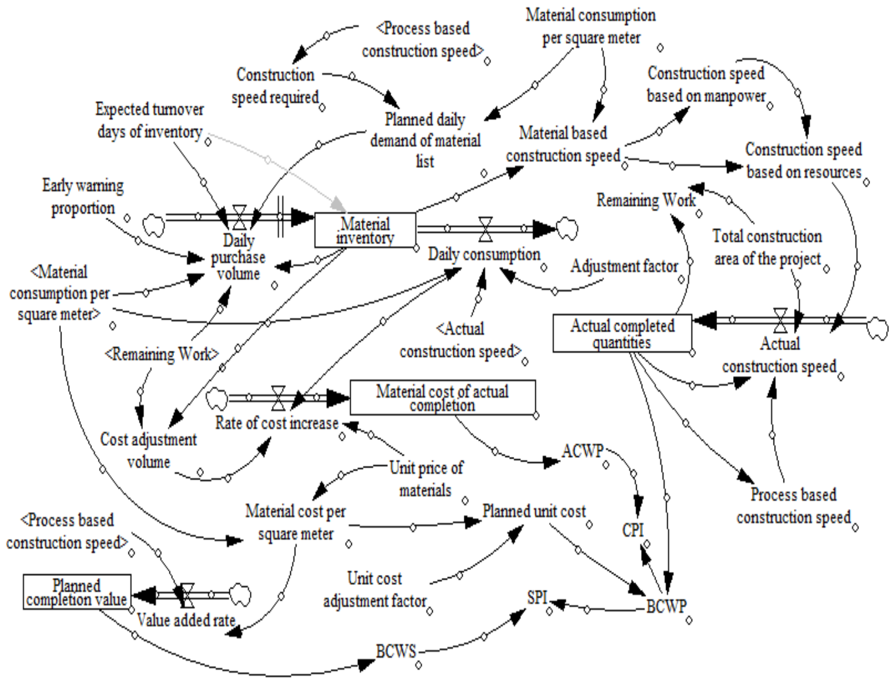

Figure. 2 Flow diagram of lean procurement system stack

2.2 Initial parameters and data sources

The model parameters are mainly obtained by querying the official statistical data of relevant departments, referring to relevant literature, and collecting data and analyzing relevant data through field investigation. The parameter design of some key variables is shown in Table 1.

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Table 1 Variable parameters

Variable Name	Data	Unit
Initial value of expected inventory turnover days	1.5	Day
Initial value of warning ratio	-0.5	
Material price	0.392	Ten Thousand Yuan/ton
Material consumption per square meter	0.05	Ton/m^2
Adjustment coefficient	0.02	
Unit cost adjustment coefficient	0.04	
Min. unit man-hour	1	Day

The object of the construction project is not the same. In order to facilitate simulation analysis, considering the availability and data integrity of the data, an apartment in south Sichuan is taken as the model basis. The relevant parameters of the project are: the total construction area of the project is 15,000 square meters, the planned total cost is 3,200,000 Yuan, and the fastest construction progress can be reached is 164 square meters per day, and the planned construction period is about 150 days. According to the project demand, the system dynamics simulation model is used to analyze the cost performance and schedule performance of each procurement plan, and to evaluate the comprehensive benefits of the plan. The simulation cycle of the model is 160 days, and the step length is 1 day.

3 Model testing and procurement strategy optimization

3.1 Model test

Before using the model for simulation analysis, the validity and accuracy of the model should be tested [12], so as to analyze whether the test model can fully and accurately explain the project. Mainly check the model structure and parameter setting.

(1) Structural inspection

The structure of the model test including check whether the variable is set is reasonable, the structure of the model is complete, boundary clear, unit Settings are appropriate, are the model results stability, etc. Vensim detection was used to find that the model passed the dimensional consistency test. Then, three simulation analyses were carried out on the model randomly, and the results showed that the cost and duration of the model were basically the same, and the model was stable.

(2) Parameter test

In this paper, the extreme condition model test method proposed by Wang Lezhi and Yuan Hongping is used [13][14]. The principle is to verify whether the simulation results of the model conform to the general engineering law under a certain parameter condition. The model parameters were tested by analyzing the relationship between the unit engineering material consumption and the procurement

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cost of engineering materials. The results are shown in Figure 3. When the material consumption per unit project changes from 0.01 ton to 0.07 ton, the change curve of material procurement cost clearly shows: The more material consumption per unit project, the higher the procurement cost of engineering materials, that is, the same amount of engineering, the more material consumption, the higher the cost, consistent with the actual situation. In addition, according to the plan to complete 15,000 square meters of engineering quantity, the actual construction speed is always less than or equal to the construction speed based on the process, in line with the engineering characteristics. Therefore, the parameters of the lean procurement system dynamics model are set reasonably and the model is effective, which can explain the real situation of the project and provide reference for the optimization of the procurement scheme.

