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Development of shipbuilding cost management and budget optimization model based on fuzzy logic control technology

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Abstract Ship manufacturing industry is facing serious challenges of cost control and budget management, and the traditional earned value analysis method is difficult to cope with the uncertainty in project schedule and quality evaluation. This study applies the fuzzy logic control technology to the traditional earned value method to construct a shipbuilding cost management and budget optimization model. By blurring the earned value index variables, introducing the triangular fuzzy function to deal with the progress data, and combining with the fuzzy comprehensive evaluation method to determine the risk rate, the accurate estimation and dynamic control of shipbuilding cost is realized. The constructed model is validated using Monte Carlo simulation method, and the results show that: the mean present value of cost of Scenario B with fuzzy earned value model is 9,632,500 yuan, which is 29.3% lower than that of Scenario A without the model; the operation cost and maintenance cost of Scenario B account for 81.9% and 17.8%, respectively, which are better than that of Scenario A's 76.5% and 23.5%. In 56KBC shipbuilding project practice, the fuzzy earned value model accurately identifies the change point where the cost performance level in the 10th month decreases from an average of 1.2 to 0.75, which provides a key basis for project management decisions. The application of the model significantly reduces the deviation of cost estimation in shipbuilding projects, and provides enterprises with targeted measures to regulate cost deviation from organizational, economic and technical aspects. The fuzzy earned value model effectively improves the accuracy and reliability of shipbuilding cost management, and provides a practical tool for shipbuilding enterprises to realize budget optimization and cost control.

Index Terms Fuzzy logic control, shipbuilding, cost management, budget optimization, fuzzy earned value model, cost estimation

I. Introduction

In today's global economic environment, the ship manufacturing industry, as an important link to international trade, is facing new challenges. Ship products as a typical complex products, “difficult to make profits” has been the reality of the troubled ship enterprises [1]. According to the data released by China Shipbuilding Industry Association, although the ship market has been improving steadily in recent years, enterprises are still facing the risk of serious decline in profits and rising costs. How to strengthen cost management, strengthen budget control, is very important to improve the profit margin of shipbuilding enterprises.

Carrying out the project cost management of shipbuilding enterprises, mainly in the project process needs to ensure that the funds used in the project are within the scope of the budget, and to carry out all-round control of the project cost to ensure the success of the project [2]. However, the cost composition of shipbuilding enterprises is complex and diverse, covering all aspects from raw material procurement to product delivery, which makes it more difficult to manage costs [3], [4]. At the same time, due to the shipbuilding strictly by stage, sub-regional organization of production, each specialty uses different organizational forms for operations, the job assignment order is the basic unit of production organization, but also the basic unit of product cost aggregation, and the carry-over process after completion will lead to lagging cost accounting [5]-[8].

Considering the above problems, some enterprises to reduce the cost of shipbuilding, the use of shrinkage of raw materials to carry out, which not only left a large safety hazard, but also to the image of the enterprise to cause a greater negative impact [9], [10]. And at the present time when the development level of China's manufacturing industry is constantly improving, for shipbuilding enterprises, paying attention to project cost management has produced a positive effect in the development of the enterprise [11]-[13]. By increasing the cost management efforts, it realizes the enhancement of the utilization rate of all resources and reduces the unnecessary cost expenditure of the enterprise, thus expanding the market efficiency of the enterprise and realizing the long-term development of the enterprise in the new period [14]-[17].

Shipbuilding manufacturing industry is an important national strategic industry, characterized by capital-intensive, technology-intensive and labor-intensive. In the context of increasingly fierce competition in the global ship market, shipbuilding enterprises must pay great attention to cost management and budget control to maintain market competitiveness. However, traditional cost management methods are often difficult to cope with the uncertainties in the shipbuilding process, leading to frequent problems such as cost overruns and budget deviations. Shipbuilding involves many processes and a large amount of materials, with a long production cycle, and is susceptible to market fluctuations, climatic conditions, technological level and other factors, which makes cost prediction and management face great challenges. Although the traditional earned value analysis method can measure the project progress and cost deviation, it has limited ability to deal with the ambiguity and uncertainty in the project process. Therefore, how to construct a more accurate and dynamic shipbuilding cost management model has become the focus of industry research. Fuzzy logic control technology, as an effective tool for dealing with uncertainty, has shown unique advantages in the field of engineering project management. Introducing fuzzy logic control technology into shipbuilding cost management and budget optimization can effectively deal with the uncertainty in project schedule evaluation, improve the accuracy of cost estimation, and provide a more reliable basis for management decisions. Scholars at home and abroad have conducted a large number of studies on the application of fuzzy Earned Value Analysis in engineering project management, but there is still a relative lack of modeling research specifically for the characteristics of shipbuilding industry.

