Research on Dynamic Prediction and Intelligent Control of Construction Project Cost Driven by Big Data

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Abstract: Aiming at the problems of data island, dynamic response lag and subjective decision-making in traditional construction project cost management mode, this paper puts forward a dynamic prediction and intelligent management and control scheme based on big data, BIM and IoT (Internet of Things). By integrating multi-source heterogeneous data, the scheme constructs a data center, and establishes a hierarchical intelligent prediction and optimization system by using machine learning and RL (reinforcement learning) algorithms. At the same time, the intelligent management and control system framework of "cloud-edge-end" collaborative architecture is designed to realize the closed-loop management of data perception, analysis, decision-making and execution. The empirical study shows that the scheme can effectively improve the accuracy of cost prediction, realize active and intelligent cost control, and promote the paradigm transition from "experience-driven" to "data-driven" in the construction industry.

1. Introduction

The traditional mode of construction project cost management has structural problems such as data island, lagging dynamic response and subjective decision-making, which leads to general cost overruns and waste of resources. With the popularization of technologies such as BIM and IoT, the construction industry has a massive data base, which provides an opportunity for change [1]; By integrating big data technology and machine learning algorithm, a closed-loop management system integrating perception, analysis, decision-making and feedback is built, which is expected to upgrade the paradigm of cost management from static experience to dynamic intelligence.

Focusing on the problem of insufficient collaboration among data, models and systems in existing cost management research, this study innovatively proposes a heterogeneous data governance system that integrates BIM, IoT (Internet of Things) and big data, designs a dynamic cost optimization method based on RL (Reinforcement Learning), and develops a lightweight terminal that supports edge computing, aiming at building a replicable and extensible intelligent cost management solution and promoting the construction industry to realize the paradigm transition from "experience-driven" to "data-driven".

2. Construction of dynamic cost forecasting model driven by big data

Break through the traditional static estimation model based on historical quota, and build a dynamic prediction model with multi-source heterogeneous big data as input, machine learning as the core and real-time response to project changes (Figure 1).

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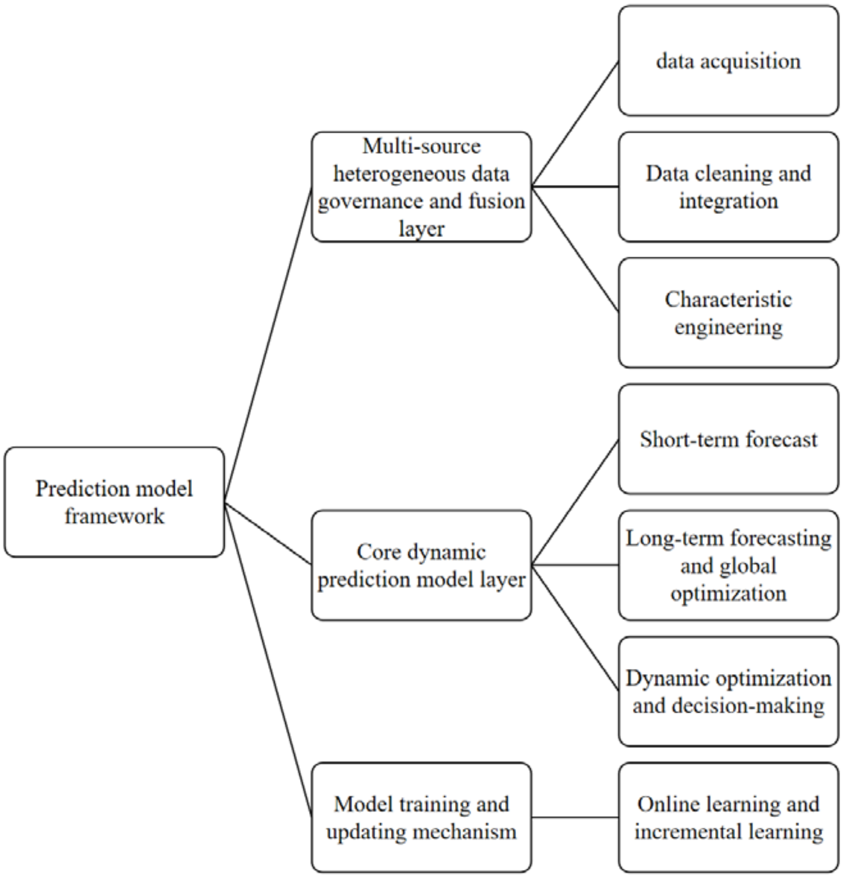

Figure 1 Big data-driven dynamic cost forecasting model framework

This system integrates multi-source heterogeneous data such as BIM model, IoT equipment, ERP system and external database to build a full-link data acquisition system covering the dimensions of engineering quantity, schedule, cost and environment [2]. Based on the idea of data center, ETL/ELT tools, natural language processing and computer vision technology are used to clean, transform and integrate structured and unstructured data, so as to realize the unified storage of multimodal data in the data lake and effectively break the "data island"; Combined with the knowledge of engineering field, feature engineering is carried out, and key features such as schedule deviation, material price fluctuation, equipment utilization rate and design change are extracted, which provides high-quality input for intelligent models and tamps the data foundation.

