System dynamics engineering cost management strategy from the perspective of supply chain management: an effective method to control the cost of construction projects

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Received: October 30, 2024 / Revised: February 25, 2025 / Accepted: February 26, 2025

Abstract

With the rapid development of the construction industry and the increasing market competition, the effectiveness of project cost management is becoming more and more important for the economic feasibility and sustainable development of the project. The purpose of this paper is to discuss the key measures to improve the level of project cost management from the perspective of supply chain management and system dynamics and put forward the strategies for effective cost control in all stages of construction projects. Firstly, the importance of scientific budgeting and optimal design in controlling the initial project cost is emphasized, and the long-term impact of the system dynamics model is analyzed. Secondly, the cost monitoring and management of the construction phase is discussed, with a focus on schedule control, material procurement, and site management, with the aim of using a system dynamics approach to predict cost changes to avoid budget overruns. In addition, rational planning of contract management and bidding processes is also seen as a key factor in controlling costs, and system dynamics can help evaluate the effectiveness of different strategies. Finally, it is suggested to improve the professional ability of project management personnel through team building and emphasize the role of system thinking in improving the overall level of project cost management. Through the implementation of these measures, it is expected to enhance the effectiveness of project cost management, achieve effective control of project costs, and promote the sustainable development of construction projects.

Keywords: Construction Project, Project Cost Management, Cost issues and countermeasures

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Introduction

Project cost management background

With the rapid development of the global construction industry, effective cost management in engineering projects has received increasing attention. As projects grow in size and complexity, controlling costs has become one of the main challenges faced by construction companies. Many construction projects often suffer from budget overruns and uncontrollable costs, which not only reduce the company's profits, but also lead to contract disputes, which can affect the reputation of the business (Harris et al, 2021). In order to meet these challenges, it is particularly important to improve the level of project cost management and implement strict cost control measures. Scientific budgeting, rational optimization of design, meticulous construction management and effective contract management are the key strategies to reduce project costs, which can ensure the rational use of funds while meeting quality and schedule requirements. However, traditional cost management models are often inadequate in dealing with the complex nature of modern construction projects. Therefore, combining the supply chain management perspective with the system dynamics approach can significantly improve the effectiveness of engineering cost management and promote the sustainable development of construction projects (Hanioglu, 2022).

Recent literature has highlighted the significant impact of Building Information Modelling (BIM) technology in improving project schedules and cost control and can provide scientific decision support through data analysis (Katke, 2020). In addition, from the perspective of system dynamics, dynamic models can be established to simulate various factors that affect costs to achieve effective cost prediction and control (Liu et al., 2020). The purpose of this study is to explore how to improve the level of project cost management from the perspective of supply chain management and system dynamics, and to put forward specific strategies for effective cost control at all stages of construction projects.

Engineering cost management from the perspective of supply chain

In today's highly competitive construction market, engineering cost management from a supply chain perspective has become critical. With an emphasis on collaboration and integration, supply chain management aims to optimize the entire process from material procurement to project delivery. By improving the efficiency of each link, enterprises can effectively reduce costs, shorten construction periods, and improve resource utilization (Luo et al., 2020). In a construction project, the supply chain includes not only material suppliers, but also design teams, construction units and supervision agencies, and the coordination of these links is the key to achieving cost control.

System dynamics provides a powerful tool for analyzing the behavior of complex systems, helping companies understand and predict the interactions between elements in the supply chain. In the context of cost management, system dynamics models can be used to simulate the long-term impact of different decisions, helping managers identify possible cost risks and potential cost savings opportunities (Ghadgeet et al., 2022). For example, by building simulation models, companies can analyze the impact of factors such as material price fluctuations,

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supplier delivery delays, and construction schedule uncertainties in the supply chain on overall costs.

Using the system dynamics mindset, construction companies can integrate cost data from different stages from a macro supply chain perspective and make adjustments for key links. Such integration not only helps to improve the project's budget accuracy but also identifies and resolves potential issues in a timely manner, leading to more effective cost control (Kazancoglu et al., 2021).

In conclusion, the combination of supply chain management and system dynamics can provide a new perspective and method for engineering cost management, so that enterprises can better respond to challenges in a rapidly changing market environment and improve the economic efficiency and sustainability of projects.

