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Research on Cost Forecast and Analysis for Projects Based On Monte Carlo Simulation

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Abstract: Traditional project costing methods have not considered the effects of uncertain factors in actual engineering projects. In this paper, the Monte Carlo Method is used to study the uncertainty of engineering project costs. According to the characteristics of uncertainty of cost elements follow the Beta-PERT distribution, Combined with Crystal Ball Monte Carlo simulation software, the total cost and sensitivity of a project were forecasted and analyzed, which helps companies control costs and risks more scientifically.

Keywords: Monte Carlo; Cost Forecasting; Sensitivity Analysis

INTRODUCTION

At present, the engineering project cost forecasting methods are mainly based on calculating a certain value according to the design documents and the quota data. The contracting enterprises will bid and formulate the cost plan according to these data. In fact, it is often affected by a variety of uncertain factors such as management level, production efficiency, market, and weather in the process of the project. Traditional cost analysis methods simply perform a summation based on the components of each cost without considering the effects of various random factors, which results in the final cost being not the certain value determined previously, but a random variable following a certain probability distribution [Wuet al., 2004].

Using the Monte Carlo Method can predict the cost of an engineering project and analysis risks, which is a method that uses a large number of repetitive experiments to simulate and solve problems with uncertainty. Under multiple influences of various random factors, the unit cost of a project is distributed within a certain interval. After numerous simulation experiments, these data will show some regularity [Wang et al., 2011]. In complex engineering projects, the results simulated by Monte Carlo are more scientific and accurate.

UNCERTANTY ANALYSIS

PrincipleofMonte Carlo

Monte Carlo is a method of generating random numbers according to a certain probability distribution to simulate uncertain factors that may occur in actual engineering projects, and obtain an approximate solution to the problem. The principle of the method [Xu et al., 2006] is: assuming the function F =f(X_1, X_2, ..., X_n) where the probability distributions of the variables (X_1, X_2, ..., X_n)are known, and each group is obtained by random independent sampling. The random value of the variables (X_{i1}, X_{i2}, ...,X_{in}) are substituted into the function relational expression to obtain the value of F. When the number of trials is sufficient, the results will be close to the actual problem.

Beta-PERT Distribution

The uncertainty in the engineering project cost is usually described by the triangular distribution [Yanget al., 2014] and the Beta distribution [Yuet al., 2005].This paper uses the Beta-PERT distribution to describe the uncertainty.

The Beta-PERT distribution is derived from the Beta distribution [Linet al., 2010]. Like the triangular distribution, Beta-PERT distribution requires the same three parameters, namely Minimum (Min), Most Likely (ML) and maximum (Max).The difference is that the curve of Beta-PERT distribution is more "smooth"(Illustrated by Figure 1).From the point of view of their mean values, the formula for the triangular distribution is $Mean_{Tri} = \frac{Min+ML+Max}{3}$, and the formula for the Beta-PERT distribution is $Mean_{Pert} = \frac{Min+4ML+Max}{6}$.

From the formula we can see that the mean value of the triangular distribution simply calculates the average of the three parameters, while the Beta-PERT distribution is a weighted average that gives 4 times weight to the most likely value (ML). In practice, we are more willing to use the estimate for the most likely value, even if it is not accurate, we expect the

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final result to be close to the estimate, so applying the Beta-PERT distribution is more appropriate.

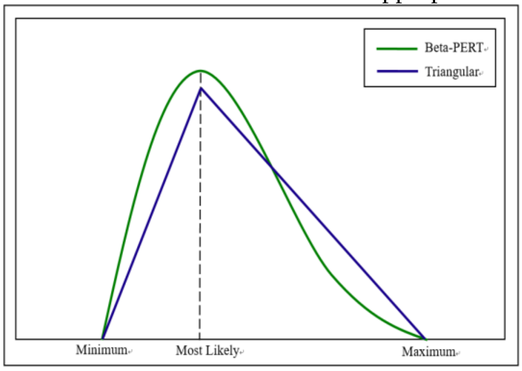

Figure 1.Curves of Beta-PERT distribution and Triangular distribution

Simulation Flow With Crystal Ball Software

The crystal ball software can simulate all possible outcomes of a process by using Monte Carlo method and gives the possibility of each result [Sunet al.,2005]. When using Crystal Ball, it only needs to specify the uncertainty variables (i.e. input variables, output variables and probability distribution type of the uncertain variables). The software can automatically complete the simulation in a short time under the set number of trials, and generate relevant charts and reports, giving various assumptions, estimate results. The simulation flow is shown as Figure 2 below.

