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# *Research on Engineering Cost Control and Optimization Methods Based on Big Data Technology*

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***Keywords:*** Big Data Technology; Engineering Cost; Cost Control; Data-Driven; Intelligent Management

***Abstract:*** The rise of big data technology has provided a new technological path for engineering cost control and optimization. This study systematically explores engineering cost control and optimization methods based on big data technology, analyzing them from three levels: theoretical foundation, key process optimization, and intelligent realization. At the theoretical level, it clarifies the core characteristics of big data and its application value in engineering management, combs the basic theories and methods of cost control, and constructs a fusion mechanism of big data and cost control. At the process optimization level, from the three dimensions of data collection and integration, improved processing and analysis capabilities, and dynamic monitoring and deviation analysis, it proposes a big data-based cost control process optimization path. At the intelligent realization level, it constructs a multi-factor integrated cost prediction model, establishes an intelligent decision support system for resource allocation, and forms a systematic framework for risk prediction and control strategies. The research shows that big data technology can significantly improve the scientific and refined level of engineering cost control, realize the paradigm shift from experience-driven to data-driven management, and provide theoretical support and practical reference for construction enterprises to promote the digital transformation of cost management.

## 1. Introduction

The continued deepening of the digital transformation in the construction industry is driving profound changes in engineering cost management models. Statistics from the Ministry of Housing and Urban-Rural Development show an exponential growth trend in national engineering cost data[1]. Traditional cost management models are revealing significant limitations when dealing with massive, multi-dimensional data. These include low data utilization rates due to information fragmentation, difficulty in ensuring accurate cost budgets, and increasingly prominent shortcomings in risk control capabilities[2]. The rise of big data technology provides a new technological path to solve the above problems. Through in-depth mining and intelligent processing of structured and unstructured data generated throughout the entire lifecycle of engineering projects, big data technology can reveal the deep-seated patterns and development trends of project costs, and achieve a paradigm shift from experience-driven to data-driven management. Research on engineering cost control and optimization methods based on big data technology is of significant theoretical and practical importance for improving cost prediction accuracy, enhancing process control capabilities, and strengthening risk prediction levels[3].

Scholars at home and abroad have conducted a series of studies on the application of big data in the field of engineering cost. Foreign research has made positive progress in data integration, cost prediction, and risk management and control. Machine learning algorithms have been widely used in historical data analysis, and dynamic early warning systems have been validated in large-scale engineering projects. Domestic research started relatively late, but in recent years, beneficial explorations have been carried out around key issues such as data collection standardization, cost index analysis, and cost deviation identification[4]. However, overall, domestic research still faces several bottlenecks: the lack of unified cost data standards leads to insufficient cross-project data comparability; the depth of data mining is insufficient, and a large amount of engineering information has not been transformed into effective decision support; and the information dynamic update mechanism is unsound, making it difficult for management personnel to keep up with market conditions and adjust control strategies[5]. The shortcomings of existing research provide a clear entry space for this study.

This research focuses on the application methods of big data technology in engineering cost control and optimization. The research content covers three levels: sorting out the theoretical basis of big data technology and engineering cost control, and clarifying the integration mechanism between the two; analyzing the optimization path of key cost control processes based on big data, covering data collection and integration, improvement of processing and analysis capabilities, and dynamic monitoring and deviation analysis; constructing cost optimization strategies and intelligent implementation frameworks, including cost prediction model construction, intelligent resource allocation, and systematic risk prediction. In terms of research methods, the literature research method is used to systematically sort out relevant achievements at home and abroad, the case analysis method is used to deeply analyze the application practices of typical projects, and the method of combining model construction and empirical analysis is used to verify the feasibility and effectiveness of the proposed method. The research is carried out according to the logical context of theoretical review—process optimization—strategy construction, and strives to form research results with theoretical depth and practical guiding value.

## 2. Theoretical Basis

### 2.1 Overview of Big Data Technology

Big data refers to data sets that cannot be captured, managed, and processed using traditional software tools within a short period. Its core characteristics are reflected in scale, diversity, velocity, and value. In the field of engineering management, the application of big data technology has brought revolutionary changes to cost control. Data acquisition technology has evolved from manual input to automatic perception and real-time transmission by sensors, IoT devices, and BIM models. Data storage technology has evolved from stand-alone databases to distributed storage and cloud computing platforms, which has solved the storage and access bottlenecks of massive data. Data processing technology has been upgraded from simple statistical analysis to intelligent algorithms such as machine learning and data mining, which can extract deep-level patterns from complex data. This technological evolution path has laid a solid foundation for the transformation of engineering cost management from experience-driven to data-driven[6].

