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# Cost Control of Engineering Project Based on Critical Path Earned Value Method

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**Abstract:** With development of market economy and progress of building construction technology in our country, more and more importance and affirmations are attached to the cost control of construction project which is also viewed as a hot issue in the construction field. Various forecasting analysis methods appear in the research course. The earned value method discussed in this paper is a outstanding one. It should be recognized that compared to other projects, the construction project is characterized by large scale, long cycle and significant external influence, so the whole earnings of project and the core competitiveness of enterprises will be profoundly impacted by the specific management process. The cost and progress are two core objectives in the management process of engineering projects. The earned value management method studied in this paper is a cost control and management method that has been widely accepted throughout the world at present. The introduction of this method in the cost control will not only effectively improve the management efficiency of engineering project, but also has an important practical significance to guarantee the economic profits of construction enterprises. The earned value method is actually a conventional method for controlling and supervising the "cost—progress" of the construction projects and can assure the successful completion of construction projects by cost control and time limit control.

**Keywords:** Critical path earned value method; Cost control; Construction progress

## 1. Introduction

With the development of market economy and rapid growth in the living standards in our country, the promotion and development of construction of engineering projects have attracted wide attentions from all sectors of society. The intensifying market competition among the construction enterprises results in squeezing profit space of the domestic construction enterprises. Under this environment, based on practical situations, the construction enterprises should further enhance the cost control to reduce the cost so as to offer the necessary supports for reinforcement of the level of core competitiveness. The cost control should run through the construction project and this requires the enterprises to base on the critical path of construction projects to analyze the cost distribution and detect the shortcomings of cost control during construction and adopt according measures timely to improve.

There are objective differences between cost and progress and this is a common case occurring in the operation process of domestic construction enterprises, such as advanced construction progress and lower actual cost than the budget cost which are mainly caused by the following reasons: first, the time limit of construction is shortened by technical methods on the premise that the quality and quantity requirements are fulfilled; second, the impacts are caused by the narrowed construction range. At the same time, there are some construction projects suffering tightness at first but looseness afterwards which also results in the difference of working efficiency between early and late construction stage, further leading to significant differences between actual cost and budgets. In fact, if we merely conduct simple contrastive analysis on the estimated value and actual value for the above cases, we will fail to effectively present the performance level of the actual cost management at different construction stages. Based on the above cases, this paper starts with the actual working progress and adopts the advanced earned value method to focus on the issues about the construct progress completed by the enterprises under the same working environment and cost control of construction cost with an expectation to offer some theoretical and data supports for effective solutions of the above issues.

## 2. Project Earned Value Theory

### 2.1. Concept of Earned Value Method

Earned value method studied in this paper refers to an effective method for comprehensive analysis on cost—progress of construction projects [1] and is also called as earned value management. Its fundamental principle is to express the construction progress with quantity of money as the unit and use the quantity of money which is translated into the construction result to replace the actual construction quantity. Through measuring and calculating the budgetary cost and actual cost for the works planned to complete, the effective evaluation will be carried out for the overall construction progress of current project and the specific implementation of budget and progress of project can be defined through contrast with the determined cost and progress in the contract [1]. The above variance analysis on cost—progress can provide necessary data support for the construction cost control of enterprises for the purpose of timely adjustment.

### 2.2. Three Intermediate Variables of Earned Value Method

(1) The budgeted cost of work performed (BCWP)
In essence, the budgeted cost of work performed is viewed as the earned value and can offer the necessary support and help for the communication between project cost and progress in the practical application process. To be specific, the estimated amount for the work quantity in the unit time of BCWP can measure the cost consumption condition for the work performed in the currency mode. Its computational formula can be:

$$BCWP = \text{actual work volume X budgeted unit price} \tag{1}$$

(2) The actual cost of work performed (ACWP)
This intermediate variable mainly refers to the cost for a certain work performed at a certain stage during the project construction and is often applied to supervise the cost consumption for the actual performed work. Its computational formula is:

$$ACWP = \text{actual work volume X actual unit price} \tag{2}$$

(3) Budgeted cost of work scheduled
This intermediate variable means prior to implementation of earned value management, firstly, the project budget should be formulated based on the expected project and the exploded views are constructed according to the contract and work structure so as to determine the overall work volume level in this project. It is generally adopted for determination of the difference between estimated project progress and the actual progress. Its computational formula is:

$$BCWS = \text{scheduled work X budgeted unit price} \tag{3}$$

### 2.3. Two Differential Analysis Variable Indexes

(1) Schedule variance (SV)
SV adopted in this research refers to the difference between BCWP and BCWS of the point item earned value during the project inspection. This value is less than 0, showing that the present project schedule has been slower than the required scheduled plan, that is, the result of schedule control is bad; on the contrary, if Scheduled Variance is greater than 0, indicating that the project schedule control is good. When this value equals to 0, representing that the schedule of this engineering project completely satisfies the plan. If there is no significant variance between the cost and plan, then we can consider that the overall level of schedule control is good and no adjustment is needed.

$$SV = BCWP - BCWS \tag{4}$$

(2) Cost variance (CV)
CV refers to the variance between the earned value and ACWP at the check time point. CV is less than 0, indicating that the project cost is overspent, namely, for the predetermined cost, the actual project cost is relatively high and the cost control should be improved; CV is greater than 0, showing that the project construction is economic and the cost control for the engineering project is effective; when the CV equals to 0, then the cost control is carried out according to the plan and the project supervisor does not have to adjust the project.

$$CV = BCWP - ACWP \tag{5}$$

### 2.4. Two Variable Indexes

(1) Schedule performed index (SPI)
SPI, the abbreviation of Schedule Performed Index, refers to the ratio of earned value and planned value of the engineering project. SPI＜1 shows the schedule has been delayed; SPI>1 indicates the schedule is advanced; SPI=1 implies the actual schedule agrees with the planned schedule [2].

$$SPI = BCWP / BCWS \tag{6}$$

(2) Cost performed index
CPI, the abbreviation of Cost Performed Index, refers to the ratio of earned value and actual cost. CPI>1 shows the actual cost is lower than the budget; CPI<1 indicates the cost exceeds the budget; CPI=1 shows the actual cost agrees with the budgeted cost.

$$CPI = BCWP / ACWP \tag{7}$$

### 2.5. One Predicted Value

If the cost control at the present stage is artificially put off to the subsequent stage, then we can perform simple calculation for the work performed cost in the future with the following formula:

$$EAC = ACWP + (\mathrm{BCWS_T} - \mathrm{BCWP}) \times \frac{ACWP}{BCWP} = BCWS_T \times \frac{ACWP}{BCWP} \tag{8}$$

The earned value method adopts the above three major parameters, four evaluation indexes and two variable indexes to analyze cost—schedule for the project. The variance analysis of cost—schedule can be achieved through contrast between actual works performed and planned work, actual cost and cost of work performed so as to carry out more scientific control and management for the project and support necessary guarantee and supports for smooth completion of construction projects.

## 3. The Application of Earned Value Method in the Cost Control

### 3.1 Determination of Analysis Path

The actual construction process is inevitably objectively impacted by the external environment and this is a common problem that all construction projects have to solve during the development of engineering projects. The costs with different properties will occur at different stages under different environments. Some projects may halt due to fund limitation, but under this circumstance, the administration cost and financial cost still occur and these costs are not the cost for the critical paths of construction projects. It is improper to incorporate these costs into the actual calculation for variance analysis of cost-schedule, as the variance at the critical paths will be definitely covered by the earned value from this data and the efficiency of data about cost-schedule for the construction enterprises will reduce as well, thus impacting the decision making. Based on the above cases, we can conclude that only the smoothly performed works at the critical paths can represent the achievement of earned values and completion of construction plan [3].

Hence the core task of analysis of cost-schedule is to find out the critical paths based on which the variance analysis can be carried out. The critical paths of construction units mainly include main body of the engineering project set forth in the contract. This critical path can be measured with the form of currency and consists of the following aspects: direct labor cost, direct materials cost, direct mechanical equipment cost, other direct costs and indirect construction cost. The above costs can be analyzed collectively or separately during specific calculation. The critical cost paths analysis is showed in the following Table 1:

### 3.2. Index Computation and Graphical Analysis

After basically completing the analysis of critical paths, we can carry out analysis with the mode of index computation. The specific details are shown in Table 2.

