Development of Construction Project Cost Performance Index Analysis Method Based on Cumulative Uncertainty of Activities

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ABSTRACT

Today, all construction project managers use various tools and methods in order to know the project cost situation. The most important method that has been developed in this field so far is the cost performance index. In this research, this tool has been developed in accordance with the uncertainties in the financial issues of the project in order to have a better understanding of the financial situation for the project elements and to see the impact of the uncertainties in the investigation of the project costs. In this regard, the historical data of the activities has been used and its output has been used in the Monte-Carlo simulation in order to examine the cumulative uncertainty in the project. The results obtained from the simulation have led to the creation of a suitable criterion for monitoring and measuring the status of the project in the entire implementation period until the end of the project. The output has more compliance with the reality of the internal and external conditions of the project. Compliance with reality will lead to a correct diagnosis of the current situation and, as a result, a correct decision regarding the future of the project.

Keywords: cost performance index, earned value method, uncertainty, Monte-Carlo simulation

1. INTRODUCTION

In recent years, we have seen a significant improvement in the areas of project time and cost management. One of the most important improvements is the Earned Value Management (EVM) technique. This technique makes it possible to accurately measure the progress of the project [1]. Currently, it is observed the proliferation of this method and its application in a diverse array of small and large projects. Determining the effectiveness of a project time and cost control plan is very important so that it shows the progress of the project and greatly affects the future costs of the project and its completion time. This importance comes from the fact that the delay in the delivery of a project has consequences. It will impose financial and credit burden on the project [2, 3]. At present, the earned value technique is one of the most important and widely used project performance control and monitoring techniques in the EVM technique, performance indicators are often compared with similar and superior projects with base values of a fixed number. This comparison forms the basis of analysis and judgment regarding the status of the project. Analyzing indicators through monitoring them over time on a trend chart is one of the conventional approaches [4].

2. LITERATURE REVIEW

EVM first emerged in the United States as a control measure in government systems to monitor project performance [4]. In the last century, one of the researchers who has done extensive research in this field is Lipke [5], who developed a ratio called cost-program. In his studies, Henderson [6] examined reliability in this field. Cioffi [7] presented a new analysis method that made the mathematics of EVM more transparent and flexible. Regarding the reliability of project costs, Lipke [8] presented a method that would increase the ability of project managers to make informed decisions.

The 2015 study by Batselier and Vanhoucke [9] has clearly shown that the method of time and cost forecasting in EV basically has a high level of accuracy compared to the actual project implementation. Therefore, the EVM method can be considered a valuable and practical basis for predicting the cost and different time frames of the project execution process. In their research, Mahmoudi and Kalantari [10] simply examined the basic concepts of one of the methods of evaluating project performance and progress, namely the EVM method. They stated in their research that this method is one of the fastest evaluation methods and one of the determining factors in this method is the project manager. They also showed that the value obtained from the project is a measure of the real progress of that project, and one of the basic features of implementing the EVM method is to measure the progress of the project and show the progress, which is considered a method to record the standard deviation of time and cost. In their research, Khasal [11] have developed the EVM technique, which is an efficient and widely used method for integrating project scope, time and cost control, considering the third factor, quality, which is very important in projects. The new criteria presented in his research are a combination of EVM, project risk management, and quality management for more effective and integrated project control and monitoring to achieve project integrity management goals.

In his research, Kim [12] found that the main performance evaluation index in the project is the financial performance index, and the stability of this performance will indicate the status of the project and the best factor for correctly predicting the remaining cost of the project. His study introduces a simulation-driven analytical model that assesses the likelihood of a project's Cost Performance Index (CPI) sustainability at a particular point in the project's timeline. Furthermore, the research utilizes the CPI stability model to pinpoint four key factors influencing cost stability. In a study conducted in 2018 by Chang and Yu [13], it was proposed that an additional independent performance metric should be incorporated into the conventional EVM technique, resulting in a three-variance methodology for the comprehensive evaluation of the performance status across the three key indicators of work, time, and cost within a specific project.

In 2019, Miguel et al presented [14] a new project management model for integrated quality management and risk management in EVM to overcome the weaknesses and limitations of traditional EVM in their research. The proposed model of this research with quality performance criteria was able to show how the issue of quality affects the cost and schedule of the project and also showed that the preventive measures taken in the risk indicators are also reflected with the progress of the project.