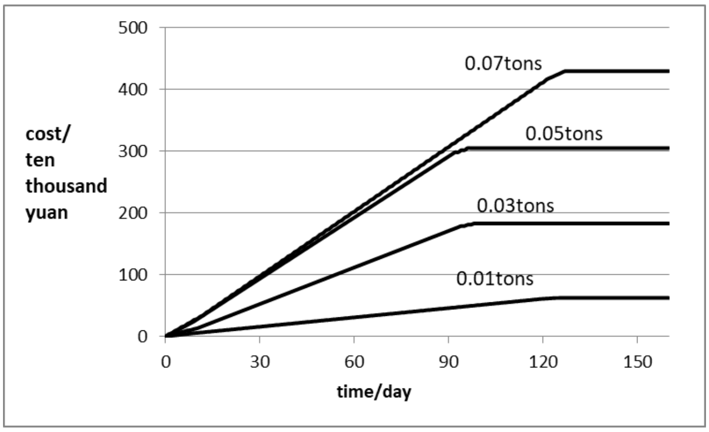

Figure. 3 Relationship between material consumption and procurement cost of unit project

3.2 Material procurement strategy analysis

Through simulation analysis of the procurement scheme at the current stage of the project, the actual construction speed of the project is obtained as shown in Figure 4, as well as the project progress and cost performance as shown in Figure 5. The results show that the project materials are in short supply under the current procurement plan. The project SPI and SPC are less than 1, the project schedule is delayed, the project cost exceeds the budget funds, and the material procurement strategy is not reasonable, which needs to be adjusted. Therefore, the introduction of two policy variables, the expected inventory turnover days and the pre-warning ratio of material procurement, to optimize the procurement plan can produce the following three major optimization strategies.

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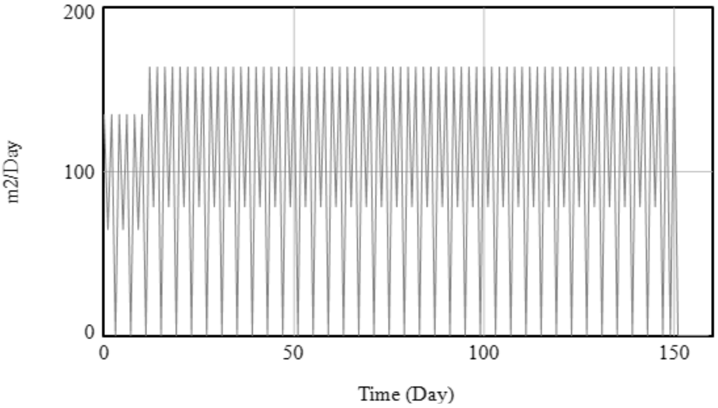

Figure. 4 Actual construction speed of the project

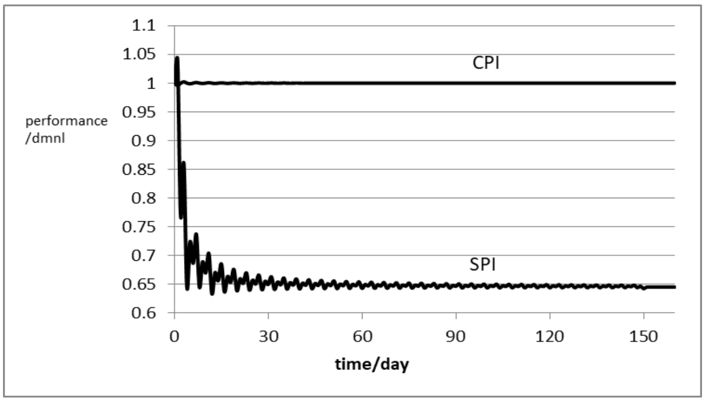

Figure. 5 Project progress and cost performance

(1) Optimize the expected inventory turnover days

Inventory estimated turnaround days are the number of days that inventory materials are expected to be available for planned construction after a purchase. On the premise that other resources meet requirement, this parameter directly affects the actual construction speed of the project. After adjusting this parameter, it can be found that the construction speed based on materials increases gradually in the process of raising the expected turnover days of inventory from 1 day to 3 days, and the construction speed reaches the maximum when it is adjusted to 2 days. At the same time, the change of progress performance (as shown in Figure 6) shows that with the gradual increase of parameters, progress performance gradually increases until it is increased to 2 days, and no further increase occurs. However, the cost performance index showed a downward trend, and the decline became faster after the turnover days increased to 2 days, as shown in Figure 7.

Therefore, adjusting the expected turnover days of material inventory can accelerate the construction speed of the project, but reduce the efficiency of capital use. At the same time, if the increased material inventory is not suitable for the construction schedule, it will not only cause idle inventory, but also increase the cost of inventory holding, resulting in an uneconomical material procurement strategy.