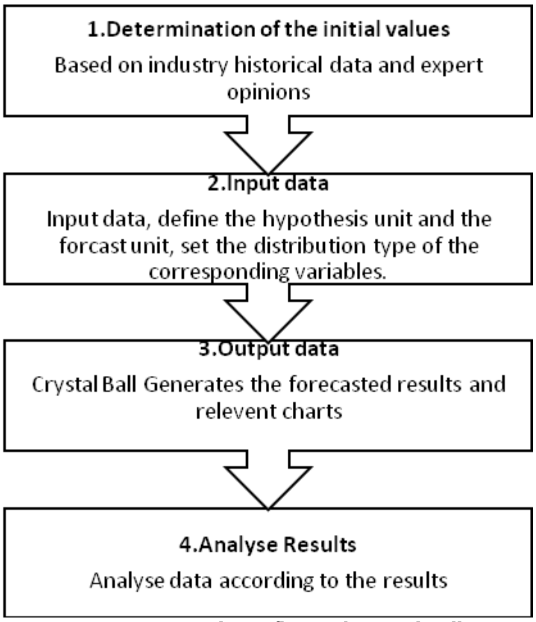

Figure 2.Simulation flow with Crystal Ball

CASE EXAMPLE

The sub-project of project A is mainly composed of the following 10 items, the uncertainty of each cost item is assumed follow the Beta-PERT distribution. According to historical data and expert opinions, the maximum, minimum and most likely values of each cost item are given in the Table 1 below:

Table 1. Unit approximate cost of itemize work

Cost Item	Quantity/m3	Minimum/yuan	Most likely/yuan	Maximum /yuan
Porous brick exterior wall	2824.60	44.13	46.33	48.57
Porous brick inner wall	2552.30	47.08	49.45	52.13
C30concrete rectangular column	139.40	482.60	507.80	533.20
C30 concrete special-shaped column	22.60	485.12	518.79	540.50
C20 frame beam, cantilever beam	43.60	518.50	545.78	574.20
C20 special-shaped beam	75.20	615.30	645.75	675.98
C20 continuous beam	65.40	502.56	530.5	555.48
90mm C20 beam plate	950.10	436.80	461.28	480.19
100mm C20 beam plate	1557.2	461.25	488.45	512.30
110mm C20 beam plate	2246.40	488.74	515.2	540.70

In Crystal Ball software, 10 cost items are defined as hypothesis units, set up as random variables distributed from Beta-PERT, and total costs are defined as forecast units. The formula for calculating total costs is as follows:

$$Cost = \sum_{i=1}^{m} fiLi$$

Among them, m is the number of cost items, fi is the unit cost of the i-th item and Li is the quantity of the i-th item.

Input parameters in the table into the software, and the simulation number are set to 50000.

Cost Forecast and Analysis

Through the simulation, the mean value of the final cost is 2,800,892.86 yuan, the standard deviation is 27,927.13 yuan, and there is a 90% chance that the total cost falls between [2,754,466.58, 2,846,725.59].The detailed statistics of the results are shown in Table 2, Table 3 and Figure 3,where Figure 3 illustrates the frequency of the total cost.

Table 2. Basic Statistics of Forecasting Results

Statistic	Forecast Values
Mean	2,800,892.86
Variance;	779,924,700.28
Standard Deviation	27,927.13
Maximum	2,892,683.31
Minimum	2,702,051.79

Table 3.Confidence interval of Total Cost

Probability	Confidence Interval
10%	[2,797,434.61, 2,804,821.51]
20%	[2,793,774.03, 2,808,453.87]
30%	[2,789,885.79, 2,812,291.89]
40%	[2,785,787.97, 2,816,287.70]
50%	[2,781,379.17, 2,820,526.16]
60%	[2,776,531.86, 2,825,220.93]
70%	[2,770,976.78, 2,830,625.58]
80%	[2,764,077.92, 2,837,133.51]
90%	[2,754,466.58, 2,846,725.59]
95%	[2,746,665.29, 2,854,426.68]

