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Analysis of Uncertainty and Cost Optimization in Construction Project Cost

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Abstract. However, engineering cost is an inevitable and very important core element in the construction industry. However, due to the influence of many uncertain factors on engineering cost, it is often difficult to estimate the engineering cost. This article systematically explains the important reasons for uncertainty in engineering cost. At the same time, the calculation methods of uncertainty were analyzed, such as Monte Carlo simulation, grey fuzzy method, and probability statistical type. These methods can help people better estimate engineering costs and reduce errors in engineering costs, and reduce the losses caused to the entire project due to inaccurate estimation of engineering costs. This article also demonstrates the impact of uncertainty in engineering cost on the entire project and proposes some effective methods to address these issues. Research has shown that through relatively scientific and extensive calculations, as well as precise risk control, the risks brought by uncertainty to engineering projects can be effectively reduced.

Keywords: Engineering Cost, Uncertainty, Cause Analysis, Calculation Method, Risk Management

1. Introduction

In the new social situation, dynamic management and control of construction project costs based on actual conditions can effectively control construction project costs, optimize project management, and ensure the economic benefits of construction enterprises [1]. At the same time, as a very important component of engineering in today's society, the estimation of the cost of housing engineering directly affects how much profit investors can obtain from this housing cost. However, in the real world, the construction cost of houses often has many uncertainties. These uncertain factors often come from various aspects, including human factors, market factors, government factors, natural factors, etc.

Uncertainty usually refers to a series of unpredictable changes in engineering cost, such as information asymmetry, market fluctuations, or changes in project quantity. In the end, it may manifest as overestimation or underestimation of costs, thereby affecting the accuracy of decision-making. Usually, the construction period of housing projects is relatively long, and external influences are relatively significant, so these issues often greatly reduce the accuracy of the entire project cost estimation. For example, in an engineering project, a lot of procurement and hiring workers are required, such as the purchase, transportation, and laying of rough stones. During this

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period, there will be a lot of expenses such as labor costs, material costs, machinery costs, etc., so there will be many uncertain factors that affect price calculation. At the same time, during economic fluctuations, the sharp rise in material prices may also cause significant deviations in the initial budget.

The significance of this study lies in: firstly, helping relevant personnel effectively avoid the instability of engineering cost estimation by analyzing the reasons for the uncertainty of engineering cost. Secondly, introduce some commonly used calculation methods and tools to help relevant personnel minimize the impact of various factors on engineering cost estimation.

The main objectives of cost management and control throughout the construction phase of new era building projects are focused on three aspects: first, directly ensuring that the cost meets expected requirements; second, providing a certain operational space for management work; and third, ensuring the comprehensive benefits of the project [2]. The research background of uncertainty in housing engineering cost originates from the rapid development of the construction industry. With the acceleration of urbanization, the number of housing projects has surged, but at the same time, it faces challenges such as raw material shortages, rising labor costs, and strict environmental requirements. These factors together constitute a source of uncertainty. In history, many large housing projects have been delayed or exceeded due to cost uncertainty, such as some real estate development projects experiencing skyrocketing costs due to supply chain disruptions during the pandemic.

2. Analysis of the causes of uncertainty

The design control of engineering cost is to regulate the relationship between the functions and costs of projects. The most important aspect of cost control in the design process is how to maximize the functionality of engineering projects while reducing costs [3]. The uncertain factors in the construction cost of houses can be roughly divided into two categories. The first type is external factors, which are mainly influenced by the overall environment, such as market price fluctuations, weather conditions, or government policies; The second type is internal factors, which are mainly influenced by project management, investor funds, or construction efficiency

2.1. Economic factors

Economic fluctuations are an uncertain factor in the cost of housing projects, as the cost of housing projects is often a relatively long-term estimate, usually up to several years, decades, or even decades for some mega projects [4]. However, during this period, inflation, interest rate fluctuations, and economic recession will directly affect material, labor, and equipment costs, leading to significant deviations in project costs. For example, the global inflation from 2020 to 2023 caused the prices of building materials such as steel and cement to rise by 20% -30% in just two years. Many residential projects that were originally budgeted for exceeded the initial estimate by more than 15%, directly disrupting the developer's funding plan. In addition, some large-scale housing projects often have transnational cooperation, such as imported materials, machinery, etc. During this period, the exchange rate will fluctuate constantly. If some huge exchange rate fluctuations are encountered, or some wars occur in the raw material supplier countries, economic crisis, and other situations will also introduce many uncertainties in housing costs. For example, during the Russia-Ukraine conflict, many housing projects in Europe that rely on Ukraine to import steel and Russian natural gas, not only because of the interruption of the supply of raw materials, but also because of the sharp fluctuations in the exchange rate of the euro against the dollar, the purchase cost of

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construction equipment imported from the United States will increase by 10% -12%, further increasing the uncertainty of the cost.