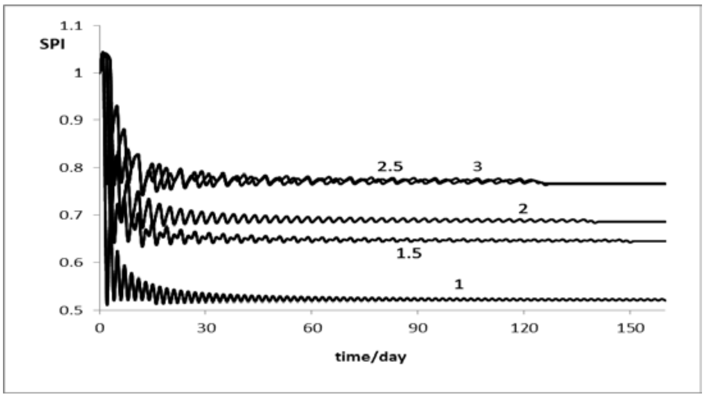

Figure. 6 Changes in progress performance

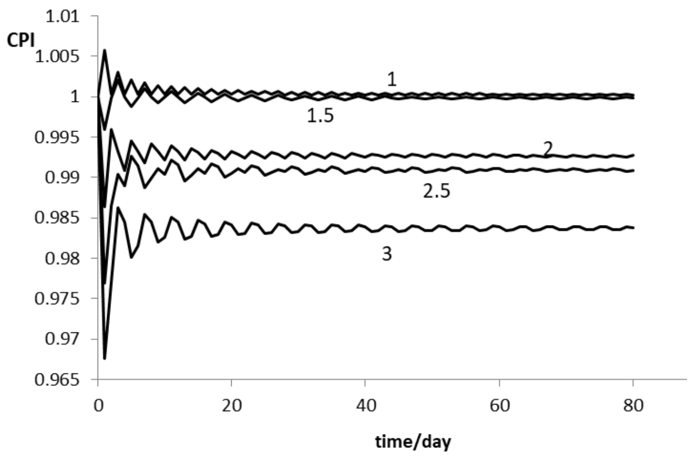

Figure. 7 Changes in cost performance

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(2) Optimize the proportion of early warning

The materials are transported from the construction site, and the supply time is needed from the purchase to the arrival of the materials. If the procurement process is not started until the material consumption is finished, there will inevitably be a problem of stoppage waiting for materials. Therefore, the policy variable of early warning ratio is introduced to judge whether to start the procurement process. The pre-warning ratio is the proportion of the remaining materials in the construction site to the daily demand after deducting the materials to be consumed on the day. Because the material daily consumption is in accordance with the plan construction schedule is estimated, according to the statistical analysis has finished project, the scope for 1 to 2 (-1 means that the material is just used up; 0 means the stock material can guarantee the normal construction for 1 day; 2 means the stock material can be used for normal construction for 3 days).

As the proportion of early warning directly affects the long-term inventory of materials, it is related to the turnover rate of material funds and inventory holding cost. Therefore, the early warning ratio was evaluated from -1 to 2 for simulation analysis. The results show that when the inventory is less than a day's demand to start the procurement plan project will stop to wait for materials; however, when the inventory materials can be supplied for more than 1 day, the procurement plan will be started and the materials will meet the schedule requirements. At the same time, according to the change of project progress performance (as shown in Figure 8), the relationship between project progress performance and the proportion of early warning is stage by stage. When the early-warning ratio is greater than 0, the project progress performance increases, the construction progress reaches the planned progress, and the curve overlaps back to the maximum progress performance.

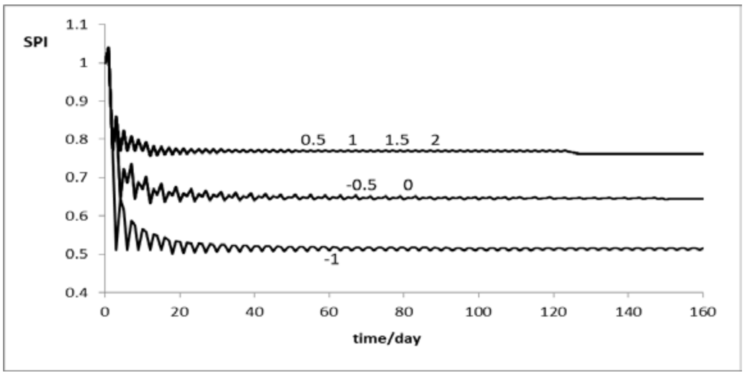

Figure. 8 Changes in the SPI of the project with changed alarm ratio

(3) Optimize inventory turnover days and early warning ratio at the same time

Comprehensive analysis of the first two strategies and adjust the single materials inventory turnover days to 2 days or more to achieve individual optimal. The construction speed cannot be increased after the inventory turnover is expected to be greater than 2 days. Considering the time value of the project funds and the cost of materials to be held, the expected inventory turnover days are set as 2 days. Therefore, the inventory turnover days were set as 2 days, and the cost benefits and schedule benefits of different early-warning ratios were analyzed to find the best advantage.