Based on the fuzzy logic control technology, this study improves the traditional earned value method and constructs a cost management and budget optimization model applicable to shipbuilding. Firstly, the basic principles and limitations of the traditional earned value method are analyzed, and the fuzzy earned value theory is introduced to realize the fuzzification of the earned value index variables; Secondly, the risk rate of fuzzy performance index manifestation is determined by fuzzy comprehensive evaluation method, and a complete fuzzy earned value model is established; then, the Monte Carlo method is applied to verify the model and analyze the cost-effectiveness of different schemes; finally, the constructed model is applied to the actual shipbuilding project, and the practicability of the model is verified through cost estimation and deviation regulation.

II. Shipbuilding cost management and budget optimization model construction

In order to effectively control and save shipbuilding costs, the study introduces fuzzy earned value theory into the traditional earned value method, and realizes shipbuilding cost management and budget optimization by establishing a fuzzy earned value model.

II. A.Application of fuzzy logic control techniques

II. A. 1) Traditional earned value methods

Earned Value Analysis (EVA) is an effective tool that can comprehensively measure the progress and cost of a project [18], which mainly measures the progress of a project by replacing the amount of work with a monetary amount and measuring the difference between the project's objectives and the plan, also known as deviation analysis. The method does not reflect the progress of the project in terms of the amount of money invested, but rather in terms of the amount of money converted into project results. The Earned Value Analysis Method measures and calculates the budgeted and actual costs of the completed work as well as the budgeted costs of the planned work, obtains information about the deviation of cost, progress and quality in the process of project implementation, and measures the probable completion time and completion cost, so as to achieve the purpose of monitoring and adjusting the implementation of the project and the cost of expenditure, reducing the risk of the project, and comprehensively measuring and reflecting the status of the project's progress.

(1) Three basic parameters of the Earned Value Analysis Method

1) The budgeted cost of the planned work BCWS, also known as the planned value PV, refers to the budgeted cost of the workload that is planned to be required to be completed at a certain stage of monitoring the project, and is calculated by the formula:

$$\text{PV} = \text{Planned workload} \times \text{Budgeted unit price} \quad (1)$$

2) Budgeted Cost of Work Performed BCWP, also known as Earned Value EV, is the cost of monitoring the actual amount of work completed at a given stage of the project as measured by the budget, and is calculated using the formula:

$$\text{EV} = \text{Completed workload} \times \text{Budget unit price} \quad (2)$$

3) Actual Cost of Work Performed ACWP, also known as Actual Cost AC, is the cost of actually completing the workload at a given stage of the project as consumed by the budget.

(2) Deviation indicators

1) Cost deviation CV, is the difference between earned value and actual cost, calculated as:

$$\text{CV=EV}-\text{AC} \tag{3}$$

When CV>0, project cost savings. When CV<0, project cost overruns. When CV = 0, the actual cost is equal to the budgeted cost.

2) Cost SV, is the difference between the earned value and the budgeted cost of the planned work, calculated by the formula:

$$\text{SV=EV}-\text{PV} \tag{4}$$

When SV>0, the project schedule is advanced. When SV<0, the project schedule is delayed. When SV=0, the actual progress is equal to the planned progress.

(3) Performance Indicators

1) Cost performance indicator CPI, is the ratio of earned value to actual cost, i.e.:

$$\text{CPI=EV}\div\text{AC} \tag{5}$$

When CPP > 1, the actual cost of the project is lower than the planned cost. When CPI < 1, the actual cost of the project is higher than the planned cost. When CPI=1, the actual cost is equal to the planned cost.

2) Schedule Performance Indicator, SPI, is the ratio of earned value to planned cost, i.e:

$$\text{SPI=EV}\div\text{PV} \tag{6}$$

When SPI>1, the project degree is ahead of schedule. When SPI<1, the project is behind schedule. When SPI=1, the actual project schedule is equal to the planned schedule.

II. A. 2) Fuzzy Earned Value Methods

In R&D project management, project progress and completion are often estimated by experienced experts or project members, and there is a certain degree of uncertainty, which cannot be analyzed accurately by directly applying the earned value method. In this paper, in the process of describing the project progress and quality evaluation, such expressions as completed, completed more than half, less than half, etc. are used, and in order to better express this ambiguity, the fuzzy language is transformed into specific values. In this paper, the fuzzy language-based earned value method is used for the comprehensive control of project cost, schedule and quality, which is very necessary for R&D project management.

(1) Fuzzy earned value definition and calculation

Fuzzy Earned Value Method is a method that uses fuzzy linguistic metrics to characterize the degree of progress of an activity, and calculates the fuzzy Earned Value of a project by giving the fuzzy number corresponding to the fuzzy linguistic metrics [19]. Based on this, the corresponding fuzzy earned value indicator system is derived for further analysis. For the fuzzy earned value $\tilde{E}V_i$ of the i th activity of a project, it is calculated as follows:

$$\tilde{E}V_1 = \tilde{F}_1 \times BAC_i = [E1_i, E2_i, E3_i, E4_i] \tag{7}$$

where $\tilde{F}_1$ is the fuzzy percentage of completion of activity i, BAC_i is the budget for completion of activity i, and it is the planned cost of completion of activity i. $[E1_i, E2_i, E3_i, E4_i]$ is a trapezoidal fuzzy number representing the fuzzy earned value of i.