Objectives of the Study

The purpose of this study is to explore the engineering cost management strategy from the perspective of supply chain management, especially the application of system dynamics analysis tools to improve the cost control ability of construction projects. The specific objectives are as follows:

1. Analyze the current status of engineering cost management: Through literature review, evaluate the current challenges and problems of engineering cost management, especially the shortcomings of supply chain collaboration and cost control.
2. Explore best practices in supply chain management: Examine industry success stories to identify and summarize effective supply chain management strategies that can lead to resource optimization and cost reduction for construction projects.
3. Establish a system dynamics model: Design and implement a system dynamics model to simulate the impact of each link in the supply chain on project costs, and then analyze the long-term effects and potential risks of different management decisions.
4. Practical suggestions: Based on the research results, this paper provides practical suggestions for construction enterprises to help them effectively apply the methods of supply chain management and system dynamics in actual operation, so as to improve the overall efficiency and effectiveness of project cost management.

Research gaps and academic contributions

Research gaps

In the interdisciplinary field of engineering cost management and supply chain management, although many studies have explored their respective theories and practices, there is still a lack of understanding of how to effectively integrate the perspectives of the two to improve the cost control ability of construction projects. The existing literature focuses on individual aspects of cost management, such as budgeting, contract management, or material procurement and the lack of integrated analysis of system dynamics has led to a lack of comprehensive understanding of the impact of various links in the supply chain on project costs. In addition, there is no mature theoretical framework for how to simulate and evaluate the effects of different management strategies through system dynamics models. Therefore, this study fills this gap and aims to provide an integrated perspective to explore the intrinsic relationship between supply chain management and engineering cost management.

Academic Contributions

The main academic contributions of this study are:

1. Theoretical innovation: By introducing the system dynamics model, this study provides a new analytical tool for engineering cost management, promotes an in-depth understanding of supply chain management, and expands the theoretical basis of related literature.

2. Practical application: This study puts forward specific supply chain management strategies for the actual cost control problems in construction projects, which provides valuable guidance for construction enterprises to apply supply chain management in actual operations.

3. Interdisciplinary integration: The organic combination of engineering cost management, supply chain management and system dynamics provides new ideas for future research in related fields and promotes interdisciplinary exchanges and cooperation.

Through these contributions, this research can not only enhance the academic understanding of the intersection of engineering cost management and supply chain management, but also provide practical solutions for practical construction projects, thereby promoting the sustainable development of the construction industry.

Literature review

Supply chain management of project cost management

Supply chain management plays a key role in project cost management. According to research, the efficiency of the supply chain has a direct impact on the overall cost and delivery time of the project (Tezel et al., 2021). In construction projects, the procurement, storage and transportation of materials belong to the scope of the supply chain, and the management quality of these links is crucial to control the project cost. Many scholars have pointed out that significant costs can be reduced by strengthening the selection and management of suppliers and optimizing the procurement process of materials (Sharma & Joshi, 2023). For example, using a supply chain integration strategy can ensure the availability of necessary resources before a project starts, thereby reducing additional costs due to material shortages or delays.

In addition, the transparency of the supply chain is also considered to be an important factor in improving the ability to control costs. When project teams have real-time access to information in the supply chain, they can respond more quickly to market changes and adjust procurement strategies and materials management (Benton Jr, 2020). In this process, the application of information technology, such as BIM (Building Information Modeling) technology and the Internet of Things (IoT), has been found to have a significant impact on improving the efficiency of supply chain management and reducing costs (Mannino et al., 2021). Therefore, the effectiveness of supply chain management not only improves the efficiency of project cost management but also provides a guarantee for the successful implementation of the entire project.

Application of system dynamics in engineering cost management

System dynamics is a theory and method for studying complex systems and their interrelationships, which has important application potential in engineering cost management. By building a system dynamics model, managers can simulate and predict cost changes in a project, so as to formulate more effective cost control strategies (Chen et al., 2023). The system dynamics model can help analyze the interaction between various project elements, identify the root causes of cost changes, and adjust management strategies through dynamic feedback.

For example, system dynamics is used to analyze cost fluctuations during construction and their long-term impacts, thereby helping companies to make better budgeting and resourcing during the design and construction phases (Ford & Lyneis, 2020). This approach can reduce cost overruns due to uncertainty and improve project economics. In addition, system dynamics can also help enterprises evaluate the effectiveness of different management strategies and provide data support for decision-making (Jahan et al., 2022). Through these applications, system dynamics not only improves the accuracy of engineering cost management, but also promotes the sustainable development of the project.

In short, the combination of supply chain management and system dynamics provides a new perspective and method for project cost management, which is helpful to improve the efficiency of cost control and promote the successful implementation of engineering projects.

Research Methodology

This study adopts a comprehensive research method combining literature analysis and case study method, aiming to deeply explore the existing theory and practical application of engineering cost management. Firstly, through a systematic literature review, the core theories, research progress and practical cases in the field of engineering cost management are sorted out and summarized, and the research results in the relevant literature are critically analyzed to identify the shortcomings of the current research and the future research direction.