In his book, Bruce [15] stated that if progress is intentionally off schedule, it should be specified that monitoring is done at a detailed level and that EVM is useful as long as the available data is reliable and timely. He stated that delays Locality can lead to the displacement of important events in the construction schedule, causing project delays and cash flow problems.

3. METHODOLOGY

3.1. Road map

In this research, based on Figure 1, in the first step, historical data related to the project has been collected, in which the difference between the amount of the planned cost and the cost of the actual activities has been determined. In the second step, the data of each activity is analyzed and the most appropriate statistical distribution is determined for each.

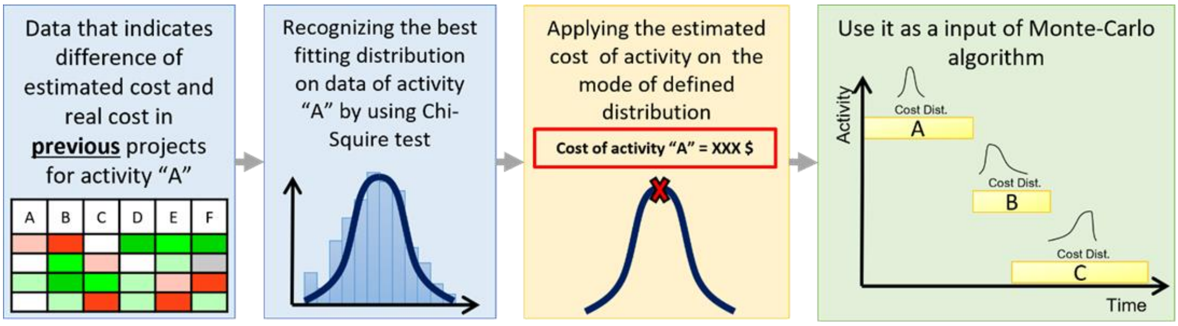

Fig. 1. *Road map of current research*

In the third step, the schedule of activities along with the corresponding cost distribution are introduced as input to the Monte Carlo simulation. In the last step, the output of Monte-Carlo will give the S-curve related to the project costs, in which the uncertainty has been seen and the minimum, maximum, most probable state and standard deviation values for each time point have been specified.

3.2. Earned Value Management

EVM integrates schedule and cost metrics as key indicators for monitoring and predicting project performance. The EVM criterion consists of three basic elements according to Table 1 [16]:

Table 1. *EVM elements*

#	Element	Short definition	Definition
1	Earned Value (EV)	Budgeted Cost of Work Performed (BCWP)	Represents the budgeted amount of work completed during a specific time frame on a scheduled activity or Work Breakdown Structure (WBS) component
2	Planned Value (PV)	Budgeted Cost of Work Scheduled (BCWS)	Indicates the estimated cost of work planned to be finished for an activity or WBS component at a particular point in time
3	Actual Cost (AC)	Actual Cost of Work Performed (ACWP)	Reflects the total cost expended to execute work on a scheduled activity or WBS component within a given time period

These data points enable project analysis and forecasting. In EVM timing analysis, Timing Variance (SV= EV-PV) and Schedule Performance Index (SPI= EV/PV) are utilized. Additionally, Cost Variance (CV=AC-PV) and Cost Performance Index (CPI=AC/PV) are employed for cost analysis in EVM [4].

As indicated in Table 2, if CV<0 and CPI<1, the project exceeds the initial budget. Conversely, if CV>0 and CPI>1, the project is under budget. Moreover, if SV<0 and SPI<1, the project is delayed; otherwise, if SV>0 and SPI>1, the project is ahead of schedule. When CV=0 (CPI=1) and/or SV=0 (SPI=1), the project is on schedule in terms of cost and/or time, respectively [4].

Table 2. *Different modes of CPI*

#	CPI area	Meaning
1	CPI <1	Work is behind budgeted schedule
2	CPI=1	The work is budgeted according to the schedule
3	CPI >1	Work is ahead of budgeted schedule

3.2.1. Cost Performance Index

As previously stated, this index is employed to assess the project's cost performance. In project management standards, this index is defined as the ratio of the earned value (value earned in the project) to the actual cost of project implementation (actual cost) at various stages of the project [17].

CPI can fluctuate due to various factors such as changes in project scope, unexpected costs or inefficiencies in the use of resources. Understanding these fluctuations is critical for project managers to maintain control over project costs. Each project may have an acceptable operating range for CPI that must be established based on historical data and industry benchmarks [18, 19].

