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The Cost Control Strategy of Geotechnical Engineering Project throughout Its Life Cycle

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Abstract: In geotechnical engineering projects, life cycle cost control is the core of improving project economic benefits and sustainability. This paper constructs an optimized life cycle cost (LCC) analysis model, clarifies the key factors affecting project costs, including geological conditions, construction technology, material costs, and labor costs, and combines dynamic programming and optimal control theory to dynamically optimize project costs and build a cost control framework for the entire life cycle. The study proposes a systematic cost control strategy throughout the four stages of design, construction, operation and termination, including specific measures for each stage, while effectively dealing with uncertainties by introducing risk management methods. Through case studies and empirical analysis, key indicators such as resource allocation efficiency, benefits and returns, and initial investment costs of 10 typical geotechnical engineering projects before and after optimization are compared. The results show that the optimization measures significantly improved the resource allocation efficiency and investment return rate of the projects, with the average resource allocation efficiency increased by 39.6% and the comprehensive income and return indicators increased by about 19.81%. The initial investment costs generally decreased, with the cost of Project 1 dropping from 8 million yuan to 7.2 million yuan, and the cost of Project 3 dropping by 8.57%. Research shows that the implementation of the life cycle cost control model effectively improves the economic benefits of geotechnical engineering projects and has strong application prospects and promotion value.

1. Introduction

In geotechnical engineering projects, cost control has gradually become a key issue in project management. Its core goal is to maximize economic benefits at all stages of the project through reasonable resource allocation and cost optimization. However, the life cycle cost of geotechnical engineering projects is affected by many complex factors, such as differences in geological conditions, technical requirements of construction technology, fluctuations in material and labor costs, etc. These factors not only increase the difficulty of project cost control but also make it difficult for traditional cost management methods to fully cope with the complexity and dynamic changes of each stage of the project. At the same time, with the deepening of the concept of sustainable development, how to balance environmental protection and resource conservation while ensuring economic benefits has become the main challenge of cost control in geotechnical engineering projects. Therefore, exploring scientific and feasible cost control methods is not only of great theoretical significance but also provides important guidance and support for the implementation of actual projects.

In view of the shortcomings of existing research, this paper focuses on key influencing factors such as geological conditions and constructs an optimization model based on life cycle cost (LCC) analysis to improve the economic benefits of geotechnical engineering projects throughout their life cycle. Different from traditional research that only focuses on cost control at a certain stage, this paper integrates cost optimization into the four stages of design, construction, operation and termination, and dynamically optimizes project costs by combining dynamic programming and optimal control theory. In addition, this paper also introduces risk management methods to effectively deal with the impact of uncertainty factors in geotechnical engineering projects. Based on case studies and empirical analysis, this paper not only quantifies the economic benefits of optimization measures but also verifies the feasibility and reliability of the model in practice, filling the gaps in existing research in practical application and data accuracy.

In the second part, this paper introduces the key theories and analytical framework of life cycle cost control of geotechnical engineering projects in detail, and defines the core variables and model construction ideas used in the study; the third part focuses on the cost optimization strategy based on dynamic programming and optimal control theory, as well as specific measures in the design, construction, operation and termination stages; the fourth part verifies the actual effect of the model through case studies of 10 typical geotechnical engineering projects, and compares and analyzes the key indicators before and after optimization; the fifth part summarizes the main conclusions of this study and looks forward to the practical application potential and future development direction of the model in the field of geotechnical engineering.