## 2.2 Basic Theories and Methods of Engineering Cost Control

Engineering cost control refers to a series of management activities carried out by enterprises throughout the entire process of engineering construction, using scientific methods and advanced means to predict, plan, control, account for, analyze, and evaluate engineering costs, with the aim of rationally using construction funds and improving investment benefits. The connotation of cost control is not limited to simple budgeting and monitoring of project expenditures, but emphasizes proactive management of costs through accurate forecasting, real-time monitoring, and dynamic adjustments.

Commonly used cost control methods include six steps: cost forecasting, cost decision-making, cost planning, cost control, cost accounting, and cost analysis. Cost forecasting uses historical data and market trend analysis to provide a basis for budget preparation. Cost decision-making selects the best path from multiple options. Cost planning decomposes goals into actionable indicators. Cost control ensures that execution does not deviate through process monitoring. Cost accounting collects all actual expenses incurred. Cost analysis reveals the causes of deviations and guides subsequent improvements[7].

At the theoretical model level, the whole life cycle cost management model advocates comprehensive consideration and control of the entire life cycle of the project from planning, design, construction, operation to demolition. Activity-Based Costing (ABC) allocates costs to specific construction activities, transforming "calculating costs" after the fact into "managing costs" in advance. Earned Value Management (EVM) achieves coordinated control of cost and schedule by dynamically comparing actual costs with planned costs and the earned value of completed work. Value engineering focuses on the matching relationship between function and cost, and seeks the optimal cost-effectiveness through function analysis.

## 2.3 Integration Mechanism of Big Data and Cost Control

The integration of big data technology and cost control is essentially the construction of a data-driven dynamic management and control system. At the model building level, cost prediction models based on big data utilize historical data and market conditions to accurately predict future costs through regression analysis, time series analysis, machine learning, and other methods, providing data support for project budget preparation. At the risk identification level, clustering analysis and association rule mining are performed on data such as cost indicators, material price fluctuations, and labor cost changes of historical projects to identify key factors and potential risk points affecting costs, providing a basis for risk prediction.

At the dynamic monitoring level, big data technology can collect real-time data on material consumption, machinery usage, and labor input at the construction site through IoT devices, dynamically compare it with budget indicators and historical data, set reasonable early warning thresholds, and automatically identify and warn of abnormal cost points exceeding the range. At the decision support level, through the integrated analysis of multi-source data, a visualized decision support platform is constructed to help managers understand cost composition, grasp changing trends, and evaluate the advantages and disadvantages of solutions, thereby achieving scientific and refined resource allocation[8].

The integration of big data and cost control is not a simple superposition of technologies, but a systematic reconstruction throughout the entire project process. Starting from the project planning stage, it is necessary to collect cost indicators and material information of similar projects. In the design stage, big data is used to optimize material selection and equipment parameters. In the construction stage, BIM models are used for pipeline optimization and cost accounting. In the completion stage, historical data comparison is used to verify the control effect. This full-process data integration mechanism transforms cost control from static, stage-based management to dynamic, continuous management and control, and from reliance on individual experience to reliance on data intelligence, providing theoretical support and technical paths for the development of engineering cost management towards refinement and intelligence.

## 3. Optimization of Key Processes for Engineering Cost Control Based on Big Data

### 3.1 Optimization of Data Collection and Integration Mechanisms

The effectiveness of engineering cost control is highly dependent on the completeness, accuracy, and timeliness of basic data. In the traditional model, data collection relies on manual reporting and periodic summarization, resulting in significant information lag, and the various participants use different data formats and standards, forming serious data silos. Optimizing the data collection and integration mechanism has become the primary task of enabling cost control with big data.

In terms of multi-source heterogeneous data collection, modern engineering technology provides a wealth of automated collection methods. The BIM model carries geometric information, material information, and cost information of the design stage, and is an important source of cost data. IoT devices and sensors can collect real-time on-site data during construction, such as concrete temperature, steel consumption, and mechanical running time. Mobile terminals and cloud platforms enable immediate uploading of on-site visas, design changes, and material entry. Drone patrols and image recognition technology can be used for earthwork measurement, progress estimation, and other scenarios. The comprehensive application of these technologies transforms data collection from discrete point records to continuous streaming perception.