**Table 1. Variance analysis of critical path cost**

| Indexes of computation Analysis indexes | Direct labor cost | Direct materials cost | Direct mechanical equipment cost | Other direct costs | Indirect construction cost | Total cost |
|---|---|---|---|---|---|---|
| CV | | | | | | |
| SV | | | | | | |
| CPI | | | | | | |
| SCI | | | | | | |
| Critical indexes | | | | | | |

**Table 2. Indexes of earned value method**

| Indexes | Computational formula | Computed result | Result analysis |
|---|---|---|---|
| CV | BCWP-ACWP=EV-AC | CV=0 | AC=EVScheduled settlement, cost is consistent |
| | | CV>0 | AC<EV Surplus cost or high efficiency |
| | | CV<0 | AC>EV Cost overrun and measures should be adopted |
| SV | BCWP-BCWS=EV-PV | SV=0 | EV=PV he actual schedule is consistent with the plan |
| | | SV>0 | EV>PV Ahead of schedule |
| | | SV<0 | EV<PV Schedule delay and measures should be adopted |
| CPI | BCWP/ACWP=EV/AV | CPI=1 | AC=EV Consistent cost |
| | | CPI>1 | AC<EV Economic cost |
| | | CPI<1 | AC>EV Cost overrun and measures should be adopted |
| SCI | BCWP/BCWS=EV/PV | SCI=1 | EV=PV Consistent schedule |
| | | SCI>1 | EV>PV Ahead of schedule |
| | | SCI<1 | EV<PV Schedule delay and measures should be adopted |
| Critical indexes | CPI*SCI | Upper limit: Greater than 1.6 | The budget plan is too pessimistic and should be adjusted |
| | | upper limit: Between 1.4 and 1.6 | The actual cost seriously deviated from the planned cost and should be adjusted |
| | | lower limit: Between 0.4 and 0.6 | |
| | | ower limit: Lower than 0.4 | The budget plan is too optimistic and should be adjusted |

### 3.3. Index Computation and Analysis of Earned Value Method

This research will collect the relative data of cost-schedule through analysis of critical path and this is the fundamental premise for detection of variance and adoption of corresponding variance removal measures in the construction process and is also a basic condition for effective progress of control of construction cost and construction schedule. During the actual analysis, it is necessary to add two critical path variance analysis indexes: MDGC (schedule variance at critical path) and DGC (cost variance at critical path) [4]:

$$SVcp = BCWPcp - BCWScp; \quad CVcp = BCWPcp - ACWPcp \tag{9}$$

Through computation and analysis on relevant data, we can further display the data via the curve graph as follows so as to offer necessary data supports for the decision makers and guarantee the provided construction schedule condition is in time and effective.

The curve graph for evaluation of earned value method with critical paths is shown as Figure 1

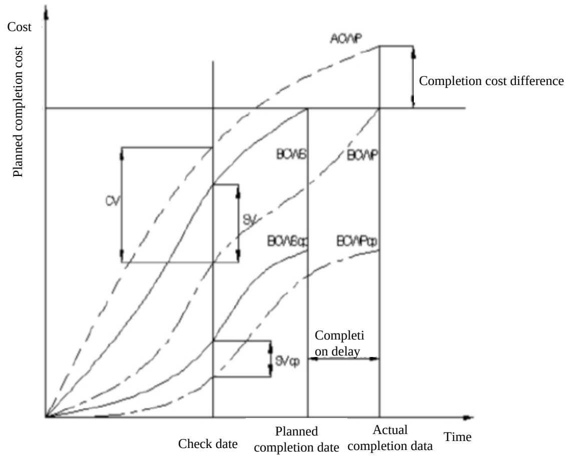


**Figure 1. Curve graph for evaluation of earned value method with critical paths**

Through simply analysis on Figure 1, we can obtain a more directive knowledge about cost-schedule state of this project so that we can not only effectively figure out the construction schedule and completion condition as well as the according cost on the check date but also determine the variance between the construction project and plan occurs at the critical path or non-critical path and effectively adjust the resources at these two paths in time, thus assuring that the overall schedule meets the requirement and successful completion of construction tasks at the critical path[5-7]. The separate analysis on critical path-schedule can really find out the causes for ahead of schedule or delaying of schedule and this has important practical significance for cost control and schedule control. The analysis of overall variance and critical path variance cannot only effectively provide the cost-schedule control conditions at the critical path, but also adjust the resources at the non-critical path so as to guarantee the smooth completion of construction tasks at critical path.