As the "brain" of the system, the core dynamic prediction model layer constructs a hierarchical intelligent prediction and optimization system. In the short term, the time series model and deep learning network are used to make fine-grained rolling prediction of unit project cost to realize real-time monitoring of cost deviation; In the long run, the macro-attributes and dynamic micro-characteristics of the project are integrated through the integrated learning model to accurately predict the completion cost of each key stage and support the target cost control [3]; The RL framework is innovatively introduced, and the cost decision-making is modeled as a sequence optimization problem. Based on the current project status, the agent learns the optimal resource allocation and scheme adjustment strategy through interaction with the environment, with cost saving and progress reaching the standard as the reward objectives, and realizes the adaptive decision-making optimization in the complex dynamic environment [4-5].

By using online learning and incremental learning technology, the model can continuously absorb the new data generated in real time during the project process, dynamically update parameters and optimize the prediction logic, and ensure that it has the ability to evolve with time, thus maintaining high-precision prediction performance throughout the project life cycle.

3. Framework design of intelligent management and control system

In order to realize the application of the above model, this study designs a closed-loop intelligent management and control system framework which integrates perception, analysis, decision-making and execution, and its core is the "cloud-edge-end" collaborative architecture (Figure 2).

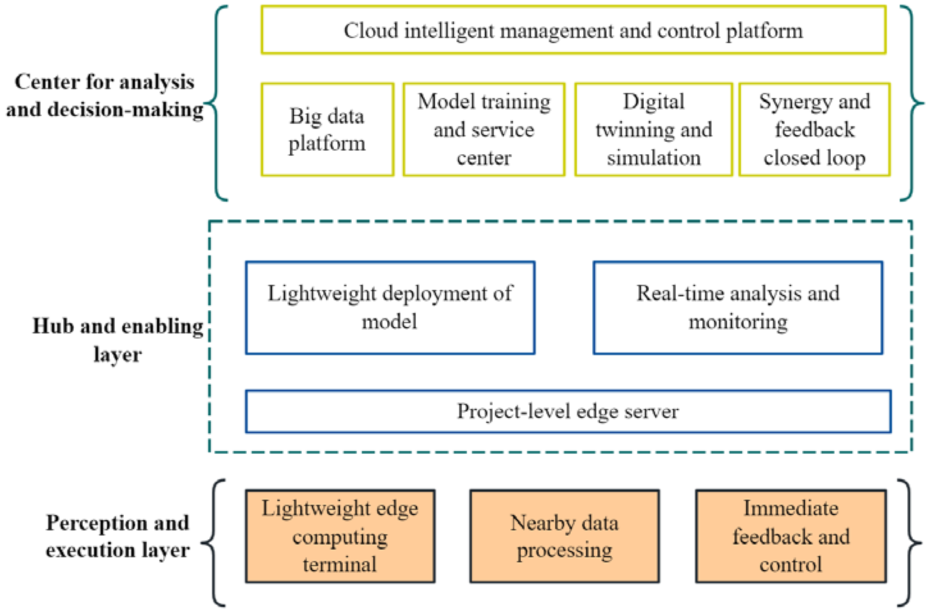

Figure 2 Closed-loop intelligent management and control system framework

3.1 "End" (perception and execution layer)

In the perception and execution layer, by deploying lightweight terminals supporting edge computing, the local data collection and real-time preprocessing are realized, which effectively reduces the pressure of cloud transmission; The terminal integrates a lightweight AI model, which supports localized real-time analysis, decision-making and alarm in scenarios such as intelligent number of steel bars and automatic acceptance of materials, and builds a fast-response closed-loop control mechanism to improve the efficiency and intelligent level of field execution [6].

3.2 "Edge" (hub and enabling layer)

The "edge" layer, by deploying the project-level edge server as an extension of the field data aggregation center and cloud intelligence, undertakes the lightweight prediction model issued by the cloud and realizes localized deployment, supporting efficient reasoning [7]; At the same time, BIM model and real-time cost data are integrated to realize the dynamic correlation and visual analysis of "BIM+ cost", provide localized management cockpit kanban for the project team, empower real-time monitoring and decision-making on site, and form an intelligent support hub for cloud-edge collaboration.

3.3 "Cloud" (analysis and decision center)

As the intelligent hub of the system, the "cloud" layer relies on the powerful big data platform to realize the centralized storage and management of massive historical and real-time engineering data, and provide sufficient computing power to support the operation of complex models. Its core functions include centralized training, optimization and version management of the model. The prediction accuracy is improved through continuous learning, and the trained lightweight model is distributed to the edge and terminal layer as needed to realize cloud-edge collaboration. The platform builds a digital twin of project cost, integrates advanced algorithms such as RL, supports the simulation and deduction of different construction schemes and resource allocation strategies in virtual environment, quantitatively evaluates their cost and schedule impact, and provides scientific basis for management decision-making.