Simulation results show that when the early-warning ratio is gradually increased from 0 to 0.17, project progress performance (as shown in Figure 9) and cost performance are no longer changed and both are greater than 1, which means that the cost and schedule are controlled within the planned scope at this time. Considering that in the actual construction process, there are many types of work and complex coordination of work types, if the early-warning ratio is set too high and the procurement is too frequent, it is not conducive to the project organization and management. Therefore, the proportion of warning should be kept as low as possible. So it's 0.17. Finally, it is concluded that when the expected inventory turnover days are 2 days and the early-warning ratio is set at 0.17, the progress performance and cost performance reach the comprehensive optimal, and then the procurement plan is the best.

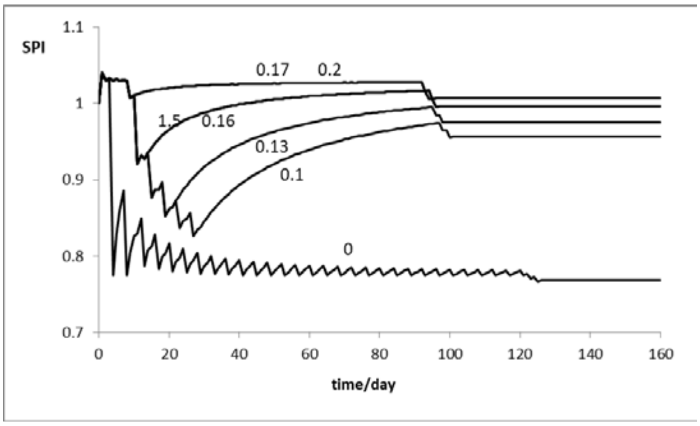

Figure. 9 Variation trend of SPI of early warning ratio

The optimized procurement scheme is applied to the simulation apartment building project. Through the simulation analysis, the project cost performance and schedule performance are both greater than 1, as shown in Figure 10. The results show that the combined control strategy of the expected days of inventory material turnover and the proportion of early warning can speed up the construction progress of the project and save the project cost. At the same time, the actual construction amount of the simulation project was 15,000 square meters, the total construction period was 96 days, and the inventory material was exactly 0 when the project was completed, and the total cost was 3.05 million Yuan. The project duration and cost have been optimized, and the comprehensive benefits have increased significantly.

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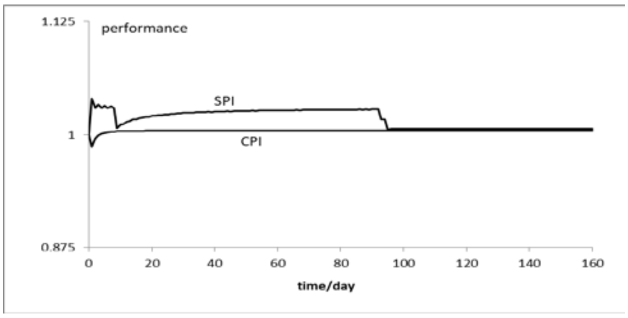

Figure. 10 SPI and CPI under optimal procurement strategy

4 Conclusions

This paper takes an apartment project as an example and USES the system dynamics method to build a lean procurement model. The results show that:

(1) Different procurement plans have a great impact on construction period and cost. In order to reduce the extra holding cost of material purchase, it is necessary to increase the material flow rate and reduce the retention time of material warehouse, so as to reduce the cost of material purchase.

(2) The mechanism of the two policy variables on the material procurement benefit was analyzed, and it was found that increasing the number of days of inventory turnover could speed up the construction progress of the project, but would increase the procurement cost. Although raising the proportion of early warning will not significantly reduce the cost-effectiveness of capital, it also has a relatively small effect on the project schedule performance. The increase of material inventory has an inverted u-shaped effect on the comprehensive benefits of the project, which means that the construction progress and comprehensive benefits cannot be promoted indefinitely.

In this paper, a combination model of system dynamics and earned value method is used to study the procurement strategy of project qualitatively and quantitatively. Though the model constructed in this paper makes up for the fact that the index system was only established in the past and no specific optimization strategy was formed. However, the model constructed in this paper is based on certain assumptions and has some limitations. Therefore, in the future research, the uncertain factors and artificial and mechanical resources can be taken into account in the system to form a more comprehensive and adaptable dynamic model.

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