3.3. Monte Carlo simulation

Monte Carlo simulation utilizes random sampling and statistical modelling to estimate mathematical functions and simulate the behavior of complex systems [20]. Figure 2 illustrates a three-step procedure comprising input, simulation, and output phases. During the simulation phase, a four-step approach is utilized to determine the most probable cost scenario. Initially, a random value for cost of each activity is chosen in the activity cost distribution stage. Subsequently, the total project cost is computed based on these random values. The third step involves comparing the iteration value with a predefined threshold to determine whether to proceed with a new iteration. Ultimately, the cost distribution for the entire project is generated [20]. Monte Carlo simulation performs better in some situations, such as construction cost estimation, compared to fuzzy logic and provides more reliable output, the reasons for which are as follows [4]:

1. Answer bias is possible in expert-based fuzzy systems.
2. Fuzzy interpolation is a linear equation and solutions to solve this problem make fuzzy logic very complicated.
3. Fuzzy logic process is like a black box and is less clear than Monte Carlo, so it is more difficult to find and solve errors in it.

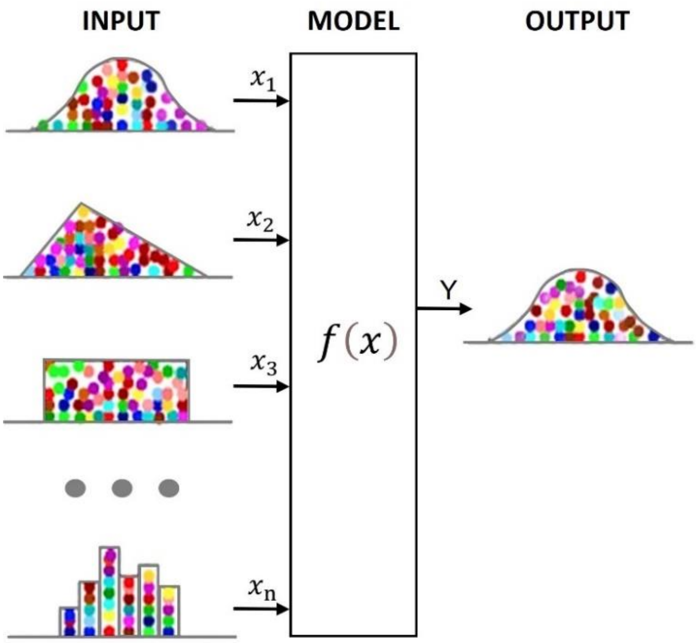

Fig. 2. *General process of Monte-Carlo simulation*

The steps required to run the simulation are as follows [4, 20]:

Step 1: Define the project objective, such as the total cost objective.

Step 2: Determine the number of iterations, for instance, “n”. This entails generating “n” random numbers for each random variable to repeat the experiment n times. The number of replications should be chosen based on the desired confidence interval length. Alternatively, if the simulation runtime is not a concern, setting the iteration value to a higher number, like 1000 or 5000, may be more convenient.

Step 3: Execute the simulation and record the outcome, specifically the total project cost.

Step 4: Gather data for each iteration until reaching the final iteration.

4. RESULT AND DISCUSSION

4.1. Historical data

Historical data related to 21 bridge construction projects were collected in a company specializing in the implementation of cable-stayed bridges. The type of data showed the percentage difference between the planned costs and the actual costs of each activity (direct costs). The analysis of this data will show how much the deviation from planning was in reality. The most important reasons for this rework difference are due to implementation errors, accident costs, mistakes in the initial estimate, material price changes, wage changes, design changes during construction, outliers in the implementation process [18]. The interaction of the impact of the proposed items and other items that sometimes alone do not have a significant effect on the deviation of project costs causes the difference between the initial estimate of the project and the actual cost of the project execution process [2, 18, 21].

4.2. Cost distribution

The collected data regarding the direct cost of each activity is analyzed by chi-square test and the most appropriate statistical distribution is obtained for each activity. Also, according to Figure 3, the value of skewness, median, mode, average, maximum, minimum and standard deviation values are extracted. The resulting distributions will be used as input for Monte-Carlo simulation.