In addition, the cloud platform establishes a complete collaborative and feedback closed-loop mechanism, which pushes prediction results, risk warnings, and optimization suggestions to relevant responsible persons in real time through multiple terminals (mobile phones, PCs), promoting the implementation of decisions; At the same time, the actual performance data after execution is automatically collected and fed back to the system for model retraining and validation, forming a continuous iterative optimization loop of "plan execute check improve" , continuously improving the system's intelligence level and management efficiency.

Based on data governance, dynamic prediction model (especially RL) is the engine, and "cloud-edge-end" collaborative system is the skeleton. It not only provides a forecasting tool, but also constructs an organic agent with perception, analysis, good decision-making and execution, and finally realizes the fundamental transformation of project cost from "after-the-fact accounting" to "during-the-fact control" and even "before-the-fact forecasting", and provides a set of reproducible and extensible comprehensive solutions for the refined and intelligent management of the construction industry.

4. Empirical research and case analysis

Taking "A Project of a Super High-rise Commercial Complex in a certain city" with a construction area of 150,000 square meters and a construction period of 28 months as an empirical case, the system was deployed in the 12th month (the main structure stage) of the project, and multi-source data such as bill of quantities provided by BIM model, materials and mechanical data collected by IoT sensors such as on-site tower cranes, mixing stations and weighbridges, man-hours and design change information in the project management system, and external market price API were accessed to construct the coverage design, construction, cost and cost.

Taking "the reinforced concrete project of the main structure" as the control target, the system firstly constructs model input features by integrating multi-source information such as BIM planning quantity, real-time IoT data and dynamic material price in the data center. Then, LSTM model carries out rolling cost forecast for the next week to realize short-term monitoring, and XGBoost model predicts the completion cost of the sub-project at the end of the month. When the prediction result exceeds the target threshold, the system will automatically trigger an early warning, and start the RL model to simulate and generate suggestions for resource allocation or construction scheme optimization, so as to realize the closed loop of intelligent management and control integrating perception, prediction and decision.

Compared with the results of traditional BIM bill of quantities valuation (static) and dynamic prediction of this model, the error is greatly reduced (as shown in Table 1). Because the dynamic model incorporates market price fluctuation and actual consumption data, the prediction result is closer to reality, which reduces the prediction error from 4.37% to 0.49% and improves the accuracy by nearly 9 times.

Table 1 Error comparison of cost completion estimation of main structure concrete project (unit: 10,000 yuan)

Prediction technique	Predicted value	Actual completion cost	Absolute error	Relative error
Traditional BIM static budget	9,850	10,300	450	4.37%
Dynamic prediction of this study	10,250	10,300	50	0.49%

In the 14th week, the system detected that the rebar price soared by 5% in a single week, which triggered the cost overrun warning (Figure 3 below). After the simulation of RL model, it is suggested that some subsequent purchase orders of steel bars should be changed from "immediate purchase" to "forward contract" to lock the price. After the project team adopted the suggestion, it successfully avoided the potential loss of about 750,000 yuan.

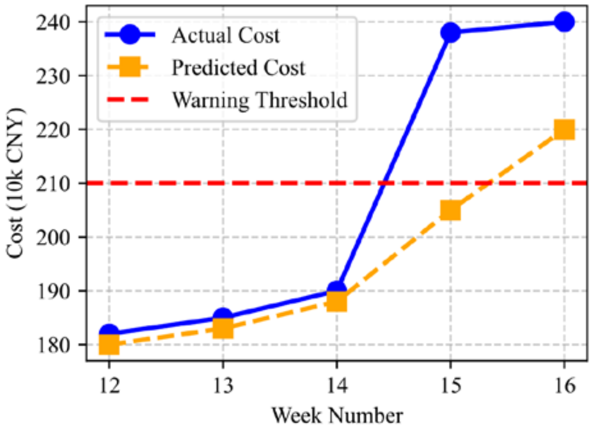

Figure 3 Cost prediction and early warning of intelligent management and control system

Through the empirical application of project A, it is proved that the big data-driven dynamic forecasting model constructed in this study has high accuracy and can effectively overcome the lag of traditional static budget. At the same time, the intelligent management and control system successfully realized the closed-loop management from "data perception" to "analysis and early warning" and then to "decision feedback", which verified its ability of active and intelligent cost control in practical projects, avoided significant economic losses for the project and realized the paradigm transition from "experience-driven" to "data-driven".

5. Conclusion

This study focuses on the problems of data island, dynamic response lag and subjective decision-making in construction project cost management. By integrating big data technology and machine learning algorithm, a heterogeneous data governance system based on BIM, IoT and big data is constructed, and a dynamic cost optimization method based on RL is designed. The empirical study shows that the model can effectively integrate multi-source heterogeneous data, realize high-precision dynamic prediction of construction project cost, and significantly reduce the prediction error from the traditional 4.37% to 0.49%. Through the "cloud-edge-end" collaborative architecture, the intelligent management and control system realizes the closed-loop management from data collection and analysis to decision execution, successfully avoids potential economic losses in project practice, and verifies its effectiveness and feasibility in practical engineering. This study not only provides a reproducible and extensible intelligent cost management solution, but also promotes the paradigm transition from "experience-driven" to "data-driven" in the construction industry, which provides strong support for refined and intelligent management.

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