2. Related Work

In geotechnical engineering projects, the study of life cycle cost control strategies is becoming increasingly important to improve the economic efficiency and sustainability of the projects. These studies explored effective cost control methods and tools. Lu et al. systematically reviewed the methods of integrating BIM with LCCA to improve the economic sustainability of buildings [1]. Riekstins et al. developed a tool that integrated economic (life cycle cost analysis) and environmental (life cycle assessment) analysis and compared full-depth road construction. They found that full-depth regeneration technology can significantly reduce emissions and costs compared to full-depth removal and replacement [2]. Miraj et al. evaluated the feasibility of green certified office buildings in Indonesia by comparing life cycle costs and proposed a cost-benefit ratio [3]. Messore et al. proposed a comprehensive probabilistic framework based on life cycle cost for seismic risk assessment of spatially distributed aging bridge networks [4]. Lee et al. proposed a preliminary estimation method based on BIM with a detail level below 2 and actual construction cost data to support decision-making in the early design stage [5]. Wang et al. compared the application of three advanced oxidation processes (Fe^{2+}/H_2O_2, $Fe^{2+}/Ca(ClO)_2$ and $Fe^{2+}/Na_2S_2O_8$) with traditional conditioning agents (Fe^{3+}/CaO) in sludge dewatering through life cycle assessment (LCA) and life cycle cost (LCC) [6]. The multi-objective framework proposed by Omidian and Khaji provided a systematic approach for decision makers to select the best retrofit strategy that can minimize life cycle costs while meeting a given level of resilience, among which various retrofit strategies can be selected [7]. Fan et al. used life cycle assessment and life cycle cost methods to analyze the environmental impact and economic cost of food waste treatment technology [8]. Kerdlap et al. combined life cycle costing and hybrid simulation modeling to compare the net present value of a small-scale distributed system with a large centralized system for sorting and recycling discarded plastic bottles and takeaway containers in Singapore over a seven-year period [9]. Karami et al. studied the optimization of nonlinear viscous dampers to reduce the life cycle cost of the structure and improve the seismic performance [10]. However, existing research still has shortcomings in practical application and data accuracy, and fails to fully consider the impact of different geological conditions. The innovation lies in proposing a more systematic cost control framework, which provides a practical solution for the full life cycle management of geotechnical engineering projects.

3. Methods

3.1 Construction of the Full Life Cycle Cost Control Model

The construction of the full life cycle cost control model aims to optimize the overall economic benefits of geotechnical engineering projects[11]. In the process of model construction, the key factors that affect the project cost must be identified first. Through quantitative analysis[12], the main cost sources of each stage are identified, thus forming a model framework and laying the foundation for subsequent analysis. By using the life cycle cost analysis method, the long-term operation and maintenance costs of the project are predicted, compared and optimized with the overall budget. At the same time, combined with mathematical tools such as dynamic programming and optimal control theory, various costs throughout the life cycle of the project are dynamically optimized[13]. This comprehensive approach not only enhances the scientificity and effectiveness of cost control but also provides decision makers with a basis for real-time adjustments, thereby ensuring that geotechnical engineering projects maximize economic benefits while meeting technical and safety requirements.

3.2 Strategies and Optimization Methods

The core of geotechnical project cost control is to adopt a progressive cost control strategy [14]. In the project design phase, the main focus is on optimizing the plan and preparing the budget; in the construction phase, it is necessary to strengthen the synchronous management of progress and cost; and in the operation phase, it is necessary to optimize maintenance and operation costs through regular maintenance and efficient operation management, thereby reducing long-term operating expenses. In addition, cost control of risk factors is also crucial. Based on this, flexible response measures must be designed for the inherent uncertainties in geotechnical projects. Through risk matrix and sensitivity analysis, the impact of various risks on project costs is evaluated, and the control strategy is adjusted in a timely manner according to the evaluation results to reduce potential economic losses. Optimal resource allocation is one of the most effective means of cost control strategy. By building a resource demand forecasting model, we can ensure that project resources are reasonably allocated and achieve efficient and low-cost utilization of resources at all stages. The introduction of the information support system has realized real-time monitoring and data support for each implementation stage, ensuring that potential cost issues can be discovered and dealt with in a timely manner during the implementation process, thereby improving the economic benefits and sustainability of the project.

3.3 Case Study and Empirical Analysis

In the full life cycle cost control of geotechnical engineering projects, case study and empirical analysis are key steps to verify the effectiveness of theories and strategies. By selecting typical geotechnical engineering projects as cases, we can explore in depth the practical application of cost control throughout the life cycle. For example, we can select a large infrastructure project and analyze in detail the cost control measures in its design, construction, operation and finalization stages. In terms of data collection, by comparing the actual cost of the project with the budget, the cost differences at each stage are identified, and the reasons for cost overruns are analyzed in detail, such as changes in geological conditions [15], construction delays, and fluctuations in material prices. At the same time, it is necessary to evaluate the effectiveness of the implemented cost control measures, such as optimizing the design scheme, strengthening construction management, and improving resource utilization efficiency. Through data analysis, it is possible to identify which strategies are effective in actual operations and which measures fail to achieve the expected goals. This provides valuable experience and lessons for future projects. By summarizing successful cost control strategies and failed experiences, it can provide guidance for subsequent projects and help project teams more effectively control costs in future geotechnical engineering projects, thereby improving economic benefits and sustainability. Table 1 is a life cycle cost control analysis table for geotechnical engineering projects.