Secondly, in order to strengthen the combination of theory and practice, this study selects representative practical construction projects as cases, and collects and analyzes the data and experience in the process of cost control. Specifically, this study focuses on the following aspects:

1. Material procurement: In the material procurement process, system dynamics models are applied to simulate the dynamic behavior of the material supply chain. Consider using an inventory control model (e.g., an economic order quantity model) to analyze the impact of inventory levels in the supply chain on procurement costs. By establishing a feedback loop of supplier selection and price fluctuations, we explore how to reduce total

costs and improve project efficiency by optimizing procurement strategies.

2. Cost management in the design stage: Using the method of system dynamics, the impact model of design changes on costs is established, and the feedback effect of design decisions is discussed. Specifically, you can use a feedback loop diagram to show the impact of design changes, such as the cost increase caused by delaying the design. Mathematical models can use methods such as linear programming to predict cost outcomes under different design choices.

3. Tender design: In the tender design phase, system dynamics is applied to analyze the interaction of different strategies in the bidding process. An overall bidding efficiency model can be established to explore the impact of quotation strategy, supplier capacity and market competition on the final bidding cost. Conduct sensitivity analysis to understand how different variables affect overall cost-effectiveness.

4. Cost monitoring throughout the construction process: System dynamics tools (such as Vensim or Stella) are used to model the cost of each project activity and its impact on the overall budget. By establishing a feedback system for monitoring indicators, it is possible to identify and respond to possible financial risks in a timely manner.

From a supply chain perspective, there is a relationship between the above four stages. The efficiency of material procurement will have a direct impact on the cost of the design phase, as inappropriate material selection can lead to design changes; Design changes can trigger additional material requirements, further impacting sourcing strategies and cost control. In addition, the quotation in the tender design will rely on prior material procurement and design decisions, thus creating a continuous feedback loop. Through the discussion of system dynamics, we can better understand the interaction between these stages, so as to formulate a more holistic management strategy.

This study will deeply analyze the best practices presented in the case studies and put forward corresponding management countermeasures and suggestions based on the research results, in order to provide empirical support for the theoretical construction and practical operation of project cost management.

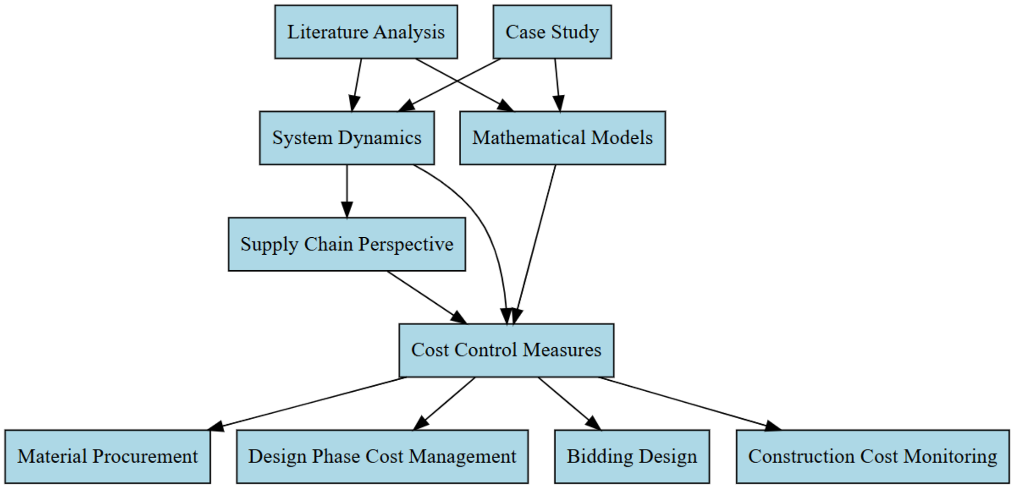

Figure 1 Conceptual framework of this study

Results and Discussion

Engineering manages the variables associated with each stage of the supply chain

Material procurement stage

During the material procurement phase, several key indicators need to be closely monitored. The first is inventory levels, which include real-time inventory levels compared to forecasted inventory needs to ensure supply chain stability. The second is the procurement cost, which covers the cost of raw materials, transportation and storage. The selection of suppliers is also crucial, and reliability and delivery time are among the core elements in evaluating supplier performance. In addition, price fluctuations are also variables that affect purchasing decisions, especially changes in the market price of raw materials. Basic variables include inventory control parameters (e.g., economic order quantities), supplier performance metrics (e.g., lead times and quality), and cost fluctuations (e.g., effects due to seasonal changes).

