Research on Cost Control and Management Strategy based on the Whole Life Cycle of Engineering

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Abstract

This thesis focuses on the in-depth study of the whole life cycle cost control of engineering, elaborates the key points of cost control in the key stages of project decision-making, design, bidding, construction and operation and maintenance, and puts forward the systematic management strategy by combining with a large amount of actual case data. The study aims to provide a comprehensive and practical theoretical basis for the engineering construction industry to improve the cost management level and realize cost optimization, and to promote the industry's economic efficiency and sustainable development ability.

Keywords

Engineering Life Cycle, Cost Control, Management Strategy, Cost Optimization.

1. Introduction

1.1. Background and Significance of the Study

Driven by the wave of global economic integration, international trade and capital flows are becoming more and more frequent, bringing new opportunities and challenges to infrastructure construction [1]. At the same time, China is in a critical period of rapid development of new urbanization and infrastructure construction, the "14th Five-Year Plan" clearly puts forward to strengthen the construction of transportation, energy, water conservancy and other major projects, urban rail transit, large-scale commercial complexes, industrial parks and other projects have landed in various places, and the scale of engineering construction continues to expand [2]. According to the National Bureau of Statistics data show that in 2023 the total output value of China's construction industry reached 31.39 trillion yuan, a year-on-year growth of 6.5%, the number of projects has also shown a year-on-year growth trend. However, behind the prosperous construction scene, the problem of uncontrolled costs is becoming more and more serious. China Construction Industry Association research data show that China's annual cost control failure leads to project overruns accounted for more than 40% of the project, part of the large-scale project overruns even more than 30%. For example, the subway construction project in a provincial capital city, due to inadequate preliminary geological survey, frequent design changes and poor management during construction, the actual construction cost exceeded the budget by 35%, which not only caused a huge waste of funds, but also led to delays in the project schedule, and negatively impacted the improvement of urban transportation [3]. The traditional cost management model often focuses on the construction phase, only focusing on direct costs such as construction material procurement and labor expenses, and ignoring the cost control of project decision-making, design, bidding, operation and maintenance phases [4]. This one-sided management approach makes the project lack systematic cost planning and control throughout the life cycle, and it is difficult to cope with market fluctuations, policy changes and other uncertainties, which substantially increases the risk of cost loss.

From the micro enterprise level, effective cost control of the whole life cycle of the project is the key to the survival and development of the enterprise [5]. In the fierce market competition environment, the profit space of construction enterprises is constantly compressed, through accurate cost control, enterprises can reduce project costs, improve the level of profit, so as to win the bidding competition with more advantageous prices and enhance market competitiveness. For example, a well-known construction company introduced the concept of whole life cycle cost management, through the optimization of the program in the design phase, the construction phase of the refined management, the operation phase of the energy saving and efficiency measures, making a number of project costs reduced by an average of 12%, which significantly improved the economic efficiency of the enterprise and the industry's reputation [6]. From the macro social level, strengthening the cost control of the whole life cycle of the project is of great significance to optimize the allocation of social resources and promote the high-quality development of the industry. Reasonable cost control can reduce the waste of resources, put limited funds, manpower and material resources into more needed projects, and improve the efficiency of resource utilization [7]. At the same time, full life-cycle cost control requires full consideration of environmental factors at all stages of the project and the use of green technology and materials, which helps to realize the coordination and unity of economic development and environmental protection, and promotes the transformation of the engineering and construction industry in the direction of greening and sustainability. In addition, standardized cost management can also promote the healthy development of the construction market, reduce contract disputes and project quality problems caused by cost loss, maintain market order, and safeguard social public interests.

1.2. Research Status

In the research field of project life cycle cost control, foreign countries started earlier and had fruitful results. 1970s, the U.S. Department of Defense took the lead in applying the concept of life cycle cost management (LCCM) to military equipment procurement and maintenance projects, through systematic analysis of the cost of equipment from research and development, production, use to the end of the whole process, to realize the efficient allocation of resources. Subsequently, this concept was gradually extended to the civil engineering field. In the 1980s, the United Kingdom incorporated Life Cycle Cost Analysis (LCCA) into the standard process of public works construction, and through the establishment of a standardized cost assessment model, the cost of each stage of the project is predicted and controlled. For example, in highway construction projects in the UK, the LCCA method is used to optimize the selection of pavement materials, which reduces the whole life cycle cost by 15%-20% under the premise of ensuring the service life of the road.