Table 1: Life cycle cost control analysis table for geotechnical engineering projects

Project Phase	**Actual Cost (10,000 RMB)**	**Budgeted Cost (10,000 RMB)**	**Cost Variation (10,000 RMB)**	**Reasons for Overrun**	**Effectiveness of Cost Control Measures**
Design Phase	150	120	30	Frequent design changes	Enhanced design review and optimization
Construction Phase	500	450	50	Uncertain geological conditions, rising material prices	Strengthened progress management and resource allocation
Operation Phase	200	180	20	Increased maintenance needs	Established regular maintenance mechanisms
Termination Phase	50	40	10	High costs for site cleanup and equipment recovery	Early planning for resource recovery strategies in the termination phase

4. Results and Discussion

In geotechnical engineering projects, a systematic experimental research framework can be constructed to evaluate the effectiveness of resource allocation efficiency, return on investment, and initial investment cost optimization. First, the initial data of each project is collected, including information such as resource allocation efficiency, return on investment indicators, and initial investment costs before optimization. After the optimization measures are implemented, the improvement effects of the project are continuously tracked and recorded, focusing on observing the changes in resource allocation efficiency, return on investment, and the adjustment of initial investment costs. Based on the collected data, a comparative analysis of various indicators before and after optimization is conducted, and the influence and actual effect of the optimization measures are evaluated to verify their significance and effectiveness. This experimental design aims to provide empirical evidence for the management of geotechnical engineering projects, improve the scientificity and economic benefits of resource allocation, and promote the sustainable development of projects.

4.1 Resource Allocation Efficiency

In geotechnical engineering projects, resource allocation efficiency plays a vital role in project cost control and execution effect. Resource allocation efficiency refers to the ratio between the economic benefits and engineering quality that a project can achieve under a certain resource input. Through efficient resource allocation, waste can be minimized, the engineering cycle can be shortened, and the stability of engineering quality can be ensured. Therefore, formulating a reasonable resource allocation strategy is crucial for the smooth implementation of the project. At the same time, combined with dynamic monitoring of resource usage and combined with construction progress and cost data, resource allocation strategies can be adjusted in a timely manner to cope with possible changes and uncertainties. Figure 1 is an average comparison of ten different geotechnical engineering projects before and after resource allocation efficiency optimization:

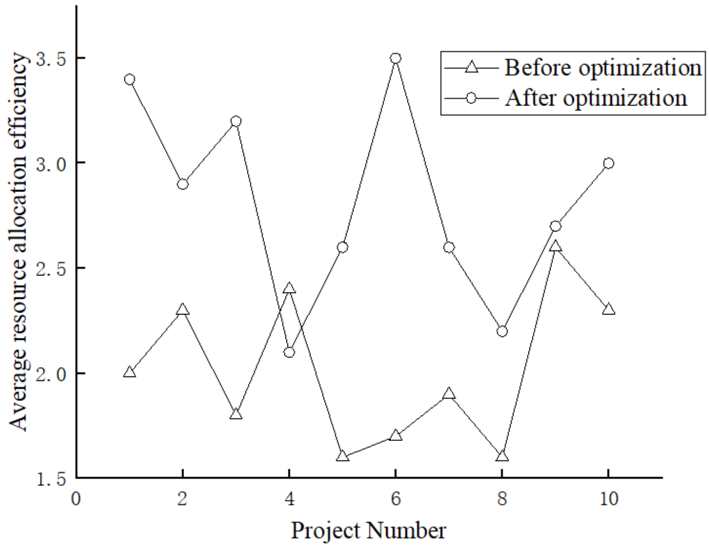

Figure 1: Comparison of average resource allocation efficiency before and after optimization