The total $\tilde{E}V$ of the project at each monitoring point is obtained by summing each $\tilde{E}V_1$, where $i = 1, 2, \cdots, n$ = (n is the number of fuzzy jobs). The total fuzzy earned value $\tilde{E}V_1$ obtained by adding up the fuzzy earned values of each activity $\tilde{E}V$ is calculated as follows:

$$\tilde{E}V = \sum_{i=1}^{n} \tilde{E}V_i \tag{8}$$

(2) Transformation of fuzzy numbers into real numbers

In order to facilitate the analysis of the calculation results, the calculated fuzzy earned values are transformed into real number indicators for trapezoidal fuzzy numbers $M = [a, b, c, d]$. Where $b, c,$ is the most probable case, a is the lower limit of probability, and d is the upper limit of probability, the transformed real number L is computed with the formula:

$$L = \frac{(a+4b+4c+d)}{10} \tag{9}$$

II. B. Fuzzy Earned Value Modeling

II. B. 1) Fuzzification of Earned Value Indicator Variables

The progress of the construction check node is usually expressed as “half completed”, “start two days”, etc. Therefore, a fuzzy function is chosen to calculate the fuzzy function, there are many kinds of fuzzy functions, in order to facilitate the calculation and ensure the accuracy of the results, this paper chooses the triangular fuzzy function to deal with the progress Data.

Let the fuzzy number on the domain R be M, if the affiliation function of M μ_M makes R→[0, 1] expressed as:

$$\mu_M(x) = \begin{cases} \dfrac{x-l}{m-l} & x \in [l, m) \\ \dfrac{x-u}{m-u} & x \in [m, u) \end{cases} \tag{10}$$

Then M is said to be a triangular fuzzy number and $\mu_w(x)$ is a triangular fuzzy function. In Eq. (10) l and u denote the lower and upper bound values of M respectively, and $0<1<m<u$, m is the value taken when the fuzzy set M affiliation degree is 1.

The budgeted cost of completed work BCWP after the work i schedule fuzzification is:

$$\tilde{BCWP}_i = \hat{n}_i \times BCWS_i = [B_{i1}, B_{i2}, B_{i3}] \tag{11}$$

In Eq. (11), $\tilde{BCWP}_i$ is the budgeted cost of the completed work for job i, and $\hat{n}_i$ is the fuzzy progress of job i, which is expressed in fuzzy values:

$$\hat{n}_i = [l_i, m_i, u_i] \tag{12}$$

After the completed work budget cost BCWP is fuzzified, the corresponding two performance indicators CPI and SPI are fuzzy formulated as:

$$\tilde{CPI} = \frac{\tilde{BCWP}}{\tilde{ACWP}} = \left[\frac{B_1}{ACWP}, \frac{B_2}{ACWP}, \frac{B_3}{ACWP}\right] \tag{13}$$

$$\tilde{SPI} = \frac{\tilde{BCWP}}{\tilde{BCWS}} = \left[\frac{B_1}{BCWS}, \frac{B_2}{BCWS}, \frac{B_3}{BCWS}\right] \tag{14}$$

II. B. 2) Fuzzy Performance Index Manifestation

Since the evaluation indicators are blurred and difficult to compare directly, it is necessary to explicitly process the evaluation indicators. This paper introduces an interval variable of α cut-off set, according to the characteristics of the construction project, the risk rate as a given α value, the upper limit of the interval variable under the α value given by this fuzzy number is taken as an object of numerical comparison, α value interval variable as shown in Fig. 1.

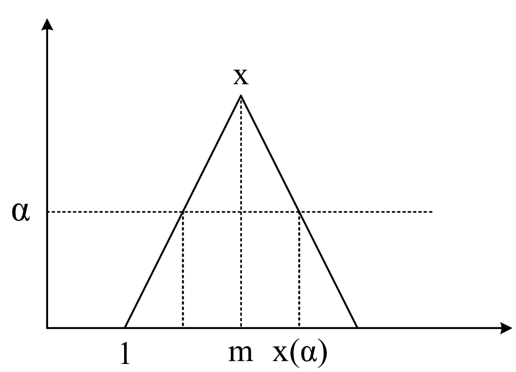

Figure 1: Interval variable graph of α values

For the determination of the value of α follow the principle of easy to calculate and closely related to the object under study, combined with the characteristics of the research in this paper ultimately choose the fuzzy comprehensive evaluation method.

(1) Determine the selected object set. $X = \{x_1\}$ ={project risk}.

(2) Determine the set of factors of the evaluation object. In the construction phase of the project, the risk factors affecting the construction process can be broadly categorized into two types, external risk and internal risk. The external risk factors mainly refer to the external environmental factors and the factors of other parties involved in the project, while the internal risk factors mainly refer to the factors affecting the internal problems of the constructor. By analyzing a large amount of literature and combining the characteristics of the case of this paper, the factors of the evaluation object are determined to be the financial status, meteorological conditions, technical level, and engineering geology, respectively.