Cost management in the design phase

During the design phase, there are several key metrics to focus on. The first is the frequency of design changes, which involves the number of design changes and their impact on the project. This is followed by the proportion of cost increases, which reflects the extent to which design changes affect the budget. In addition, design delay time is also an important indicator, and the delay has a direct impact on the cost of the project. The basic variables include the factors influencing the design change, such as the complexity of the design and the number of participants, the parameters of the cost prediction model (such as the results of linear programming), and the impact factor of the delay on the overall cost of the project.

Tender design stage

There are a number of metrics to consider when developing a quoting strategy. The first is the quotation strategy, which involves comparing the quotation strategy of competitors with their own quotation to ensure competitiveness. The second is the supplier capability, which evaluates the supplier's technical level and its position in the market. In addition, market competitiveness is also a key indicator that reflects the number of competitors in the market and their influence on the market. Basic variables include bidding efficiency metrics such as bid success rates, competitive market indices, and quote model parameters, which cover data such as minimum and average bids, which are used to optimize the bidding strategy

Cost supervision stage of the whole construction process

In financial management, several key metrics need to be closely monitored. The first is the budget overrun rate, which reflects the ratio of actual costs to budget and helps assess whether the project is over budget. The second is the financial risk indicator, which mainly includes the current ratio and the debt ratio, which are used to measure financial risk. In addition, oversight indicators focus on the timeliness of project activities and their impact on overall schedules and costs. Basic variables include budget execution metrics, such as actual vs. budgeted spending, predictive model parameters for financial risk, and feedback loops for monitoring metrics to improve management processes.

System dynamics model

From the above variables, we can build a system dynamics model, which includes the following steps. Firstly, a feedback loop is established to present the interaction between the indicators in the form of a feedback loop, so as to clearly show the correlation of each variable. Secondly, mathematical modeling is carried out, using linear programming and other mathematical methods to simulate the changes of different variables and analyze their impact on the overall system. Next, tools such as Vensim or Stella are used to conduct simulation analysis to explore the stability and performance of the supply chain under different scenarios.

Here are some examples of feedback loop models: First, supply chain cost feedback loops, where inventory levels affect procurement costs, which in turn affect inventory decisions. The second is the design change feedback loop, where design changes directly affect cost increases, which in turn prompt further design evaluation and adjustments. In addition, in the feedback loop of bidding efficiency, the supplier's ability will affect the quotation strategy, which in turn will affect the degree of market competition, and then affect the bidding cost. Such a model helps to analyze the stability of the engineering management supply chain, identify potential risks and identify opportunities for improvement.

Mathematical model of cost management in the four stages of engineering supply chain

The mathematical equations of the four-stage reference model and the meanings of the variables in each equation.

Material Procurement Model

Equation:

$$Cp = Cf + (D \times Cu) / Q+S \tag{1}$$

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Variable Help:

- Cp: Procurement Cost
- Cf: Fixed Costs (e.g. Procurement Overhead)
- D: Quantity required (quantity of material required per unit time)
- Cu: Cost per unit of material (may be affected by market price fluctuations)
- Q: Quantity per order (i.e. economic order quantity)
- S: Inventory carrying costs (including storage, insurance, etc.)

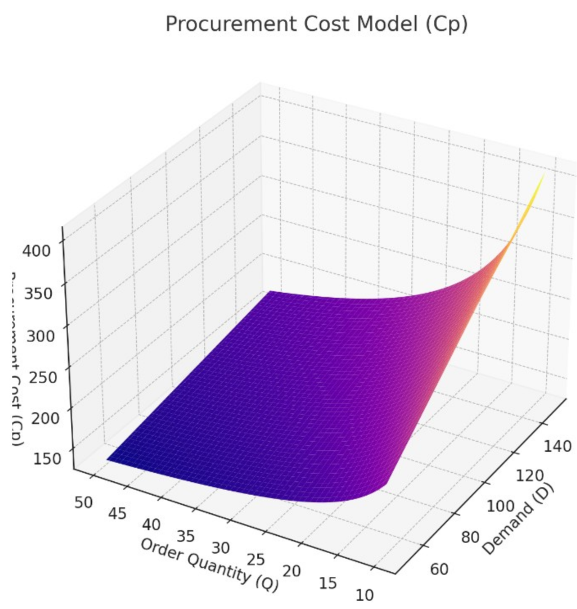

Figure 2 3D view of the material procurement cost management model

Here is the 3D surface plot representing the Procurement Cost Model (CpCpCp) based on the equation:

$$Cp = Cf + (D \times Cu) / Q+S$$

Description of the Plot:

- X-axis: Represents the demand (D), which indicates the quantity of materials required within a unit of time.
- Y-axis: Represents the order quantity (Q), which refers to the quantity ordered each time (Economic Order Quantity).
- Z-axis: Represents the total procurement cost (Cp), calculated based on fixed costs, demand, unit material cost, and inventory holding cost.