Data standardization processing is the core component of the integration mechanism. Data from different sources differs in format, units, accuracy, timestamps, and other aspects, and must be cleaned, transformed, and aligned before it can enter a unified database. Specifically, this includes: a unified material coding system and classification standards to ensure the comparability of the same material in different projects; standardizing the collection frequency and time labels of time-series data to support dynamic comparative analysis; establishing data quality verification rules to automatically identify and correct outliers and missing values. The construction of a unified database adopts a distributed storage architecture, which classifies and stores structured and unstructured data, and realizes the interconnection of various business systems through data interfaces.

In response to practical problems such as untimely information collection and inconsistent data standards, a collaborative solution should be adopted from both institutional and technical levels. At the institutional level, the data reporting responsibilities and time limit requirements of all participants should be clarified, and the data quality should be incorporated into contract terms and assessment systems. At the technical level, we could establish a unified data exchange platform, formulate standardized data interface specifications, and realize automatic data synchronization between different software systems. Through the above optimizations, a dynamic database covering the entire life cycle of the project is formed, laying a solid foundation for subsequent analysis and control.

### 3.2 Enhancing Data Processing and Analysis Capabilities

Unlocking the value of massive data sets hinges on efficient processing technologies and in-depth analysis methods. Traditional data processing methods struggle to cope with the scale and complexity of engineering data, necessitating the introduction of advanced computing frameworks and intelligent algorithms to comprehensively enhance data processing and analysis capabilities.

Distributed computing technology serves as the foundational support for processing massive engineering data. The data volume generated by engineering projects has progressed from the GB level to the TB level and even the PB level, rendering single-machine processing capabilities inadequate. Utilizing distributed computing frameworks such as Hadoop and Spark, large-scale data is decomposed into multiple sub-tasks for parallel processing, significantly improving computational efficiency. Stream processing technology enables continuous computation of real-time data, meeting the needs of dynamic monitoring at construction sites. Cloud computing platforms provide elastic computing resources, dynamically adjusting computing power configurations based on data volume changes, thereby avoiding resource wastage.

Machine learning algorithms are playing an increasingly important role in cost data analysis. Regarding cost factor identification, association rule mining uncovers the inherent relationships between material prices, labor costs, and construction techniques, revealing the driving factors behind cost variations. In terms of anomaly detection, cluster analysis is used to identify cost data points that deviate from the normal range, aiding in the localization of management loopholes or potential risks. Concerning pattern recognition, deep learning models extract typical cost composition patterns from historical projects, providing reference benchmarks for new projects.

Regression analysis and time series methods are classic tools for cost prediction, experiencing renewed vitality in the big data environment. Multiple regression models can quantify the quantitative relationships between various influencing factors and costs, identifying key variables and measuring their impact. Time series analysis, through trend decomposition, cycle identification, and fluctuation analysis of historical cost data, constructs autoregressive moving average models or seasonal autoregressive integrated moving average models, enabling short-term forecasting of future costs. Combining these two types of methods considers both the mechanism of action of influencing factors and captures the evolution patterns of the time dimension, significantly improving prediction accuracy. In practical applications, appropriate methods can be selected for different cost items such as material prices, labor costs, and machinery expenses to build differentiated prediction models.

## 4. Optimization Strategies and Intelligent Implementation of Engineering Cost Based on Big Data

### 4.1 Construction and Optimization of Cost Prediction Models

Cost prediction is the starting point of engineering cost control, and its accuracy directly determines the scientific nature of budgeting and the effectiveness of subsequent control. The cost prediction model based on big data significantly improves the accuracy and adaptability of prediction through in-depth mining of massive historical data and comprehensive consideration of multi-dimensional factors.

The design of cost prediction models should integrate a variety of analysis methods. Time series analysis is suitable for cost subjects with stable trends. By decomposing the trend and identifying the cycle of historical cost data, a differential autoregressive moving average model is constructed to achieve short-term prediction of material prices, labor costs, and other data. Regression analysis focuses on the causal relationship between cost and influencing factors, and uses project characteristics, regional differences, and market environment as independent variables to establish a multiple linear regression model, quantifying the impact of each factor on the cost. The introduction of machine learning algorithms further improves the prediction ability. Methods such as random forest and gradient boosting tree can handle high-dimensional data and non-linear relationships, and exhibit higher prediction accuracy in complex scenarios.

Multi-factor integration is the key to improving the practicality of the prediction model.

