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CONSTRUCTION COST INTEGRATED CONTROL BASED ON COMPUTER SIMULATION*

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Abstract: Construction cost control is a complex system engineering. The traditional controlling method cannot dynamically control in advance the construction cost because of its hysteresis. This paper proposes a computer simulation based construction cost integrated control method, which combines the cost with PERT systematically, so that the construction cost can be predicted and optimized systematically and effectively. The new method overcomes the hysteresis of the traditional systems, and is a distinct improvement over them in effect and practicality.

Key words: construction cost, integrated control, computer simulation
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INTRODUCTION

Construction cost control is important activity for efficient management of a construction project. A cost control system must be designed to control well the construction (Wang Shouqing, 1996). This system should be provided with the function to let the project manager know the current cost level, and then compare it with the plan, so that he can take measures to improve the cost control. Most cost control systems in existence have the limitation of hysteresis, which means they provided information based on finished work, which leads to the weaknesses of those systems in dynamically controlling the cost in advance (Zhuyan, 1998). This limitation is also the main reason why such system cannot be generalized and applied in practical projects.

The hysteresis of the traditional cost control system is due to two reasons. One is that cost control models in use only take cost into account, but ignore progress and quality. As everyone knows, the major concerns of project management, cost, progress and quality, are intimately interrelated, and to control one of them will inevitably affect the other two. So it is necessary to consider both progress and quality while controlling cost; which means the cost control model must be an integrated model considering the above three concerns comprehensively. Another reason is that the traditional systems cannot estimate and predict the changing trend of the cost, and so cannot provide effective measures to control or correct the cost differential. For solving the hysteresis problem of the systems, this paper proposes a method for cost integrated control based on computer simulation. Through integrating cost and progress, the method predicts and optimizes the cost by applying computer simulation. This method, not only resolves the two above-mentioned problems, but also increases the system efficiency and improves its practicability.

INTEGRATED COST CONTROL SYSTEM BASED ON COMPUTER SIMULATION

1. Model of the system

Integrated cost control based on computer simulation is carried out by using network scheduling technology. The project is first broken down into a series of logically related, certain duration, activities requiring resources at corre-

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sponding cost. Then the network model parameters are calculated by using computer simulation. Through such a simple procedure, the construction cost can be controlled effectively. In other words, cost integrated control is achieved by constructing the project model using network scheduling technology, which can be used to schedule progress, allocate resources, and break down the cost planning object simultaneously. Computerized simulation, prediction and optimization of project cost can result in much better management and control of project cost. As shown in Fig. 1, the system model includes several elements: a series of activities to complete the project, logical relationships among the activities, working time of each activity, necessary resources of each activity, and necessary costs of each activity (including fixed costs and resource costs). After each activity has been assigned certain time, resource and cost, the integrated cost control model of the whole project can then be constructed.

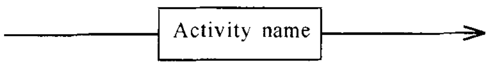

Fig. 1 Cost integrated control model based on computer simulation

Duration: optimistic time estimate, pessimistic time estimate, and skew value

Necessory resources: equipment, labour

Costs: fixed costs, resource costs

2. Computer simulation

What is computerized system simulation? It is a method that compares and simulates the system's structure, function, and action. The initiator's thinking and behavior also joins in dynamically controlling system by computer. The method can not only study and analyze the system on the basis of the simulating model, but can also show the whole process of the system as well. Since the method has some advantages in solving some difficult or certain impractical problems, optimizing problems of complicated systems that cannot be solved by analysis, comparison and optimal selection of a large number of schemes, dangerous phenomena, higher cost phenomena, etc., it develops very quickly and finds application in many fields (Zhaowei, et al., 1988). Construction engineering should be one of the fields that we should pay more attention to as soon as possible. This paper optimizes and forecasts construction cost planning by computer simulation technique, which has three main functions: optimizing and adjusting the initial network scheduling in order to gain minimum cost and still meet the requirements of project duration and quality; optimizing and adjusting the unfinished part of the network according to the existing information at any moment during the construction to reduce costs differential; predicting and analyzing, and controlling especially the cost and progress of the still unfinished part of the project. The basic procedure of computerized system simulation presented in this paper is as follows: first, the given distribution of the duration of each activity should be generated by computer, each time generating a random duration of each activity is equivalent to constructing or simulating once. Then according to the duration of each activity, calculate the total project duration, plan the cost of each activity and the total costs, and decide the key path, which should all be used to control the cost at any time. The steps are as follows:

(1) Generation of the random number of duration of each activity (Xie, et al., 1988; Mitrani, 1982)

Actually, the duration of different kinds of activity has different probability distribution. Generally, it is desired that the probability density of the duration of each activity should have the following characteristics:

1) It has a distributive interval (a, b), within which the probability density is always a limited positive value;

2) Within the distributive interval (a, b), the curve of the probability density has a single hump.