2.2. Natural factors

Natural factors are an uncertain factor in housing cost that is difficult to avoid, because natural factors often have a completely unpredictable nature. Some extreme climates, such as floods, sandstorms, typhoons and a series of natural disasters, which cannot be predicted in large advance, may lead to the extension of the construction period, damage to the housing structure and other situations, thus causing many uncertainties in the estimation of housing project cost, and some even a devastating blow to the whole project. For example, when the typhoon "Du Suri" landed in Fujian in 2023, many local residential projects under construction were suspended for nearly two weeks due to strong storms and rain, which not only led to the delay of the construction period, but also caused the damage of scaffolding and the rejection of building materials in water. As a result, some projects have added about 8% -10% of the repair and rush cost, Completely beyond the initial cost estimate and during the 2020 Yangtze River Basin flood, residential construction sites along the river in Jiangxi, Anhui, and other areas were flooded, causing foundations to become soft and existing low rise structures to crack. Some projects even needed to be rebuilt, ultimately resulting in costs exceeding the original budget by more than 30%, causing huge economic losses to developers.

2.3. Market factors

The relationship between market supply and demand is a key factor, as labor shortages or insufficient material supply can lead to significant price increases. In the construction industry, there is often a high demand for labor, so during this period, workers' wages become a huge uncertainty factor. In China, in some remote areas such as highlands or border areas, workers' wages are often higher than those in regular areas. During holidays, some large housing projects need to be constructed continuously due to project schedules or other factors. However, during the Spring Festival or some traditional holidays, the number of disposable workers sharply decreases, so workers' wages are often higher than those during regular working hours. For example, during the Spring Festival in 2024, multiple coastal vacation residential projects in Sanya, Hainan, needed to be constructed continuously to meet the deadline. Due to a large number of workers returning home for the holiday, the daily wage of local construction workers has increased from the usual 350 yuan to over 600 yuan, and the labor costs of some projects have directly exceeded the budget by 20%, bringing enormous pressure to project cost control. When the market competition is fierce, supplier quotations are unstable and it is easy to change after winning the bid at a low price. For example, in the 2023 bidding for a certain affordable housing project in Guangdong, a building materials supplier won the bid at a price 15% lower than the average market price. But during the supply phase, the supplier requested a price increase on the grounds of rising raw material prices, otherwise the supply would be stopped. In order to avoid delays in the project schedule, the project party was forced to accept price increases, which ultimately led to building material procurement costs exceeding the original budget by 10%, and also caused uncertainty in the cost.

In the Chinese real estate market, the instability of land prices is an important factor in the cost of housing construction. Because all land is subject to government control and influence, such as purchase restrictions or changes in land auction mechanisms, this can directly lead to significant deviations in the cost of early-stage housing projects, and even this deviation is completely unacceptable to developers or investors, resulting in the failure of the entire project. For example, in

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2021, the Qinglong unit residential land project in the Shenhua district of Hangzhou estimated that the land cost would account for 40% of the total project cost when the developer acquired the land. However, the local government subsequently introduced stricter land auction price limit policies, and the auction prices of surrounding plots fell sharply, causing the land cost ratio of the project to soar to 55%, far exceeding the developer's affordability. Eventually, the funding chain broke and the project was abandoned. In addition, incomplete market supervision may lead to material quality issues, which will further increase maintenance costs in the middle or later stages of the entire project.