By analyzing the data in the above figure, we can find that most projects have achieved efficiency improvements after implementing optimization measures. Especially for Project 1 and Project 6, the average resource allocation efficiency is 2 and 1.7 respectively before optimization, while it is significantly improved to 3.4 and 3.5 after optimization, showing the remarkable effectiveness of the optimization measures. This shows that effective strategies in resource management and allocation can significantly improve the economic benefits of the project. However, the situation of Project 4 is relatively special. The average efficiency before optimization is 2.4, but it drops to 2.1 after optimization. This may indicate that the optimization measures do not work as expected in this project, and further analysis of the reasons is needed, such as unreasonable resource allocation or changes in the external environment. In general, although the resource allocation efficiency of most projects has been improved, we still need to pay attention to the negative trends of individual projects. In the future, we should strengthen the evaluation of the effectiveness of the optimization measures of each project to ensure the scientificity and effectiveness of the resource allocation strategy, so as to further improve the overall project management level.

4.2 Benefits and Returns

In geotechnical engineering projects, benefits and returns are the key to measuring the success of the project. Revenue usually refers to the direct economic benefits generated by a project during its life cycle, while return takes into account investment costs, operating expenses and other related expenditures, reflecting the project's economic return level and investment value. Through reasonable benefit and return analysis, project managers can make better decisions to maximize their investments. After implementing optimization measures, the benefits and returns of the project often increase significantly. These optimization measures may include improving construction efficiency, reducing material costs, improving resource allocation, etc. Through these means, not only can the project revenue be increased but also unnecessary expenditure can be reduced, thereby improving the return on investment (ROI). Figure 2 is a comparison of the comprehensive indicators of a geotechnical engineering project before and after optimization (the comprehensive indicator is the ratio of income to return):

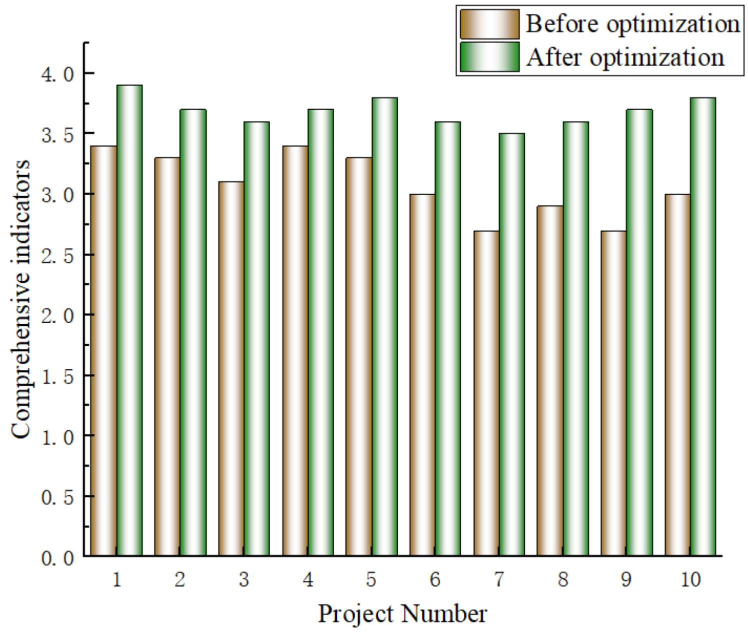

Figure 2: Comparison of comprehensive indicators before and after optimization

By analyzing the comprehensive indicators before and after the optimization of the project number, it can be clearly seen that the comprehensive indicators of all projects have improved. Specifically, the comprehensive indicator of Project 1 has increased from 3.4 to 3.9. The significant increase shows that the optimization effect of this project in terms of revenue and cost control is significant. The comprehensive index of project 5 increases from 3.3 to 3.8, showing a good optimization effect. These projects achieve higher returns on investment by improving construction efficiency, reducing material costs or improving resource allocation. The comprehensive index of Project 7 increases from 2.7 to 3.5, with a significant change. The comprehensive indexes of

Projects 8 and 9 also show good growth, from 2.9 and 2.7 to 3.6 and 3.7, respectively, reflecting the effective improvement of resource allocation and management.