In the 21st century, foreign scholars continue to innovate in theories and methods. German scholars have proposed a dynamic management system of whole life cycle cost based on BIM technology, which realizes the in-depth correlation between cost data and building components through the establishment of a three-dimensional information model, so that the cost information can be shared and updated in real time in the design, construction, and operation phases, which significantly improves the efficiency of cost control. American scholars further introduce Monte Carlo simulation, genetic algorithm and other quantitative analysis methods into the whole life cycle cost risk assessment, through a large number of simulation calculations, quantify the degree of impact of risk factors on costs, and provide scientific basis for the development of risk response strategies. Domestic research on the whole life cycle cost control of engineering began in the 1990s, and with the rapid development of the construction industry, the relevant research has been gradually deepened. Early research focused on the introduction and digestion of foreign theories, and after entering the 21st century, domestic scholars began to innovate by combining with local engineering practice. For large-scale public building projects, a group from Tsinghua University has constructed a "target - process - feedback" trinity of whole life cycle cost control model, which realizes the refined management of cost by setting cost targets, decomposing control nodes, and monitoring feedback in real time. In terms of practical application, the Shanghai Center Tower project uses the concept of whole-life cost management, adopts green building technology to reduce operational energy consumption in the design phase, and shortens the construction period and reduces labor costs through assembly construction technology in the construction phase, ultimately realizing a whole-life cost saving of about 8%.

Although many achievements have been made in this field at home and abroad, there are still obvious shortcomings in the existing research [8]. For one thing, the details of cost control in the pre-decision stage and operation and maintenance stage of a project are not explored deeply enough. For example, in the decision-making stage, some studies lack systematic identification of risk factors, which leads to large deviation in investment estimation; in the operation and maintenance stage, there are fewer studies on dynamic prediction methods for equipment renewal, energy consumption and other costs. Second, the management strategy lacks systematic integration. Most studies only propose control measures for a single stage or a certain type of cost, failing to form a management system that covers the whole life cycle and synergizes all stages. Third, there is a lag in the application of new technologies. Although BIM, big data and other technologies have been gradually applied to cost control, how to deeply integrate these technologies with the cost management process to realize intelligent and automated cost control still needs further exploration.

2. Theoretical Basis of Engineering Full Life Cycle Cost Control

2.1. Engineering Full Life Cycle Concept Definition

The whole life cycle of engineering is a systematic and dynamic concept, which regards engineering construction projects as an organic whole, covering the whole process from the conception of the project to the final retirement, including project decision-making, design, bidding, construction, operation and maintenance, and disposal of the six major stages of the end-of-life. Each stage has unique core tasks and management objectives, but also intertwined with each other, layer by layer, the effectiveness of the management of any stage will have a chain reaction on the subsequent stages and the overall project cost, quality and schedule. Engineering life cycle stages are closely linked, the former stage to lay the foundation for the latter stage, the latter stage is the continuation of the previous stage and implementation. For example, the decision-making stage to determine the project positioning and scale, directly determines the direction of the design phase of the program and cost limits; the results of the design phase is the bidding and construction phase of the basis; and construction quality affects the operation and maintenance phase of the cost of expenditure. Therefore, only by establishing the concept of whole life cycle cost control and coordinating the work of each stage can we realize the optimization of project cost and maximization of benefits.

2.2. Project Life Cycle Cost Composition

The whole life cycle cost of the project consists of direct cost, indirect cost, intangible cost and special cost. Direct costs include materials, labor, equipment and other costs; indirect costs cover management costs, financial costs, etc.; intangible costs such as environmental impact, social reputation, etc.; special costs include unforeseen costs, risk loss, etc [9]. For example, Table 1 shows the proportion of the whole life cycle cost composition of a residential project.

Table 1. Composition of the total life cycle cost of a residential project

Cost Category	Percentage	Main content
Direct Cost	65%	Construction materials, construction personnel wages, construction equipment rental, etc.
Indirect Costs	20%	Salaries of project management personnel, office expenses, financial interest, etc.
Intangible costs	8%	Management of construction impacts on the surrounding environment, maintenance of the project's social image, etc.
Special costs	7%	Losses caused by natural disasters, additional costs for design changes, etc.