2.4. Design factors

When it comes to engineering cost management, design factors are a common influencing factor. Many projects are not optimized according to scientific and reasonable design methods before design, resulting in a continuous decrease in project reliability and feasibility. This not only causes serious economic losses, but also faces enormous competitive pressure in future development [5]. At the beginning of the design, a lot of surveying and exploration are required. In some large-scale housing projects, geological exploration is also required, during which geological exploration data may be inaccurate, leading to cost overruns in basic engineering. For example, in the early geological exploration of the 2022 Shenzhen Qianhai Yiwanfu residential project, only shallow soft soil layers were discovered, but deep karst caves were only discovered underground during construction. The originally designed pile foundation needed to be lengthened and reinforced, directly resulting in a 28% increase in basic engineering costs compared to the original budget and a delay of nearly three months in the construction period.

During construction, some housing projects may temporarily change their designs due to changes in local regulations or make adjustments to the aesthetics or practicality of the buildings. However, this can trigger a chain reaction and affect the overall cost. For example, in 2023, the Shanghai Pudong Development Renheng Coral Century residential project was under construction. Originally designed according to the old regulations, the thickness of the external wall insulation layer was 5 centimeters. However, during the construction period, new regulations were introduced locally, requiring the insulation layer thickness to be increased to 8 centimeters. The project party had to readjust the design and replace materials, ultimately resulting in a 12% increase in the cost of the external wall project and an overall increase in cost.

2.5. Construction factors

During the construction phase, there are often claims related to certain projects, which are also the most controversial and difficult issues to resolve between both parties [6]. Labor disputes or equipment malfunctions are also common problems in housing engineering, but they are also factors that affect cost uncertainty. For example, in some housing engineering projects, if workers are injured or killed, the price of compensation in the later stage is often difficult to estimate. For example, during the construction of the Runxi Phase II residential project in Shenzhen's Huarun City in 2024, a worker was injured due to the collapse and fall of scaffolding. The project party not only had to bear the medical expenses, but also had to pay disability compensation and the loss of work stoppage for rectification. The final compensation and rectification costs exceeded the original budget by nearly 500000 yuan, directly pushing up the project cost.

In China, most housing projects are located in densely populated urban areas, where traffic control or neighborhood interference increase uncertainty, which can prolong the construction period

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and lead to increased expenses for workers and equipment. For example, in 2023, the residential project next to Wangjing SOHO in Chaoyang District, Beijing, was delayed by 2 months due to complaints from surrounding residents about construction noise. The local urban management department required the project to be suspended at night, and the transportation of building materials during the day was affected by the morning and evening rush hour restrictions, resulting in an additional 8% increase in worker wages and equipment rental costs, causing cost overruns.

2.6. Policy and legal factors

For a long time, the determination of engineering costs in China has been strictly based on national or regional unified quotas and relevant rates stipulated [7]. At the same time, the uncertainty of the legal and policy environment is particularly prominent in China. The laws, regulations, management methods, and standard specifications related to engineering general contracting projects in China are all in the process of transformation and reshaping. Market entities' understanding of them is gradually deepening. Engineering general contracting is still a market with highly incomplete contracts, and both parties repeatedly play games over their own interests in the process of contract signing and implementation, which will affect the formation and sharing of implicit cost risks [8]. Land policies, environmental regulations, or tax adjustments will directly affect the cost significantly. Legal disputes such as property disputes can also delay projects and increase indirect costs. These factors combined are often enormous and even unacceptable to either party in the end. For example, in multiple residential projects across the country, Evergrande Group's funding chain has been disrupted due to the tightening of national real estate regulation policies (such as the "three red lines" financing restrictions), resulting in the suspension of a large number of ongoing projects. At the same time, some projects have also been stalled due to policy and legal issues such as land use right mortgage disputes and environmental compliance reviews, which not only directly result in significant cost overruns, but also generate huge overdue compensation and resumption of work rectification costs due to long-term shutdowns. In the end, the uncertainty of these projects' prices has exceeded the tolerance of all parties, becoming a typical case of policy and legal factors affecting project costs.

In summary, these reasons overlap to form a huge network in the cost of housing engineering. However, identifying these factors is the basic method of cost control. Only by considering these factors as much as possible in the early stage can the cost be estimated relatively accurately, thereby bringing a stable and controllable environment to all parties involved.

3. Calculation method of uncertainty

The cost of housing often has uncertainty, and engineering cost control runs through the decision-making, design, construction, and completion stages of construction projects [9]. Therefore, below I will introduce several common methods and models to quantify risks and make them controllable.