Set $W = \{w_1, w_2, w_3, w_4\}$ ={funding status, meteorological conditions, technical level, engineering geology}.

(3) Determine the set of rubrics for the evaluation object. Set $V = \{v_1, v_2, v_3, v_4, v_5\}$ ={very high risk, high risk, average risk, low risk, very low risk}.

(4) Determine the weight vector of evaluation factors. This paper adopts the method of questionnaire to determine the weight vector of the evaluation factors, targeted questionnaires were issued to the construction unit, and the object of filling out the questionnaire has a certain degree of representativeness.

(5) Single-factor fuzzy comprehensive evaluation to determine the evaluation matrix R.

(6) Multi-indicator fuzzy comprehensive evaluation. Synthesize the fuzzy weight vector A with the fuzzy relationship matrix R to get the fuzzy comprehensive evaluation result vector of each evaluated object B.

III. Monte Carlo-based model validation

This chapter uses the Monte Carlo method to simulate the example to verify the practicality of the shipbuilding cost management and budget optimization model constructed based on the fuzzy earned value method above.

III. A. Monte Carlo simulation method

Monte Carlo method, also known as statistical simulation experiment method, which belongs to a branch of experimental mathematics. The method is based on the theory of statistical sampling, and uses random numbers to obtain statistical eigenvalues (e.g., mean, probability, etc.) from statistics, sampling experiments, or stochastic simulations of the random variable in question, and use them as the numerical solution to the problem to be solved [20]. In essence, the Monte Carlo method is to use a certain probability distribution to generate random numbers to simulate the actual possible random phenomena in the project, and statistical characteristics of its data, and then get the numerical solution of the actual problem. The principle of this method is that in the simulation process, independent samples are taken from the probability distribution of the costs of the activities that constitute the cost of completion of the project, and these samples are subjected to trial calculations. During the trial calculations, the sample values for one project completion cost may be optimistic while the sample values for another project completion cost may be pessimistic, but it is based on the probability distribution of the costs of each activity of the project that determines the frequency of occurrence of the sample data. Therefore, after a large number of simulation trial calculations, the project completion cost statistics can basically reflect the actual cost distribution of the project.

Monte Carlo method can be applied to the random variable obeys any distribution, the reliability calculation of any combination of random variables, this method is simple, easy to prepare the computer program, can ensure that according to the probability of convergence, the calculation accuracy with the increase in the number of simulations and improve. The theoretical basis of the Monte Carlo method is the law of large numbers, a fundamental law in probability theory. Therefore, in principle, the method has no limitations on the scope of application.

III. B. Analysis of model validation results

The fuzzy earned value model was simulated using the Crystal Ball 11.1.1 software package. It was assumed that the number of simulations was 1000 times and the confidence level was 95%. One thousand PC sample values were obtained through the operation of the Crystal Ball 11.1.1 software package. On this basis, the histogram of the PC sample values of a certain shipbuilding project was plotted to obtain the simulation numerical analysis and the proportion of each cost.

Scheme A does not use the fuzzy earned value model. The sample values of the present cost of this scheme are shown in Figure 2. The average operation cost was 7.02 million yuan. The present value of the cost of Plan A is mainly distributed between 12.2 million and 13 million yuan, with a probability of 98.06%.

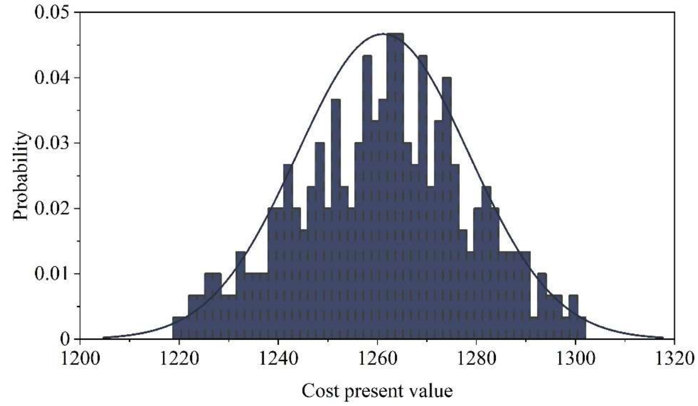

Figure 2: Project A cost present value sample value

The sample values of the present value of cost after using the model in Scheme B are shown in Figure 3. The average operation cost is 5.2 million. It indicates that the initial construction cost of Scheme A is higher than that of Scheme B. The present value of the cycle cost of Plan B is mainly distributed between 9.1 million and 10.15 million yuan, with a probability of 99.63%.