2.3. Theory of Cost Control

1) Target Cost Management Theory: Guided by market demand, target cost is determined in the early stage of the project and decomposed to each stage and each department to ensure that the target is realized through the whole process of control. The formula for calculating target cost is: target cost = market acceptable price− target profit. Subsequently, this target cost will be further decomposed into various aspects such as design, construction and procurement.

2) Value Engineering Theory: Through the systematic analysis of function and cost, the necessary function of the product or operation can be realized at the lowest total cost and the value can be increased. The formula for value is:$V = \frac{F}{C}$, where V stands for value, F stands for function, and C stands for cost.

3) Cost-benefit analysis theory

comparing cost inputs and benefit outputs, selecting the program with optimal cost-effectiveness, and providing a basis for decision-making. Commonly used evaluation indicators include net present value (NPV) and internal rate of return (IRR). The formula for calculating NPV is $NPV = \sum_{t=0}^{n} \frac{(CI-CO)_t}{(1+i)^t}$, where CI is the cash inflow, CO is the cash outflow, i is the benchmark discount rate, t is the time, and n is the project life period.

3. Key Points of Cost Control in Each Stage of the Whole Life Cycle of the Project

3.1. Project Decision-Making Stage

In the project decision-making stage, the effectiveness of cost control plays a decisive role in the cost of the whole life cycle of the project, and decision-making errors in this stage often lead to subsequent costs that are difficult to recover. The project decision-making stage needs to comprehensively consider the policy guidance, market demand, technical feasibility and other factors, the necessity of project construction, feasibility and economy for a comprehensive demonstration. The core task of this stage is to prepare a scientific and reasonable project proposal and feasibility study report to clarify the project's functional positioning, construction scale, technical programs and investment estimates [10]. As a key link in the decision-making stage, the accuracy of investment estimation is directly related to the financing of the project and the setting of cost control targets. Commonly used investment estimation methods include analogical estimation method, parametric estimation method and detailed estimation method, etc. Different methods are applicable to different phases of the project, for example, analogical estimation method is commonly used in the conceptualization phase of the project in the preproject stage, and it is estimated by referring to the cost data of similar completed projects combined with the characteristics of the current project, although the error range is large, about ±25%, but it can quickly provide the project with the preliminary concept of cost. While the detailed estimation method is applicable to the construction drawing design stage, the error can be controlled within ±5% by detailed calculation of each item of the project. At the same time, the decision-making stage of the project also needs to carry out a comprehensive risk assessment, identify potential risk factors such as policy changes, market price fluctuations, technical difficulties, etc., and use the risk matrix, sensitivity analysis and other methods to assess the probability of risk and the degree of impact, and formulate the corresponding risk response plan. For example, in the decision-making stage of a city rail transit project, through sensitivity analysis, it was found that the fluctuation of steel price had a significant impact on the project cost, so a certain proportion of the reserve cost of price difference was set aside in the investment estimation, and a long-term strategic cooperation agreement was signed with the steel supplier, which effectively reduces the cost risk of the rising steel price. In addition, the construction plan comparison is also an important means of cost optimization in the project decision-making stage. Through the technical and economic analysis of different technical solutions, construction scale and site layout, the cost-benefit analysis, value engineering and other methods are used to select the plan that can meet the functional requirements of the project and achieve the optimal cost, so as to lay a solid foundation for the cost control of the whole life cycle of the project.

3.2. Project Design Stage

The project design stage is the key link to transform the conception of the decision-making stage into a specific implementable program, which plays an important role in the whole life cycle cost control of the project. This stage needs to meet the functional requirements of the project, quality standards and specifications under the premise of full consideration of cost factors, through scientific and reasonable design optimization to achieve cost control objectives. Limit design as the core means of cost control in the design stage requires the designers to take the investment estimate as the upper limit, decompose the cost target to each specialty, each unit project and branch project, and strictly control the design estimate not to exceed the investment estimate while guaranteeing the design quality and function. For example, in the design of a high-rise residential project, the cost target of civil engineering was decomposed into foundation works, main structure, decoration and other division works, and the designers reduced the cost of civil engineering by 12% by optimizing structural selection, reasonably determining the height of the floor and the size of the opening and other measures. The application of value engineering further enhances the cost control effect in the design stage. Through the systematic analysis of project functions, it clarifies the necessary and unnecessary functions, and eliminates or simplifies the unnecessary functions under the premise of guaranteeing the necessary functions, so as to reduce the cost. For example, in the public area design of a commercial complex, value engineering was applied to analyze the ceiling decoration scheme , removing overly complex decorative shapes, and saving about 8% of the cost of decorative materials without affecting the aesthetics of the space and the use of functions. In addition, design change management is also an important content of cost control in the design stage, design changes often lead to construction cost increase, schedule delays, so we need to establish a strict design change approval process, the necessity of change, technical feasibility and economic rationality for a comprehensive assessment.