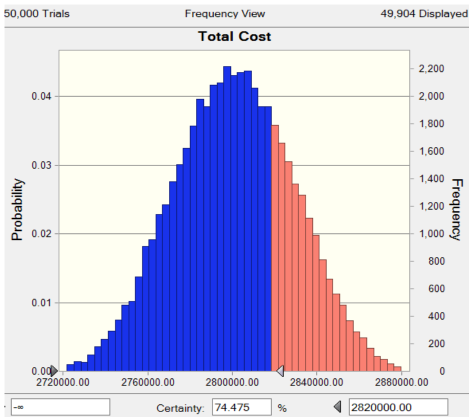

Figure 3. Frequency Chart

It can be seen from Table 3 and Figure 3that:

1) The total cost of the sub-project is distributed normally. There is a 95% chance that the cost of this work falls within the range of [2,746,665.29, 2,854,426.68].
2) If the enterprise budget for this part of work is 2820000yuan, there is a 74.475% chance that it can be completed within the budget, that is, a 25.525% chance of overspending.

Sensitivity Analysis

In Crystal Ball, the sensitivity analysis chart and tornado chart can be directly derived, and the sensitivity factors that have a significant impact on the cost of the project can be found out from multiple uncertainties, which are used to analyze and calculate the sensitivity degree and impact degree of the project cost, the sensitivity chart is given below.

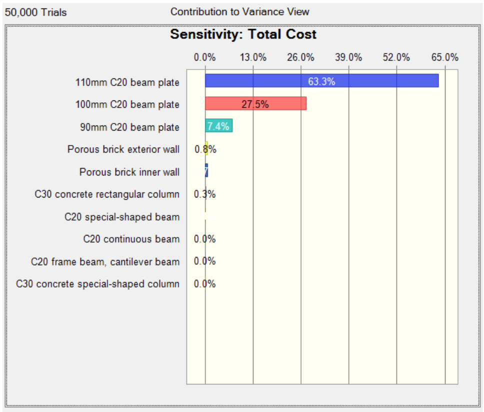

Figure 4.Sensitivity Chart

As can be seen from Figure 4, the 110mm C20 beam plate has the greatest impact on the total cost, reaching 63.3%, followed by the 100mm C20 beam plate and the 90mm C20 beam plate. Their impact on the total cost is 27.5% and 7.4% respectively. And the remaining cost factors have little or no impact on the total cost.

Tornado Analysis

Tornado analysis (Figure 5) is a quantitative risk analysis method in project management, which is helpful to compare the impact degree between variables with high uncertainty and relative stable variables.

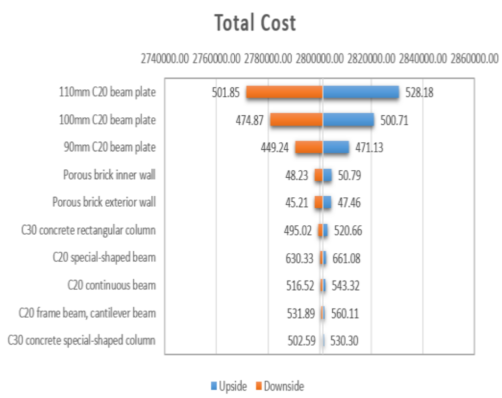

Figure 5.Tornado Chart

It can be seen from the figure 5 that if the unit cost of 110mm C20 beam plate increases to 528.18 yuan and decreases to 501.85 yuan, the total cost of this sub-project increases to 2830000 yuan and reduces to 2770000 yuan. Similarly, if the unit cost of 100mm C20 beam plate increases to 500.71 yuan and decreases to 474.87 yuan, the total cost will increase to 2822000 yuan and decrease to 2790000 yuan accordingly. The change of porous brick interior wall, porous brick exterior wall and C30 concrete rectangular column has small effect on the total cost. The change of C20 special-shaped beam and C20 continuous beam has little effect on the total cost.

The tornado chart in Crystal Ball clearly and intuitively describes which part of the activity should be properly controlled. The cost of 110mm C20 with beam plate is the most likely factor to lead to cost overruns. If the total cost is to be controlled within 2,800,000 yuan, the unit cost of 110mm C20 with beam plate should be optimized to within 510 yuan as much as possible.

SUMMARY

Project cost forecasting and analysis are faced with multiple effects of uncertain factors. The Monte Carlo method fully considers the uncertainty of each factor and can quantitatively analyze the uncertain factors to help people understand the nature of the problem and Provide a more scientific and rational method of forecasting and analysis.

Although the Monte Carlo method has significant advantages in analyzing uncertainty problems, it should be noted that when using this method, the key point is to determine the initial values properly based on historical data and expert opinions, which requires a lot of data support. The inaccuracy of the initial data will lead to large deviations in the final results.

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