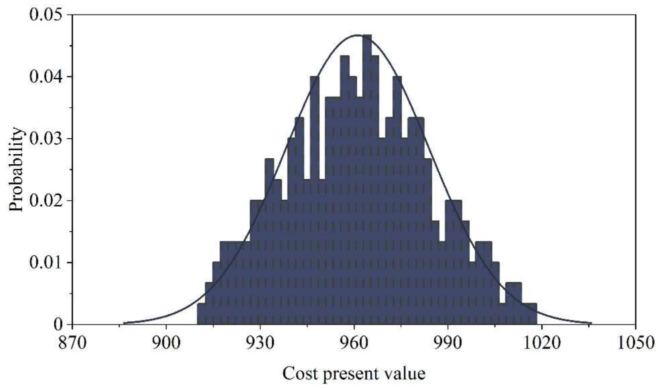

Figure 3: Project B cost present value sample value

The simulated values are analyzed as shown in Table 1. The mean values of Scenario A and Scenario B are 13,626,200 yuan and 9,632,500 yuan, respectively. It shows that the cycle cost of Scenario A is much higher than that of Scenario B.

Table 1: Numerical analysis

Scheme	Mean	SD	Min	Max	SDE
A	1362.62	40.63	1163.21	1463.61	0.53
B	963.25	26.93	843.62	1043.63	0.39

The percentage of each cost of the cycle is shown in Table 2. Option A operation cost and maintenance cost account for 76.5% and 23.5% respectively. Option B operation cost and maintenance cost account for 81.9% and 17.8% respectively. It shows that the maintenance cost of Option A is larger than that of Option B, and more money needs to be spent in the later stage to ensure normal operation.

Table 2: The proportion of the cost of the cycle (%)

Scheme	Precost	Operating cost	Maintenance cost			
			Daily management and maintenance cost	Medium cost	Cost of major or technical transformation	Tot
A	0	76.5	6.5	1.4	15.6	23.5
B	0.3	81.9	8.7	3.8	5.3	17.8

To summarize, both the operation cost in the construction period and the maintenance cost in the operation period of Scheme A are much higher than that of Scheme B. In the case of technical feasibility, it is economically more cost-effective to construct Scheme B than Scheme A. Therefore, the fuzzy earned value model constructed in this paper can realize the shipbuilding cost management and budget optimization.

IV. Application of cost control cases in shipbuilding projects

This chapter is based on the fuzzy earned value method for cost control of shipbuilding project of Company A. By demonstrating the process of applying the fuzzy Earned Value Method in specific examples, it provides a reference for applying the method in future shipbuilding projects.

IV. A. Basic project overview

IV. A. 1) Preparation of project plans

Before developing a shipbuilding program, this paper breaks down all the work required for shipbuilding into modules to make each module easier to control and adjust. For a shipbuilding project, the work structure decomposition should be easy for each work department to control and track the progress of the project. This paper takes the specific work structure decomposition of 56,000 DWT bulk carrier construction as the basis for the preparation of the basic plan. At the same time, the project is specifically assigned to the corresponding responsible departments, which in turn clarifies the responsibilities. Based on the analysis of the work tasks of the 56KBC shipbuilding project of Company A, it is found that it can be divided into eight nodes, including the start of construction (Node 1), keel laying (Node 2), dock shifting (Node 3), main engine loading (Node 4), launching (Node 5), re-checking (Node 6), sea trial (Node 7), and delivery of the ship (Node 8).

IV. A. 2) Determination of test points and data collection

In the process of ship production, only by determining the inspection time point can we use the method of earned value management to analyze why the deviation occurs, and then take corresponding measures to adjust the project to ensure the production schedule and control the production cost. Determining the accurate and appropriate inspection point is especially important for ship construction cost control. Inspection time is related to the progress, accuracy and workload of ship construction. If the inspection period is too long, the workload will be less and easier, but it is difficult to control the cost accurately. If the inspection time is set too closely, the workload will be extremely heavy, which makes it difficult to carry out the management work, but the timeliness and accuracy of cost control will be very high. Therefore, according to the project cycle, each stage of the production process connection and other related circumstances of the overall consideration, comprehensive analysis, in order to determine the most reasonable testing time point. Generally speaking, the time point of the earned value data inspection is set in the following ways: firstly, the nodes with milestone significance in the process of shipbuilding. Secondly, the testing time point is set according to the natural time point, such as 1 month, 3 months, 6 months and so on. Third, the important process connection points in the shipbuilding process. Considering the above three ways, this paper combines the natural time points, key process nodes of shipbuilding and milestone points, and sets up project cost control data detection nodes, such as “starting work, laying keel, dock shifting, launching, re-checking, sea trial” nodes. Appropriate adjustments can be made according to the project characteristics and the actual production process.