The characteristic is comparatively in accord with the actual distribution of the duration of activity. For general activity, the distribution of β is quite representative. Within the interval (a, b), the probability density of random variation of the distribution of β is as follows:

$$f(x) = \frac{\Gamma(r+s)}{(b-a)^{r+s-2}\Gamma(r)\Gamma(s)}(x-a)^{r-1} \cdot (b-x)^{s-1}$$

$$a \leqslant x \leqslant b,\ r > 0,\ s > 0 \qquad (1)$$

The distribution of β is actually a 4-parameter distribution. Parameters a and b determine the distribution interval, while r and s determine the distribution figure. This provides the distribution of β with flexibility which can fit random location and shape when needed. Generally, the figure has three shapes: left skewed (Fig.2b), right skewed (Fig.2c) and symmetrical (Fig.2a). If the figure is left skewed, i.e. mode m leans to a, then parameter r and s are about 1.586 and 4.414 respectively. If the figure is right skewed, i.e. m leans to b, and then r and s are approximately 4.414 and 1.586 respectively. If the figure is symmetrical, i.e. m is in the center of a and b, then r and s are 4. When using the distribution of β to simulate the duration of each activity, first estimate the value of a, b (optimistic value, pessimistic value) and skew value of c (when the figure is left skewed, $c = 1$; right skewed, $c = 3$; symmetrical, $c = 2$) of the duration of each activity, then determine r and s by the above method.

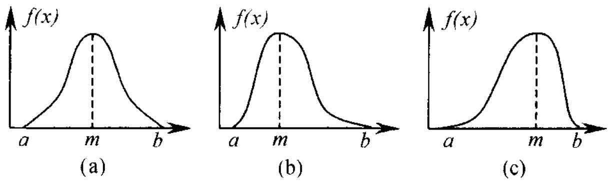

Fig.2 Figure of the probability density of the distribution of β
(a) symmetrical; (b) left skewed; (c) right skewed

The random number of the duration of activity which follows the distribution of β is generated by using acceptance and rejection methods. That is carried out by:

1) Estimating the value of a, b, c, and defining the value of parameter r and s;

2) Calculating YA, the maximum of $f(x)$, $YA = f(x) \mid x = m$, of which mode m can be obtained from the following formula:

$$m = \frac{b(r-1) + a(s-1)}{r + s - 2}$$

3) Generating the random numbers r_1 and r_2 which are uniformly distributed at the interval $[0, 1]$;

4) Calculating the value of $f(a + (b - a) r_1)$;

5) Verifying whether the inequality $f(a + (b - a) r_1) \geqslant r_2 \times YA$ is true. If so, then the value of $a + (b - a) r_1$ is the random number of duration of activity which follows the distribution of β. Otherwise repeat from step 3) to step 5), until the above inequatity is true.

(2) Calculating the cost of each activity

The cost of each activity consists of the fixed costs and the resource costs. The fixed cost is the sum of the materials cost and indirect cost of each activity. The resource cost is the sum of the cost of labour and machinery to complete the activity, which can be defined by the total amount of resources, duration and corresponding resource ratio.

(3) Calculating the time parameter of each activity, the total project duration and the total costs, and determining in succession the critical path.

(4) Repeating from Step 1 to Step 3, defining the distribution of probability and the average value of the total project duration and the total costs; meanwhile determining the distribution of probability and the probability of the critical path of each activity, etc.

The model of computer simulation is shown in Fig. 3.

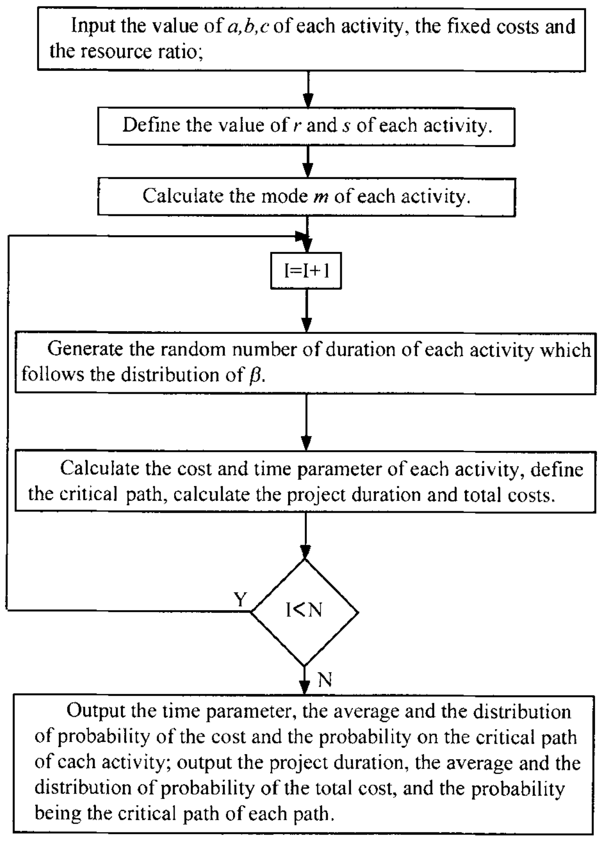

Fig.3 The simulation model

EXAMPLE

As an example, Fig. 4 shows a network of some project. The three data on each shaft of the network are the respective values of Ⅰ, Ⅱ and Ⅲ of each activity. The cost and resource parameter of each activity are shown in Table 1.