3.3. Project Bidding Stage

As a key link in the construction process, the bidding stage of the project has a far-reaching impact on the whole life-cycle cost of the project. The cost composition of this stage not only involves the direct capital investment in project construction, but also covers the hidden costs that may be triggered by the mismanagement of the bidding process. During the preparation of bidding documents, the bill of quantities needs to be accurately accounted for, and any omission or miscalculation may lead to an increase in the cost of the construction phase. At the same time, the development of contract terms is also critical, the terms of the price adjustment mechanism, payment methods, breach of contract liability, etc., is directly related to the subsequent implementation of the project in the process of cost risk. Bid evaluation and finalization also contains cost control points. Different bid evaluation methods will lead to different winning results, thus affecting the project cost. Reasonably low price method may reduce the quality of the project due to excessive pursuit of low price and increase the maintenance cost in the later stage; although the comprehensive assessment method can take into account the quality, technology, price and other factors, but the evaluation process is complicated, which may produce higher bid evaluation costs. In addition, the management costs in the bidding process, such as bidding agent fees, bid evaluation expert fees, site rental costs, etc., also form part of the cost of this stage.

3.4. Project Construction Stage

The project construction stage is the core stage of the formation of the engineering entity, and is also the key period of large input of resources and concentration of costs, and the effectiveness of its cost control is directly related to the realization of the cost objectives of the whole life cycle of the project. In this stage, the advantages and disadvantages of construction organization design play a decisive role in cost control. Scientific and reasonable construction organization design can effectively reduce costs by optimizing the construction sequence, reasonably deploying manpower and mechanical equipment, and shortening the construction period. Only from the construction organization, change management, cost accounting and other multi-dimensional fine control, in order to effectively control the cost of the construction phase, to lay a solid foundation for the optimization of the project life cycle cost.

4. Engineering Full Life Cycle Cost Control Management Strategy

4.1. Organization Management Strategy

Scientific organizational management is the core guarantee of project life cycle cost control. Enterprises need to build a cost control-oriented multi-level organizational structure, set up by the project leader, covering the design, construction, procurement, finance and other key members of the cost control leading group, the overall coordination of cost management. The leading group is responsible for formulating cost control objectives, approving major cost decisions, and holding regular cost analysis meetings to supervise the implementation of costs at all stages. At the same time, clarify the specific responsibilities of each department in cost control to form a management system with clear responsibilities. For example, the design department needs to reduce the cost by optimizing the design scheme under the premise of meeting the functional requirements; the construction department needs to strictly implement the construction plan and control the material loss and labor cost; and the purchasing department needs to reduce the cost of material purchasing by comparing the suppliers and centralized purchasing. A large construction company through the establishment of the "company - project department - operation team" three-tier cost management system, the cost index breakdown to the individual, to achieve full participation in cost control, the average project cost reduction of more than 10%, significantly improving the cost management effectiveness of the enterprise.

4.2. Technology Management Strategy

Technological innovation is the key driving force to enhance the level of cost control throughout the life cycle of the project. In the application of information technology, digital tools represented by Building Information Modeling (BIM) are playing an important role, and BIM technology realizes automatic calculation of project quantity and real-time dynamic simulation and monitoring of cost by establishing a three-dimensional visualization model and integrating the geometric information, material information and cost data of each stage of the project. According to the statistics of China Construction Industry Association, projects applying BIM technology can reduce design changes by 25% in the design stage, and through collision detection and construction simulation in the construction stage, it can reduce rework costs by 18% and save the construction period by 11%, as shown in Fig. 1a. At the same time, the application of BIM technology in project management is extensive and in-depth, research data show that in the project planning stage, about 82% of enterprises will use BIM technology for site analysis and program selection; in the construction management process, 75% of the projects with BIM to achieve progress simulation and resource optimization. In the operation and maintenance phase, 68% of buildings use BIM models to establish equipment management systems and realize whole-life asset tracking, as shown in Fig. 1b.