Starting from the signing of the contract until the final delivery of the ship, the entire ship production process continuously generates cost, progress and various other data. Relevant data are accurately and immediately collected, counted and analyzed to provide the most direct reference data for ship production managers, which is the basis for the effective management of production cost of shipbuilding projects. Accurate cost data is the prerequisite for production management using the earned value method. Company A can only obtain more accurate and systematic data during the subsequent implementation of shipbuilding, laying the foundation for the subsequent earned value analysis by setting up a unified earned value calculation method throughout the project according to the standard at the beginning of the shipbuilding project, which will help to control the progress of the shipbuilding progress and costs of Company A and provide guidance for the subsequent work. In order to obtain more accurate and systematic data in the subsequent shipbuilding implementation process, it can lay the foundation for the subsequent earned value analysis, which in turn helps to control the ship construction progress and cost of Company A and provide guidance for the subsequent work. Among them, in the process of data statistics, the following aspects need to be paid attention to: First, according to the 56KBC shipbuilding project plan and the aforementioned nodes, calculate and analyze the estimated cost of completing the expected workload at each node. Secondly, based on the nodes set in the previous section, quickly obtain the completion of the actual work at each time point, calculate the real spending at each time point, and compare it with the estimated cost and schedule, in order to provide guidance for the subsequent shipbuilding. In summary, the node data required by the earned value method are obtained.

IV. A. 3) Statistical project data

The cost and expenses corresponding to each planned detection node are compiled as shown in Table 3. Among them, the cost required at the time of ship delivery is the highest, totaling 65.2 million yuan.

Table 3: The corresponding costs of each node

Node	Time	The percentage of the assembly/%	Cost completion/10 thousand yuan
Node 1	2023.03.22	0%	0
Node 2	2023.06.08	23%	1321
Node 3	2023.09.23	74%	4960
Node 4	2023.10.29	86%	5285
Node 5	2023.12.06	87%	5804
Node 6	2024.01.01	93%	6293
Node 7	2024.02.26	94%	6421
Node 8	2024.03.22	100%	6520

In summary, the cost breakdown corresponding to each program node is calculated as shown in Table 4. Each node mainly needs to consume costs in steel, parts, paint, labor, gas and diesel, electricity, consumables, equipment rental, etc.

Table 4: The cost details of each node

Node/Cost item	Steel	Parts	Paint	Artificial	Diesel oil	Electric charge	Consumable	Equipment leasing	Sum
Node 1→Node 2	1000	60	110	85	3	20	43	-	1321
Node 2→Node 3	2000	500	490	35	300	93	542	1000	4960
Node 3→Node 4	63	1526	1235	635	963	152	711	-	5285
Node 4→Node 5	16	36	631	1634	963	152	1096	1276	5804
Node 5→Node 6	900	1630	1450	600	900	500	200	113	6293
Node 6→Node 7	-	1523	1204	900	500	850	1052	392	6421
Node 7→Node 8	-	-	63	1722	1236	1634	1364	501	6520
Sum	3979	5275	5183	5611	4865	3401	5008	-	36604

Table 5: Analysis of the earning value of the 56KBC ship construction project

Task number	PV	EV	AC	CV
1	102.02	101.83	99.93	0.01
2	23.93	24.08	23.13	-0.01
3	32.17	31.93	40.44	0.05
4	2357.17	2353.09	2382.85	-3.63
5	1716.93	1714.9	1730.41	-2
6	641.15	641.22	660.91	0
7	525.46	525.42	523.32	0
8	550.03	548.17	546.52	-2
9	615.72	613.91	625.83	-1.84
10	355.62	355.52	369.28	-0.05
11	260.16	258.33	256.49	-1.95
12	24.23	24.43	26.67	0.05
13	24.48	24.34	26.48	-0.01
Sum	7229.07	7217.17	7312.26	-11.38

IV. B. Application Analysis of Fuzzy Earned Value Methods

IV. B. 1) Computational analysis of basic parameter data

Assuming that the construction is currently at the fourth inspection point, the relevant statistical earned value analysis of the 56KBC vessel on October 29, 2023 based on the summary of relevant data collection is shown in

Table 5 If the traditional earned value method is used, it only focuses on the project as a whole and can only know that on October 29, 2023, the overall project schedule of the 56KBC vessel is slightly delayed and cost overruns are incurred, i.e., the last row of the total of Table 5 is shown. Using the Fuzzy Earned Value Method is analyzing the overall multi-level sub-projects and can tell which specific sub-project is responsible for the final cost overrun of the project.

IV. B. 2) Cost estimation and analysis

Due to the large amount of data collection and consumption of resources using fuzzy earned value cost estimation, this part collects the cost data of sub-project pipe system fabrication and installation of 56KBC ships for the application of this improved method, and the basic data and calculated performance indicators are shown in Table 6 and Table 7. The table collects data from each month with equal time interval and applies the fuzzy earned value cost estimation model. The construction cost is controlled dynamically, and the traditional formula is used for earned value cost estimation when the change point is not detected, and the fuzzy formula is used for earned value cost estimation once the change point is detected. Assuming cyclical CPI cost performance data are independent of each other, change points are calculated after ensuring significant changes in performance trends.