The computer simulation of this network model has been implemented in the programme language Visual Basic. The simulation times have been predetermined as 10 000.

3. Total planning cost

By simulation, the average value, variance and the distribution of probability of the total planning cost can be defined. In this example, the average value and standard deviation are ¥262 240 and ¥2 917 respectively. The probability distribution is shown in Fig. 5. That is the general cost of the construction control.

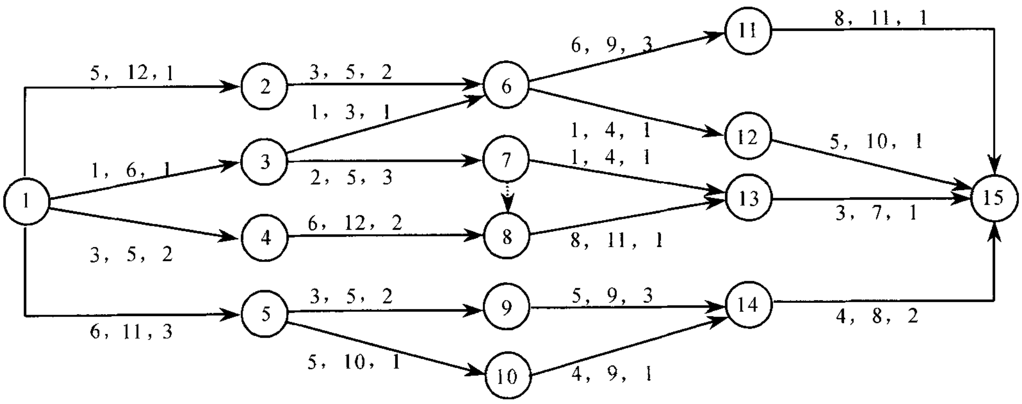

Fig.4 The network of some project

Table 1 Resource and cost parameter of each activity

Activity	1 - 2	1 - 3	1 - 4	1 - 5	2 - 6	3 - 6	3 - 7	Resource ratio
Amount of material Ⅰ	3	3	5	0	0	3	3	150
Amount of material Ⅱ	0	3	0	3	3	2	2	200
Amount of material Ⅲ	0	0	0	2	1	1	1	180
Fixed costs	14000	6500	7500	2100	7700	1200	8000	
Activity	**4 - 8**	**5 - 9**	**5 - 10**	**6 - 11**	**6 - 12**	**7 - 13**	**8 - 13**	
Amount of material Ⅰ	3	5	5	5	5	3	3	150
Amount of material Ⅱ	0	0	0	3	3	2	2	200
Amount of material Ⅲ	1	2	2	1	1	1	1	180
Fixed costs	19000	7300	10500	16700	3000	2700	20000	
Activity	**9 - 14**	**10 - 14**	**11 - 15**	**12 - 15**	**13 - 15**	**14 - 15**		
Amount of material Ⅰ	0	0	0	0	3	0		150
Amount of material Ⅱ	3	3	0	0	0	2		200
Amount of material Ⅲ	1	1	2	2	0	0		180
Fixed costs	5000	7000	17500	7500	3200	5000		

4. Item breakdown

The project cost is too vague to control, so the project manager should first break it down for each activity. After that, he should calculate the average value and variance of the planning cost, average duration and the probability of the critical path of each activity. For activity possibly lying on the critical path, activity such as 1 - 2, 1 - 5, 2 - 6 and 14 - 15, due to their great probability to be critical activity, they should be controlled more strictly. Otherwise the activity will be delayed and the costs will increase. Table 2 shows the simulation results.