4.3 Initial Investment Cost

In geotechnical engineering projects, the initial investment cost is a key factor affecting the overall economic benefits of the project. The initial investment cost includes land acquisition, design, material procurement, construction and equipment investment. Reasonable control of initial investment costs can not only improve the return on investment but also provide greater financial flexibility for the subsequent operation of the project. By optimizing the design, selecting cost-effective materials, and introducing advanced construction technology, the initial investment cost can be effectively reduced, thus laying the foundation for the long-term benefits of the project. Figure 3 is a comparison of the initial investment cost of a geotechnical engineering project before and after optimization (unit: 10,000 yuan):

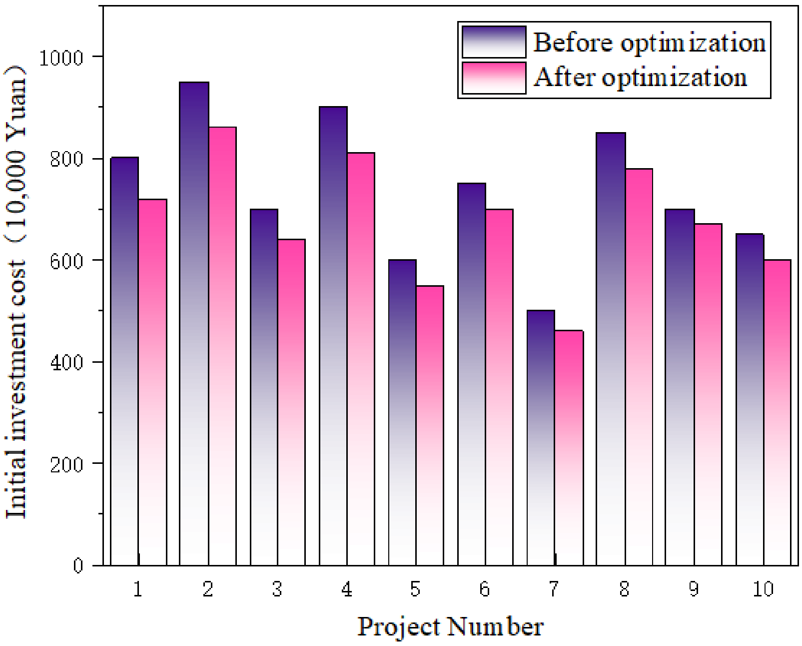

Figure 3: Comparison of initial investment costs before and after optimization

By analyzing the data in the above figure, it is obvious that the initial investment costs of most projects have decreased. The initial investment cost of Project 1 has dropped from 8 million yuan to 7.2 million yuan, showing the effectiveness of the optimization measures. The cost reductions for Project 3 and Project 5 are also significant, from 7 million yuan to 6.4 million yuan and from 6 million yuan to 5.5 million yuan, respectively, indicating that these projects have achieved successful optimization in resource allocation and material procurement. The initial investment cost of Project 7 is reduced from 5 million yuan to 4.6 million yuan. Although the initial cost is low, the effect after optimization is still significant. Although the initial investment costs of Projects 2 and 4 are reduced, the reduction is relatively small, and the room for optimization is limited. The initial investment costs of Project 6 and Project 8 also decrease significantly, from 7.5 million yuan to 7 million yuan and from 8.5 million yuan to 7.8 million yuan, respectively. The reduction in initial investment costs of all projects reflects the successful implementation of optimization measures. In the future, project managers should continue to focus on controlling investment costs to achieve a higher return on investment.

5. Conclusion

This paper constructs an optimization model based on cost analysis, proposes a systematic cost control strategy from the four stages of design, construction, operation and termination, and combines dynamic programming and optimal control theory to effectively improve the overall benefits of geotechnical engineering projects and the rationality of resource allocation. The research results show that the optimization measures have increased resource allocation efficiency by an average of 39.6%, improved comprehensive benefits and returns indicators by 19.81%, and significantly reduced initial investment costs, verifying the practical application value and reliability of the model. The contribution of the research is that it fills the gap that traditional methods fail to fully cover cost control at all stages of the project. At the same time, it innovatively introduces risk management methods to deal with uncertain factors such as geological conditions, providing theoretical support and practical guidance for the field of geotechnical engineering. The practical significance lies in improving the economic benefits of the project while promoting sustainable development. However, there is still room for improvement in the applicability of the model, the diversity of geological conditions and the accuracy of data. In the future, the scope of application of the model can be further expanded, the data analysis method can be optimized, and its versatility and practicality can be enhanced.

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