## 4. Case Analysis of Earned Value Management of Engineering Project based on Critical Path

A city plans to rebuild and expand a road section in the city in order to further improve the urban traffic and increase the road capacity. The project management personnel adopt the earned value method based on critical path to carry out integrated control and management over the cost and schedule of this project. This project can be divided into 6 sub-projects according to the actual construction environment and the estimated project cycle is 10 months and the critical procedures are A, B, D and E. The budgeted total cost is 5.5815m Yuan. The management personnel makes the following schedule and cost budget shown as Table 3.

At the sixth month, the project supervisor found that there was significant difference between the actual work performed and actual unit price, thus the earned value analysis was carried out for the completed work. The collected and sorted data is shown in the following Table 4.

**Table 3 .Schedule and cost budget of road rebuilding project of a city (Unit: 10,000 Yuan)**

| Evaluation parameters | Work package | operation before tightness | planning cycl | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| BCWS | A | —— | 1 | 111.37 | | | | |
| | B | A | 2 | | 40.36 | 30.98 | | |
| | C | A | 1 | | 50.69 | | | |
| | D | B | 5 | | | | 27.43 | 30.41 |
| | E | C | 4 | | | 18.35 | 21.46 | 30.58 |
| | F | D,E | 2 | | | | | |
| | Accumulative total | —— | 10 | 110.37 | 91.05 | 49.33 | 48.89 | 60.99 |
| Evaluation parameters | Work package | operation before tightness | planning cycl | 6 | 7 | 8 | 9 | 10 |
| BCWS | A | —— | 1 | | | | | |
| | B | A | 2 | | | | | |
| | C | A | 1 | | | | | |
| | D | B | 5 | 40.12 | 19.27 | 20.5 | | |
| | E | C | 4 | 27.33 | | | | |
| | F | D,E | 2 | | | | 50.13 | 40.17 |

**Table 4. Parameter analysis of road rebuilding construction project as of June 30(Unit: 10,000 Yuan)**

| Evaluation parameters | Work package | executive condition | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|
| BCWP | A | completed | 110.3 | | | | | |
| | B | completed | | 40.35 | 31 | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C | completed | | 50.7 | | | | |
| | D | delayed | | | | 27.21 | 29.18 | 20.13 |
| | E | delayed | | | 19.35 | 21.45 | 30.57 | 20.35 |
| | Accumulative total | —— | 110.3 | 91.05 | 50.35 | 48.66 | 59.75 | 40.48 |
| ACWP | A | completed | 113.2 | | | | | |
| | B | completed | | 40.36 | 31.27 | | | |
| | C | completed | | 50.73 | | | | |
| | D | delayed | | | | 27.23 | 29.54 | 21 |
| | E | delayed | | | 19.43 | 22.13 | 30.55 | 23.14 |
| | Accumulative total | —— | 113.2 | 91.09 | 50.7 | 49.36 | 60.09 | 44.14 |

Through the analysis of above two tables, we can find out that the construction work of Section A, B and C has been completed, but Section D and E are delayed and Section F has not started yet. According to computation with the above-mentioned formula, we can obtain the six-month schedule, cost variance and according execution index of this project. The specific data is shown in Table 5 and Table 6.

**Table 5. Index analysis from January to June of road rebuilding project (Unit: 10,000 Yuan)**

| Parameter indexes | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| SV | -0.07 | 0 | 1.02 | -0.23 | -1.24 | -26.97 |
| CV | -2.9 | -0.04 | -0.35 | -0.7 | -0.34 | -3.66 |
| SPI | 0.99937 | 1 | 1.0207 | 0.995 | 0.9797 | 0.600148 |
| CPI | 0.97438 | 0.99956 | 0.9931 | 0.986 | 0.9943 | 0.917082 |