This graph illustrates how the procurement cost varies with changes in demand and order quantity, providing valuable insights for optimizing purchasing strategies.

Cost management model in the design phase

Equation:

$$Cd = C0 + \alpha \cdot (X - X0) + \beta \cdot T \tag{2}$$

Variable Help:

- Cd: The total cost of the design phase
- C0: Base cost (forecast cost without change)
- α\alpha: the cost increment factor caused by each design change
- X: The number of changes to the current design
- X0: Number of base design changes
- β\beta: Additional costs due to delays (e.g., schedule delays)
- T: Design delay time

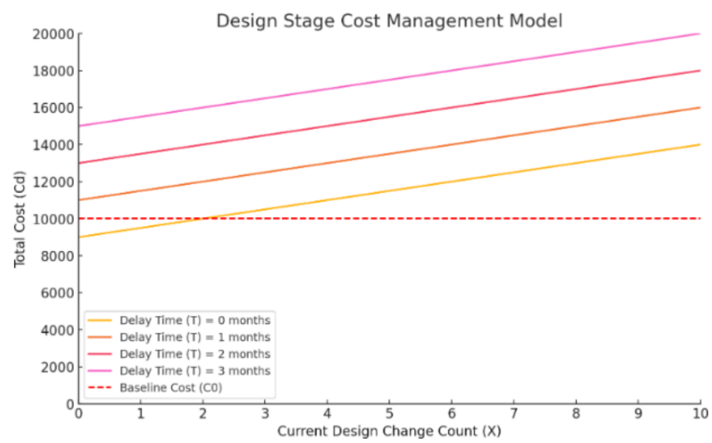

Figure 3 Cost management model diagram in the design phase

Here is the graph illustrating the Design Stage Cost Management Model based on the provided equation:

Graph Description

- X-axis: Represents the current design change count (X), ranging from 0 to 10.
- Y-axis: Represents the total cost (Cd), ranging from 0 to 20,000.
- Curves: Each line corresponds to a different delay time (T):
  - o T = 0 months: Represents the total cost without any delays.
  - o T = 1, 2, and 3 months: Each subsequent line shows the increase in total cost due to design changes and delays.
- Red Dashed Line: Indicates the baseline cost (C0), which serves as a reference point for cost predictions without any design changes or delays.

This visualization helps illustrate how the total cost increases with both the number of design changes and the associated delays.

Tender Design Model

Equation:

$$Ct = C_{b+\gamma} \cdot (Qs - Q_d) + \delta \cdot M \tag{3}$$

Variable Help:

- Ct: Total cost at the tender stage
- Cb: Base cost (e.g. cost of basic requirements of the project)
- γ\gamma: The cost impact factor between the supplier's capacity and the quoting strategy
- Qs: Supplier's Offer (Average Quote in the Market)
- Qd: Expected Quote (Reasonable Expectation Based on Historical Data)
- δ\delta: the coefficient of the impact of market competition
- M: Market competition index (e.g. number of competitors and intensity of competition)