3.1. Sensitivity analysis

Sensitivity analysis is the evaluation of the impact of variable changes on cost. By changing a single variable, such as a 15% increase in material prices, observe the total cost deviation through a series of changes. This method is relatively simple and easy to implement, and is suitable for preliminary cost estimation in the early stages of the entire project. In housing engineering projects, Excel

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modeling can be used to input variable ranges and calculate critical points. But the limitation lies in ignoring the correlation between variables.

3.2. Monte Carlo simulation

Monte Carlo simulation uses random sampling to simulate uncertainty. Assuming the variable follows a probability distribution, such as a normal distribution, calculate the cost distribution through multiple iterations. This method can provide a confidence interval, such as a 95% probability that the cost will not exceed X yuan. Applied in software such as Risk, suitable for large-scale housing construction projects. The advantage lies in handling multivariate correlations, but due to the large computational complexity, it requires significant resources, so small-scale housing construction projects generally do not use this model for calculations.

3.3. Probability distribution model and fuzzy mathematics method

A probability model of cost variables can be established based on historical data such as historical material costs. Use Bayesian methods to update prior distributions. For material costs, the maximum and minimum values can be analyzed to ensure that the material costs are controlled within a controllable range. In housing engineering, this method is used for risk assessment, calculating expected values and variances.

Fuzzy methods handle subjective uncertainty by quantifying fuzzy concepts using membership functions. If the material price is "high", use fuzzy sets to represent it. This method is suitable for the early stages of construction or design where information is relatively vague. In China, grey system theory is used to predict fluctuations in housing project costs.

3.4. Statistical analysis based on historical data and whole process cost control method

Utilize historical project data for regression analysis or machine learning to predict uncertainty. If using the unit price method, adjust the historical unit price to consider uncertainty. The cubic method is used to estimate the cost of multi story houses, adjusted based on their volume. Emergency calculator to assess potential impacts.

A large amount of dynamic testing is required throughout the entire engineering project, which can effectively adjust the prediction of the entire project cost and significantly reduce uncontrollable factors in the project cost. Especially in today's increasingly fierce economic globalization and market competition, risk assessment and dynamic management have become key means to ensure engineering cost control [10]. Combining earned value analysis with uncertainty. It is best to reserve a risk buffer fund, accounting for 5% -10% of the total cost. For example, in the 2023 Zhangjiang Science City industrial residential supporting project in Shanghai, an 8% risk buffer was reserved in the early cost calculation, and the earned value analysis method was used to dynamically monitor costs throughout the process. When encountering an unexpected situation of a 12% increase in building material prices during construction, the project party directly used buffer funds to cover the overspending, and adjusted the subsequent procurement plan based on earned value analysis. The final project cost only exceeded the original budget by 1.2%, far below the industry average overspending level.

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4. Conclusion

The uncertainty of housing engineering cost is an unavoidable core challenge in project management. This article systematically analyzes the main causes: macroeconomic fluctuations, changes in market supply and demand, variations in design and construction technology, inadequate management coordination, and instability in the policy and legal environment. These factors are intertwined and often result in actual costs deviating from the budget by 10% -35%, leading to overspending, delays, and even project failures. Practice has shown that relying solely on empirical estimation is no longer sufficient to cope with the complexity of modern engineering.

In terms of quantitative methods, sensitivity analysis can quickly identify key risk variables, Monte Carlo simulation can realistically depict the probability distribution of costs, and probability models, fuzzy mathematics, and statistical analysis based on historical data are applicable to different stages of information completeness. With the integration of BIM, digital twins, and AI technology, uncertainty assessment will evolve towards dynamic and real-time prediction in the future.

Looking ahead to the future, with the advancement of the "dual carbon" goal, building industrialization, and intelligent construction, housing engineering will face new uncertainties such as fluctuations in green material prices, supply chain stability, and new regulatory requirements. Meanwhile, the application of big data and artificial intelligence will also bring breakthroughs to risk management. Cost practitioners need to continuously update their knowledge, iterate tools, and actively participate in the digital transformation of the industry in order to take the initiative in complex environments and provide solid economic support for high-quality housing construction.

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