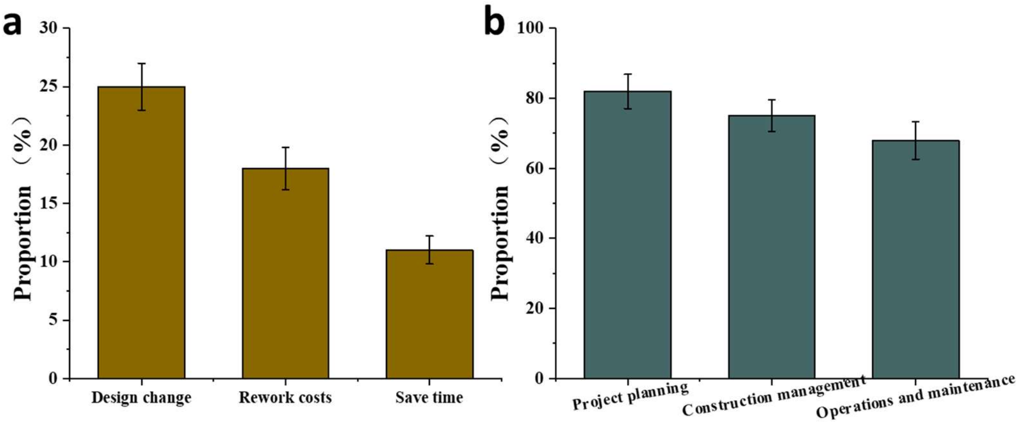

Fig.1 (a) Efficiency Improvement of BIM Technology (b) Improvement of Resource Optimization by BIM Technology in Each Stage

4.3. Contract Management Strategy

The contract is a legal document that regulates the rights and obligations of all parties involved in the construction of the project, and it is also an important basis for cost control. In the stage of contract terms preparation, it is necessary to focus on the price adjustment mechanism, payment methods, change claim terms and other contents. For projects with a long construction period, a dynamic adjustment formula for material prices should be set up, agreeing that when the price fluctuations of steel, cement and other major materials exceed a certain range, the contract price can be adjusted to avoid market price risks. The data of International Federation of Consulting Engineers (FIDIC) shows that the cost overrun caused by material price fluctuation in projects without price adjustment clause reaches 8%-12% of the total contract price on average; and the cost fluctuation can be controlled within 3% in projects with reasonable setting of dynamic price adjustment formula.

4.4. Risk Management Strategy

The engineering construction project has a long cycle and many influencing factors, and risk management runs through the whole life cycle, which is crucial for cost control. In the risk identification stage, the Delphi method and brainstorming method are adopted to organize industry experts and project team members to comprehensively sort out policy risks, market risks, technical risks, natural risks, etc., and establish a detailed risk list. For example, in overseas projects, it is necessary to focus on identifying risks such as exchange rate fluctuations and unstable political situation; in water conservancy projects, it is necessary to pay attention to natural risks such as floods and geological disasters. In the risk assessment link, risk matrix, sensitivity analysis and other methods are used to quantify the probability of risk occurrence and the degree of influence, and determine the risk level. Differentiated response strategies are developed for different levels of risk. For high-risk events, risk avoidance or transfer strategies are prioritized, such as purchasing engineering insurance and signing fixed lump-sum contracts; for medium and low-risk events, strategies such as risk mitigation and risk retention are used to reduce losses by optimizing the construction plan and reserving risk reserves.

5. Conclusion and Prospect

This thesis systematically elaborates the key points and management strategies of cost control in the whole life cycle of the project, and verifies its effectiveness through case studies. It clarifies the focus of cost control at each stage and puts forward multi-dimensional management strategies such as organization, technology, contract, risk, etc. to provide comprehensive guidance for engineering cost control. The study has the shortcomings of limited case selection and insufficient in-depth research on the application of emerging technologies in cost control. In the future, the scope of the study can be expanded to deeply explore the application of artificial intelligence, big data and other new technologies in the cost control of the whole life cycle of the project, and further improve the cost control theory and method system.

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