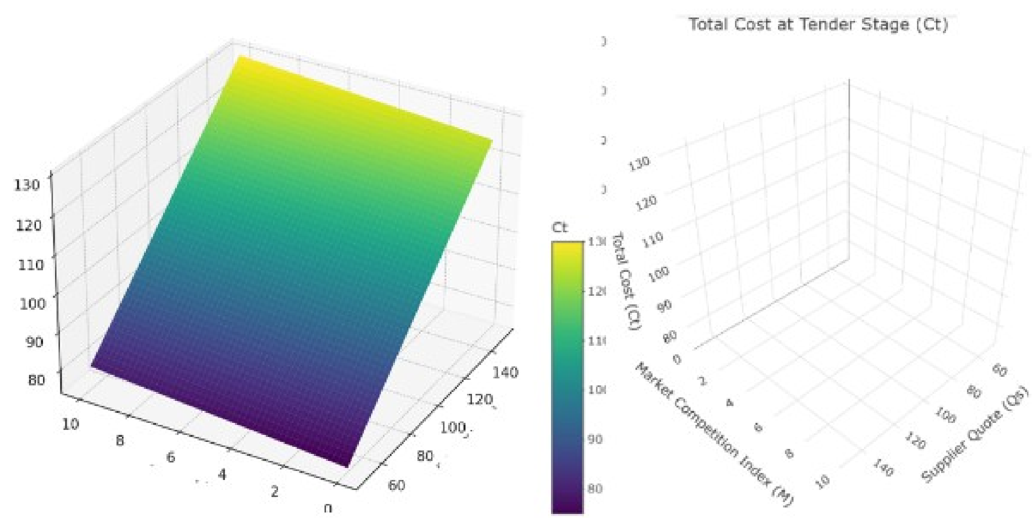

Figure.4 Mathematical model diagram of cost management in the bidding design stage

This is a three-dimensional graph showing the total cost Ct at the tender stage in relation to the supplier's offer Qs and the market competition index M.

- X-axis represents the supplier's quotation Qs.
- The Y-axis represents the market competition index M.
- The Z-axis shows the total cost Ct.

As you can see from the graph, the total cost Ct will change accordingly as the supplier's quotation and the market competition index change. This helps to understand the trend of costs in different quotations and competitive situations.

Construct a cost supervision model for the whole process

Equation:

$$Cm=C_{initial}+\sum(Ca)+R \tag{4}$$

Variable Help:

- Cm: The total cost of the construction process
- Cinitial: Initial budget or forecasted cost
- Ca: Cost by project activity (e.g., itemized cost of construction, materials, etc.)
- R: Sum of financial risk indicators (e.g., additional costs for budget overruns)

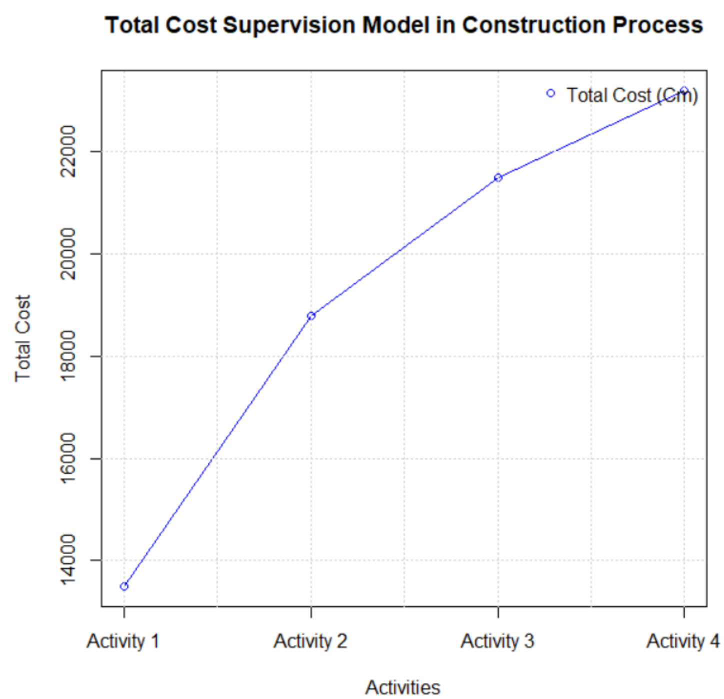

Figure 5 Cost supervision model diagram of the whole construction process

Integrated system dynamics model

In the equations for each of these stages, we can integrate them into a holistic system dynamics model to assess the stability of the overall supply chain. This can be achieved by setting up feedback loops that influence each other

The overall supply chain cost equation is as follows:

$$Ctotal = Cp + Cd + Ct + Cm \tag{5}$$

Here, Ctotal represents the total cost of the entire supply chain, which is the sum of the costs of the various stages. The interactions and feedback between the individual costs can be further analyzed by parameter tuning for sensitivity analysis to determine how to optimize costs at various stages and improve the stability of the supply chain.