Engineering cost is affected by multiple factors, and a single model can hardly fully capture its complex laws. The study organically combines the time dimension, spatial dimension, and project characteristic dimension: the time dimension reflects price fluctuations and market trends, the spatial dimension reflects regional differences and resource endowments, and the project characteristic dimension covers individual factors such as building type, structural form, and construction period requirements. By constructing a mixed model or integrated learning framework, the three types of factors are incorporated into the prediction system to achieve deep integration of multi-dimensional information. For example, in material price forecasting, variables such as historical price trends, regional market supply and demand, and seasonal fluctuations are considered simultaneously, which significantly improves the accuracy of the prediction.

## 4.2 Intelligent Resource Allocation and Decision Support

The degree of optimization of resource allocation directly affects the control effect of engineering cost. The resource allocation system based on big data constructs an accurate resource demand prediction model through in-depth analysis of historical project resource consumption data, and realizes dynamic allocation and intelligent optimization of labor, materials, and mechanical equipment.

The construction of the resource demand prediction model is based on historical data, combined with project characteristics and construction organization plans, to predict the resource demand in each construction stage. Labor demand prediction considers factors such as the structure of labor types, the size of the work surface, and the arrangement of the construction period; material demand prediction focuses on variables such as consumption quotas, procurement cycles, and inventory costs; mechanical demand prediction focuses on factors such as equipment type, operating efficiency, and rental costs. Cluster analysis is used to identify the resource consumption patterns of similar projects, providing a reference benchmark for new projects; regression analysis is used to quantify the impact of key factors on resource demand, improving prediction accuracy.

The intelligent decision support system integrates the prediction model and optimization algorithm into a unified platform to provide a scientific basis for resource allocation. The core functions of the system include scheme comparison, cost-benefit analysis, and dynamic adjustment. At the scheme comparison level, multiple resource allocation schemes are generated for the same construction task, simulating the cost composition and construction period impact of each scheme, and assisting managers in selecting the optimal path. At the cost-benefit analysis level, the resource input and output effects are correlated and analyzed to identify efficiency bottlenecks and improvement space in resource utilization. At the dynamic adjustment level, the system tracks the on-site resource consumption in real time, compares it with the predicted value, and automatically generates adjustment suggestions after discovering deviations, realizing dynamic optimization of resource allocation.

## 4.3 Systematization of Risk Prediction and Control Strategies

Project cost control faces challenges from multiple uncertain factors, including market price fluctuations, design changes, and changes in construction conditions. A big data-based risk prediction system enables early identification, quantitative assessment, and systematic response to risks through in-depth mining of historical risk events and dynamic monitoring of real-time data.

The construction of a high-frequency risk monitoring system relies on the integration of a historical risk database and real-time monitoring data. The historical risk database compiles records of risk events from completed projects, including risk types, occurrence times, impact levels, response measures, and disposal effects. Through cluster analysis and association rule mining of historical data, high-frequency risk types and their typical characteristics are identified, and the precursory signals and evolution patterns of risk occurrence are summarized. Real-time monitoring data comes from IoT devices on the construction site and dynamic updates from business systems. The system compares real-time data with historical risk characteristics, and a warning is triggered immediately upon detection of similar signs.

The integration of project-wide risk identification and response strategies runs through all stages. In the design phase, potential cost risks in the design are identified through risk data analysis of similar projects, assisting in optimizing material selection and equipment parameters. In the bidding phase, real-time analysis based on market data is used to predict material price fluctuation trends, and risk factors are reasonably considered in the quotation. In the construction phase, key risk indicators are monitored in real-time, such as abnormal fluctuations in material prices and labor shortages for key work types. After a warning is triggered, the system pushes response recommendations. In the completion phase, the disposal effects of risk events are summarized and analyzed, and the overall performance of risk management is evaluated to accumulate experience for subsequent projects.

## 5. Conclusion

This study systematically explored engineering cost control and optimization methods based on big data technology. At the theoretical foundation level, it elucidated the core characteristics of big data and its application value in engineering management, reviewed the basic theories and methods of cost control, and constructed a fusion mechanism of big data and cost control. At the key process optimization level, from the three dimensions of data collection and integration, processing and analysis capability improvement, and dynamic monitoring and deviation analysis, it proposed an optimization path of cost control process based on big data, realizing the transformation from periodic inspection to continuous management and control. At the intelligent implementation level, it constructed a multi-factor integrated cost prediction model, established a resource allocation intelligent decision support system, and formed a systematic framework for risk prediction and control strategies.

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