Table 6: The basic data of the project during the production and installation

Moon	Periodicity PV	Cumulence PV	Periodicity EV	Cumulence EV	Periodicity AC	Cumulence AC
1	39.48	39.52	36.36	36.38	34.27	34.21
2	50.87	90.19	46.04	82.11	44.27	78.29
3	43.33	133.37	43.09	125.4	41.38	119.9
4	50.61	184.29	39.18	164.84	38.07	157.97
5	53.39	237.56	48.05	212.73	48.97	207.08
6	65.68	303.43	55.45	268.09	60.06	267.02
7	45.42	348.9	38.02	305.88	30.54	297.53
8	42.6	391.37	42.45	348.51	35.25	332.85
9	49.15	440.43	46.21	394.39	40.21	373.07
10	55.5	495.99	49.18	443.47	40.35	413.72
11	43.4	539.37	54.04	497.71	45.45	459.29
12	52.22	591.59	40.26	537.76	61.34	520.19

Table 7: Cyclical and cumulative cost performance indicators

Moon	Periodicity CPI	Cumulence CPI
1	1.046	1.077
2	1.061	1.041
3	1.057	1.045
4	1.01	1.05
5	0.959	1.041
6	0.913	1.006
7	1.256	1.025
8	1.2	1.048
9	1.139	1.056
10	1.23	1.069
11	1.201	1.081
12	0.64	1.034

Variable point detection was performed at each node as the project progressed, and a change in the CPI trend was able to be detected when the project was constructed to the end of the 12th month. The CUSUM of cyclical CPI is shown in Figure 4. The CUSUM graph of cyclical CPI turns in the 6th and 10th month, indicating that the cost performance trend is likely to have changed and there is a change point. The formula calculates that there is no real change in the level of cost performance in the 6th month, while the confidence level of change in the 10th month is 91.63%, and it can be determined that the cost performance does change in the 10th month. At the same time, the 10th month is determined to be the change point, and the average level of cost performance at that point in time changes from 1.2 to 0.75. The average cost performance changes from greater than 1 to less than 1, indicating that the actual cost changes from savings to overruns. The project manager should realize that a significant or persistent change in a factor in the construction process is not accidental and the root cause of the change must be investigated. After investigation, it was found that the main reason was the rising price of the main steel pipe used in the fabrication of the pipe system during the construction period, which led to a change in the cost performance trend, which required the project manager to take timely cost control measures based on the actual situation at the time.

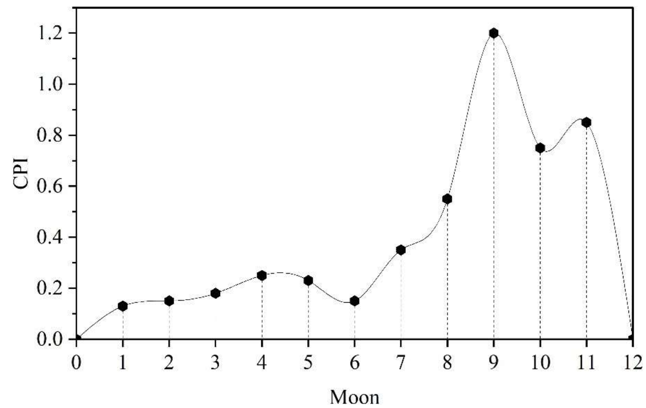

Figure 4: CUSUM chart of periodic CPI

A comparison of the EAC estimation deviations of the fuzzy Earned Value model and the traditional Earned Value model is shown in Figure 5. As the completion time approaches, the estimated completion cost gets closer to the final actual completion cost. The fuzzy earned value model estimates are consistently closer to the final actual costs. Between month 5 and November, the accuracy of the fuzzy earned value model estimation fluctuates more than that of the traditional earned value method, and the stability is insufficient, which may be due to the fact that there is less data accumulated after the change point, and the accuracy and stability of the estimation are affected by the small amount of data. It shows that the use of fuzzy Earned Value Modeling improves the accuracy of completion cost estimation, increases the credibility of the comparison with the target cost, and is conducive to the dynamic control of ship construction cost.

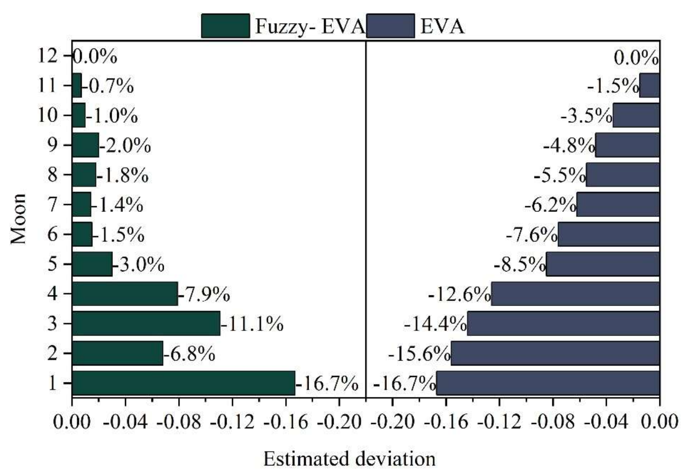

Figure 5: Fuzzy-EVA is compared with the EAC estimation deviation of EVA

IV. B. 3) Cost deviation regulation based on fuzzy earned value approach

In view of the current deviation, it is necessary to analyze the reasons and then make targeted regulation according to the specific reasons. 156KBC ship project earned value reasons are analyzed as shown in Table 8. 156KBC ship cost overruns are mainly concentrated in the price increase of materials and equipment, and the cost of catching up with the delay in progress, the procurement of materials is mainly due to the price increase of steel and tubes, and the outfitting of engine room equipment into the cabin and the outfitting of the bottom. The cost overrun for material procurement was mainly due to the price increase of steel and pipes, while the price increase of cabin equipment and bottom outfitting was mainly due to the price increase of cabin equipment.