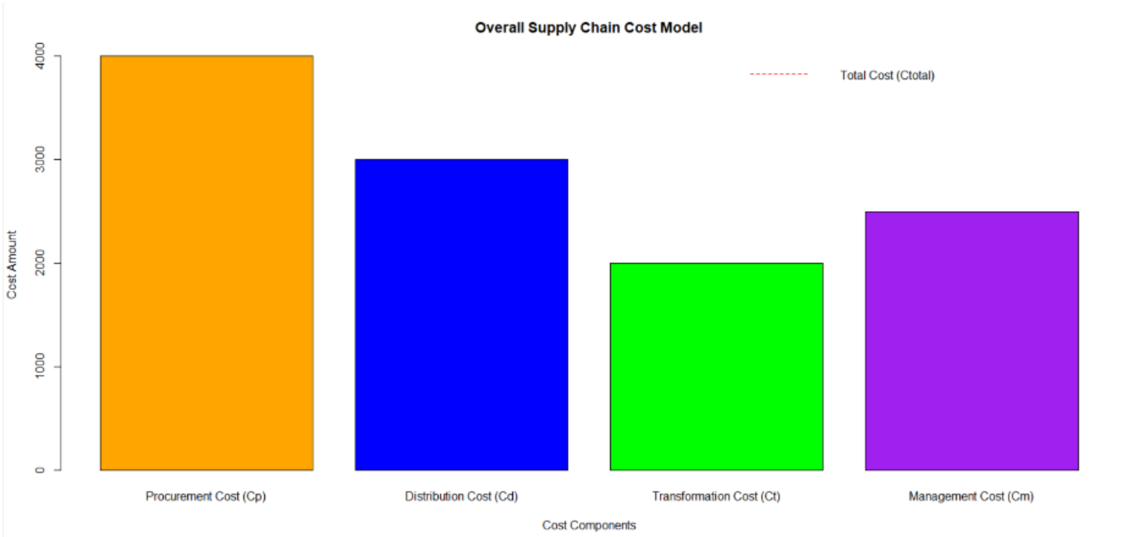

Figure 6 Diagram of the overall supply chain cost management model

These mathematical equations can help us build system dynamics models that assess the performance and stability of the overall supply chain by simulating changes in individual variables. By conducting a sensitivity analysis, you can identify potential areas for improvement and develop strategies to reduce total costs and improve project effectiveness.

Related actions of project cost management

Material procurement cost control

The high amount of material consumed and the frequent price fluctuations during the construction process pose a great challenge to cost management. In the procurement stage, the price of materials must be strictly controlled and forecasted, and a reasonable procurement strategy must be implemented according to market conditions to ensure the effectiveness of cost control.

Improve cost management with modern and intelligent technology

In the digital era, construction enterprises must rely on modern information technology and BIM technology to conduct data analysis and improve the level of cost management. The growing role of these technologies in cost control has helped to significantly reduce production costs.

Cost management in the design phase

Cost management during the design phase plays a key role in ensuring the economics of the project. Through design optimization and the involvement of technicians, costs can be controlled and economic benefits can be improved while achieving design goals.

Strengthen cost supervision

Strengthening the cost supervision of the whole process of the project can ensure the quality and safety of the project while reducing costs. Assembling a professional supervisory team and maintaining transparency in project management is essential to achieve effective cost control.

Figure 7 Conceptual diagram based on the system dynamics model

The diagram above illustrates the variables and their causal relationships at each stage of the engineering management supply chain.

Case Study

Cost management in construction is a complex and dynamic process that is influenced by a variety of internal and external factors. Building a system dynamics model can help understand and analyze the interactions between these factors, thereby providing decision support for cost management.

The following is a dynamic model building process based on the theme of "Construction Cost Management", with model diagrams and flowcharts attached to help readers understand.

Define the system boundaries and scope

First, we need to determine the scope and main variables covered by the model. Cost management of construction projects involves many factors such as labor, material costs, construction time, design changes and management expenses, etc.

System Scope:

- Direct costs: labor, materials, equipment, etc
- Indirect costs: overheads, insurance, taxes
- External factors: market volatility, interest rates, changes in laws and regulations

Identify the main variables

In dynamic models, state and flow variables are important elements to describe the system. We can divide the core variables of a construction cost management system into the following categories:

State Variables:

- Total Construction Cost (TCC): The expected cost of the overall project.
- Progress: The progress of the completion of the construction project.

Flow Variables:

- Labor Cost: The change in personnel wages with time and human resources input.
- Material Cost: Varies with fluctuations in material demand and market prices.
- Equipment Cost: Depends on the time and frequency of use.

Parameter:

- Construction Efficiency: The ratio of construction speed to quality.
- Material Price Volatility: The market volatility of material prices.

Establish causal relationships between variables

In construction projects, the interaction between cost variables is very important. For example, changes in construction efficiency affect construction schedules, which in turn affect the total cost. Fluctuations in material prices can also directly change the cost of materials, which in turn affects the overall cost.

Example causality:

- Relationship between labor and material costs and total costs: As construction progresses, labor and material costs accumulate and drive up total costs.
- Design changes and delays: Design changes can delay construction schedules, which in turn can increase overheads and overall costs.

Mathematical description of the model

Based on the causal relationship between variables, we can use a set of equations to describe the dynamic behavior of the system.