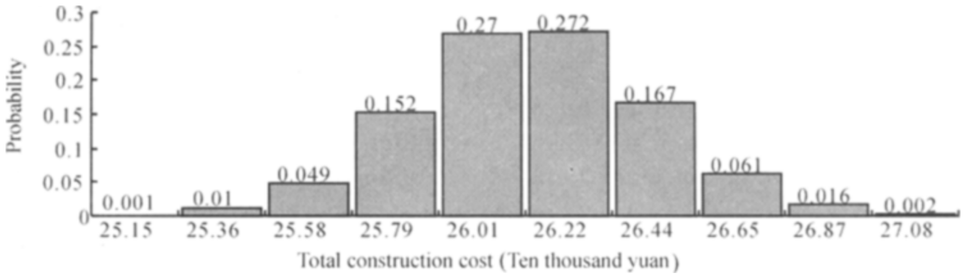

Fig.5 The probability distribution of the total planning cost

Table 2 Average value and variance of the cost and average duration of each activity

Activity	1 - 2	1 - 3	1 - 4	1 - 5	2 - 6	3 - 6	3 - 7
Average value of cost(¥)	17400	10300	10500	11300	10620	3260	11820
Standard deviation of cost(¥)	487	886	248	826	261	324	559
Average duration	8	2	4	10	4	2	4
Probability of the critical path	0.404	0	0.064	0.531	0.404	0	0
Activity	4 - 8	5 - 9	5 - 10	6 - 11	6 - 12	7 - 13	8 - 13
Average value of cost(¥)	24470	11540	17060	28940	6060	4760	29270
Variance of cost(¥)	628	371	876	863	749	506	505
Average duration	9	4	6	8	2	2	9
Probability of the critical path	0.064	0.338	0.193	0.404	0	0	0.064
Activity	9 - 14	10 - 14	11 - 15	12 - 15	13 - 15	14 - 15	
Average value of cost(¥)	11240	10900	20740	9660	5000	7400	
Variance of cost(¥)	527	649	182	305	305	269	
Average duration	8	5	9	6	4	6	
Probability of the critical path	0.338	0.193	0.404	0	0.064	0.531	

5. Implementation and adjustment of the plan

The simulation results, can be used to construct the planning network model, which provides the general cost of the project, the planning cost of each activity, and the average duration and the probability of the critical path of each activity. If practical information on the progress and cost of the project is input into the model, during project construction, the network will be adjusted again; and after comparison with the planned model, will yield information about the progress and cost. If some activity is advanced or delayed, the influence on the successive activity and the whole project can be analyzed. Table 3 shows the actual data checked from the project after being constructed two weeks. The results in Table 4 can be derived from this. In the end, the total project costs will increase 15.48 percent, and the total duration will lengthen one day. So the manager should take measures to shorten duration and decrease cost in the following construction.

Table 3 Actual implementation of cost control based on information in the first two weeks

Activity	1 - 2	1 - 3	1 - 4	1 - 5	2 - 6	3 - 6	3 - 7	6 - 12	7 - 13
Actual cost(¥)	16950	10400	11250	11140	8840	4290	11700	7590	6820
Actual duration in weeks	7	2	5	10	3	3	4	3	4

Table 4 Results of comparison

Activity	1 - 2	1 - 3	1 - 4	1 - 5	2 - 6	3 - 6	3 - 7	6 - 12	7 - 13	Total
Implementation of cost control	450	- 100	- 750	60	780	- 1030	120	- 1530	- 2060	- 4060
Percentage	2.59	- 0.97	- 7.14	0.53	7.34	- 31.59	1.02	- 25.25	- 43.28	- 15.48
Implementation of duration	1	0	- 1	0	1	- 1	0	- 1	- 2	- 1

Note: positive in the table means decrease of the cost and shortening of the duration, while the negative means the contrary.

6. Precision analysis

In this paper, the precision of simulation results according to a central limit law. The formula for estimating the error is as follows:

$$\varepsilon = U \frac{\delta}{\sqrt{N}}$$

Where N is simulation times, which is supposed to be 10 000 in this instance; δ is standard deviation of the example. If the credibility β is given, U can be obtained by looking up Table $N(0,1)$. The formula is $\Phi(U) = (\beta + 1)/2$. If $\beta = 0.99$, $U = 2.57$.

That means that if the simulation error of the average total cost ¥262,240 is ¥74.97, then the probability that the absolute error of the average total cost being less than ¥74.97 is 0.99. In the same way, one can analyze the accuracy of the cost, duration, and the probability of the critical path of each activity. It is proved that the computer simulation method presented in this paper is precise, credible and practical.

CONCLUSIONS

Conclusively, the cost integrated control system based on computer simulation has some characteristics as follows. First, it accomplishes the purpose of integrated control of the cost, which overcomes the disadvantage of the independent control of cost, progress and resources, and combines the cost control with progress and resources control, and so, makes cost control more systematical and effective. Second, application of network scheduling technology results in a unique cost control model that integrates cost, progress, resources and quality. That makes the calculation more simple and the cost control more practical and flexible. Third, the real-time computerized simulation of the system can optimize the cost plan, and the results of its implementation can be forecasted, the hysteresis of the system can be overcome, and advance dynamical control be achieved. Fourth, the integrated control of the cost makes it possible for every step and every aspect of the project management to share the data of the whole project. That is beneficial for the systematical and scientific management approach in engineering projects.

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