Table 8: Analysis Table of the Reasons for the Earned Value Deviation of 156KBC

Node	Progress deviation	Cost deviation	Progress situation	Cost condition	Causal analysis
Node 1	0	2.13	Normal	Economy	Completion
Node 2	0	0.61	Normal	Economy	Completion
Node 3	0	-8.61	Normal	Overspend	Price rise
Node 4	-1.31	-16.34	Delay	Overspend	Progress delay
Node 5	0.06	2.34	Advance	Economy	Completion
Node 6	-0.36	-11.4	Delay	Overspend	Progress delay
Node 7	-2.31	1.64	Delay	Economy	Progress delay
Node 8	-0.2	-2.34	Delay	Overspend	Progress delay
Sum	-4.12	-31.97	Delay	Overspend	Progress delay

According to the current construction status of 156KBC ships, Shipyard A can take the following corrective measures to ensure cost savings with on-time completion.

Organizationally, improve the co-ordination ability of project management personnel to reduce the increased cost of catching up due to delayed work processes. For the problem of delayed delivery of purchased equipments or materials, the relevant production management personnel will place material orders in advance, the procurement department will make timely purchases and actively follow up the process of transportation, and then do a good job of connecting the materials and equipments with the production management personnel after entering the site, so that the production personnel can carry out the production in a timely manner. For the problem of delayed segmentation process, production management personnel should do a good job of personnel deployment, while finding ways to improve the enthusiasm of production personnel, accelerate production efficiency, and ultimately achieve the progress without delay, reduce rush. Project managers should not only coordinate personnel, but also consider the site arrangements, resource loading and other requirements, in a timely manner to the corresponding production work to provide the appropriate site and resources, to avoid subsequent delays in progress and the cost of catching up.

On the economic side, it is necessary to strengthen the audit of the actual volume of the project and the related payment. From the overall viewpoint, it is necessary to consider whether the structural decomposition of shipbuilding work, progress planning and cost planning are unified, whether the cost decomposition structure can reflect the demand for the use of funds at each stage, whether the changes occurring in the project are necessary or not, and whether the additional funds have exceeded the budget and so on. In addition to the objective factors of rising material and equipment prices, the use of materials and equipment need to do a good job in the deployment of materials and equipment, the standardization of material consumption and the recovery of excess materials need to strengthen the management efforts to improve the efficiency of the use of equipment in order to save costs.

In terms of technology, according to the problems of outfitting, Shipyard A can make an in-depth analysis of the construction technology and process of integrated shell, outfitting and coating of the segment, optimize the production process of the segment, adjust the production process, improve and optimize the existing technology, improve the production capacity, and solve the problem of delayed progress, and at the same time, the improvement of the technology and optimization of the process also provide a technical basis for the reduction of the cost of production. In addition, the technical department should also make technical preparations for the problems that may arise in the subsequent processes, conduct training and cognitive use of the new equipment purchased in the subsequent docking process in advance, and do a good job in the technical inspection of important equipment to ensure the quality.

V. Conclusion

The fuzzy earned value model effectively improves the accuracy and reliability of shipbuilding cost management by introducing fuzzy logic control technology. Monte Carlo simulation validation shows that the present value of cost of Program B cycle with fuzzy Earned Value Model is mainly distributed in the range of 9.1~10.15 million yuan, with a distribution probability of 99.63%; the average cost is 9.6325 million yuan, and the proportion of maintenance cost is only 17.8%, which is significantly better than the traditional method in terms of economic benefits. In the practice of 56KBC shipbuilding project, the fuzzy Earned Value method accurately identifies the cost performance change point, and the cost performance level is reduced from 1.2 to 0.75 from the 10th month onwards, which provides a scientific basis for the management decision. The application of the model significantly reduces the deviation of the completion cost estimation, and for the 4.12% schedule delay and 31.97% cost overrun during the construction process of 156KBC, targeted control measures are formulated from three aspects: organizational coordination, economic audit and technical optimization. Through the dynamic monitoring and analysis of 8 key nodes in the shipbuilding process, the fuzzy Earned Value Model realizes the accurate identification and effective control of cost deviation. The model provides a practical cost management and budget optimization tool for shipbuilding enterprises, which is of great significance to improve the economic efficiency of enterprises and enhance market competitiveness.

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