**Table 6. Index analysis of various activities from January to June of road rebuilding project (Unit: 10,000 Yuan)**

| Parameter indexes | BCWS | BCWP | ACWP | SV | CV | SPI | CPI |
|---|---|---|---|---|---|---|---|
| A | 110.37 | 110.3 | 113.2 | -0.07 | -2.9 | 0.99936577 | 0.974381625 |
| B | 71.34 | 71.35 | 71.63 | 0.01 | -0.28 | 1.000140174 | 0.996091023 |
| C | 50.69 | 50.7 | 50.73 | 0.01 | -0.03 | 1.000197278 | 0.999408634 |
| E | 97.96 | 76.52 | 77.77 | -21.44 | -1.25 | 0.781135157 | 0.983926964 |
| F | 97.72 | 91.72 | 95.25 | -6 | -3.53 | 0.93800082 | 0.962939633 |

Through preliminary analysis on Table 6, we can find out that the schedule variance data of these six months are respectively -0.07, 0, 1.02, -0.23, -1.24 and -26.97. The schedule variance of the first two months was relatively small, indicating that the road rebuilding project is developed smoothly on these two months, but this data also shows that the project is developed slowly. The schedule variance at the third month is 1.02, showing that the schedule on this month has been improved and has surpassed the planned schedule. While on the fourth, fifth and sixth months, the schedule variance is negative, implying that the schedule at current stage falls behind the plan and the overall quality of schedule control drops. Especially in D and E, the reduction of control quality is significant and the schedule variance is further enlarged. Meanwhile, the schedule variance at critical path at this stage is relatively large. According to the above table, we can find out that the total of schedule variance of A, B and D is -21.5. If the above case is not controlled and improved in time, the overall construction schedule must be exposed to serious negative impact and the project will not be completed as scheduled, resulting in great economic losses. Thus the management personnel for schedule control should adopt effective measures in time based on the practical situations.

If the above cases are caused by failed delivery of equipments and materials in time, then the purchasing department should be responsible for timely procurement of the equipments and materials which should be put into use within a short time; if the above cases are caused by the human factors such as insufficient technical level and unskilled handling, then it is necessary to train the related operators in time.

The cost variances of the first six months are respectively -2.9, -0.04, -0.35, -0.7, -0.34 and -3.66. The cost variances at this stage are all negative, showing the serious cost overrun occurs in the practical construction process. The cumulative cost variance of the first six months is -7.99 including -4.43 for the critical paths of A, B and D. The relative management personnel is required to find out the influence factors as soon as possible and adjust accordingly based on the practical situations. The execution index of schedule of cost of road rebuilding project as of June 30 is shown as Figure 2.

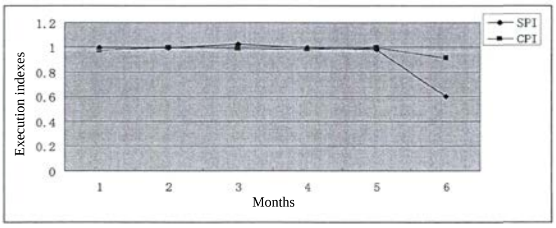


**Figure 2. Execution index of schedule of cost of road rebuilding project as of June 30**

Through analysis of Figure 2, we can find out that the schedule execution indexes at the first five months fluctuate around 1, showing that the construction of this project basically complies of the plan and the relative management personnel has adopted right measures for control of cost and schedule. But the schedule delay is abnormally obvious in June and the cost overrun occurs as well. The specific schedule execution index and cost execution index are respectively 0.6 and 0.92, showing that the schedule delay and cost overrun are serious in June. It is assumed that the present cost control can last, according to the formula

$$EAC = ACWP + (BCWS_r - BCWP) \times \frac{ACWP}{BCWP} = BCWS_r \times \frac{ACWP}{BCWP} \quad (10)$$

The cost is predicted to be 5.6928 million Yuan and is 111,300 Yuan more than the budget. Both the difference between cost and budget and the difference between project schedule and plan will necessarily block the normal operation of project and impact the profit level finally, thus the project management personnel should timely adopt the effective measures to adjust cost-schedule and improve the cost control status fundamentally.

## 5. Conclusion

In an objective view, the construction enterprises are special, so they have to adopt the analysis methods satisfying their won features in the process of practical cost control and schedule control. The earned value method introduced in this research can effectively meet the demands at different stages with significant differences of cost and schedule and separately complete cost-schedule variance analysis at every stage and time point to offer the effective data supports for the management personnel to adjust construction schedule and construction cost in time and greatly improve the effects of cost control.

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