Example Mathematical Models:

1. Total Cost Model:

$$TCC = LC + MC + EC + IC \tag{6}$$

Thereinto:

- LC: Labor Costs
- MC: Material cost
- EC: Equipment cost

- IC: Indirect Costs (Overheads, Insurance, etc.)

2. Changes in Labor Costs Over Time:

$$dLC/dt = \text{number of people in the labor force} \times \text{wage rate} \quad (7)$$

Change in material costs over time:

$$dMC/dt = \text{material usage} \times \text{material unit price} \quad (8)$$

The unit price of materials may be adjusted according to market volatility:

Material Unit Price = Initial Price × (1 + Market Volatility)

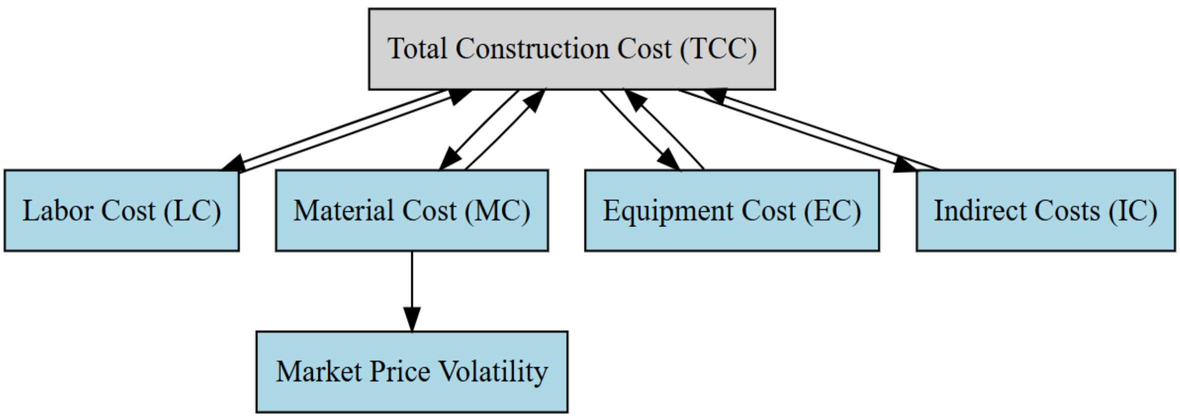

Figure.8 Interaction of dynamic analysis factors of engineering cost management system

Conclusions and Recommendations

Conclusion

From the perspective of supply chain management, combined with system dynamics, this paper discusses the key measures and strategies to improve the level of construction project cost management. The study shows the importance of scientific budgeting and optimal design in controlling the initial project cost, and using the system dynamics model to analyze its long-term impact, which can help to improve the accuracy of cost forecasting. In the construction stage, this paper emphasizes the key roles of schedule control, material procurement, and site management in order to ensure the effectiveness of cost monitoring and management, and proposes a system dynamics approach as an important tool for predicting cost changes. In addition, rational planning of contract management and bidding processes is considered to be a key factor in cost control, and the application of system dynamics enables the evaluation of the effectiveness of different strategies. Finally, improving the professional ability of project management personnel through team building and emphasizing the importance of system thinking can significantly improve the overall level of project cost management.

In general, the implementation of the above measures can not only enhance the effectiveness of project cost management, achieve effective control of project costs, but also promote the sustainable development of construction projects. The results of this study provide valuable guidance for construction enterprises in the current competitive market environment, which is helpful for them to cope with the challenges of engineering cost management.

Recommendations for future research

1. Expand the application scope of the system dynamics model: Future research may consider expanding the application scope of the system dynamics model to explore the characteristics of different types of construction projects and their impact on cost management, so as to provide more targeted cost control strategies.

2. Empirical research and case analysis: It is recommended to conduct an empirical study to deeply explore the specific application effects of supply chain management and system dynamics in engineering cost management through case analysis, so as to provide practical support for theoretical research.

3. Integrating new technologies: With the development of new technologies such as Building Information Modelling (BIM) and the Internet of Things (IoT), future research can explore how these technologies can be combined with supply chain management and system dynamics to further improve the efficiency and accuracy of cost management.

4. Interdisciplinary research: It is suggested that future research can start from an interdisciplinary perspective, combining knowledge from the fields of economics, management, and engineering to form a more comprehensive research framework for cost management.

5. Policy and management recommendations: Further research can explore government policies and their impact on construction project cost management and put forward corresponding management recommendations to promote the healthy development of the construction industry.

These suggestions will help deepen the research on supply chain management and system dynamics in engineering cost management, promote academic exchanges in related fields, and provide more forward-looking solutions for practice.

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