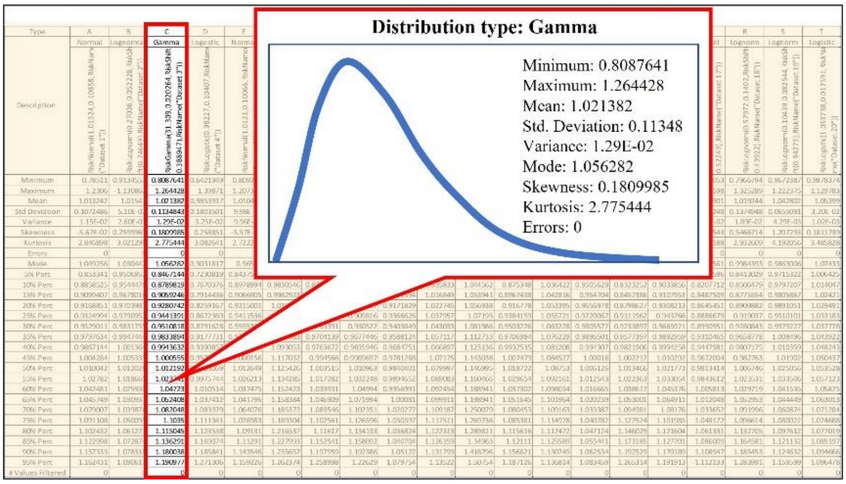

Fig. 3. Statistical distribution resulting from data analysis of an activity

4.3. Uncertainty simulation

As shown in Figure 4, Monte Carlo simulation for project costs is performed in such a way that priority and delay relationships between activities are defined in the first stage and the classical case of project scheduling is formed. Each activity is then assigned a cost distribution based on raw data instead of an absolute number. In the next step, the model is implemented based on the distributions and the total cost of the project is obtained in the most probable way possible. Among the side information of this model is the standard deviation of the time and cost of the entire project and the minimum and maximum values of each of the project's time periods.

4.4. Cost performance criteria

In order to compare the current situation with the initial plan, we have to create the S-curve of the initial plan, and at each point in time, the obtained value values are compared with the expected value in the S-curve. In this process, classically, only one value in the S-curve is compared with the existing situation, and if it is not achieved, we will compare the implementation and the program. But there are many uncertainties in the execution process, which have been seen in the Monte Carlo simulation, and the S-curve has been created according to Figure 5.

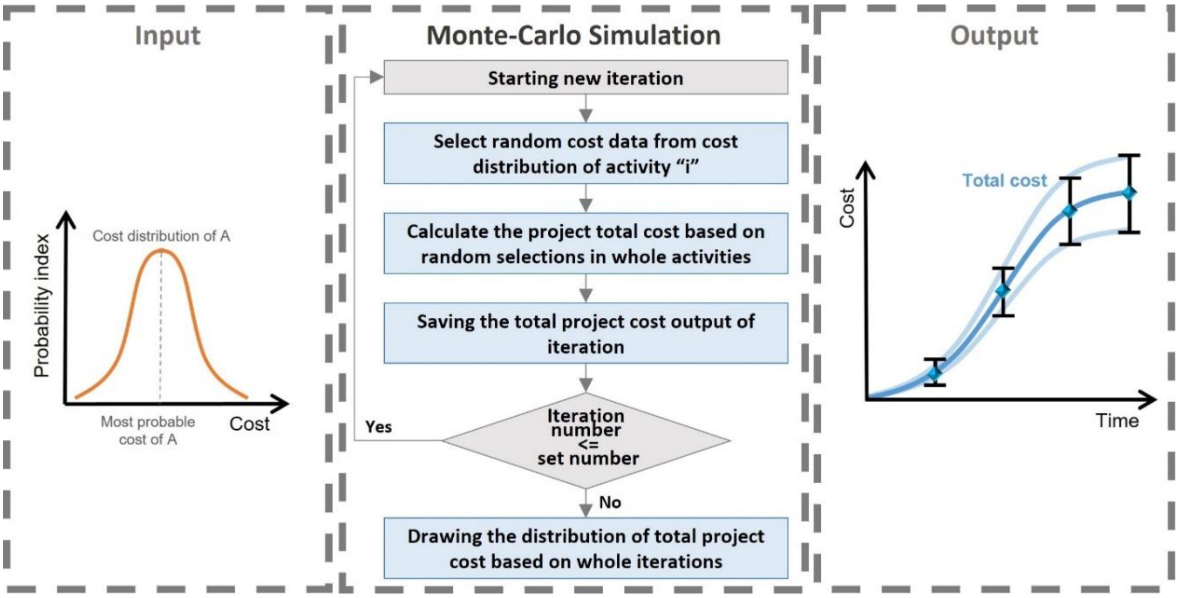

Fig. 4. *Monte Carlo simulator input, processing and output*

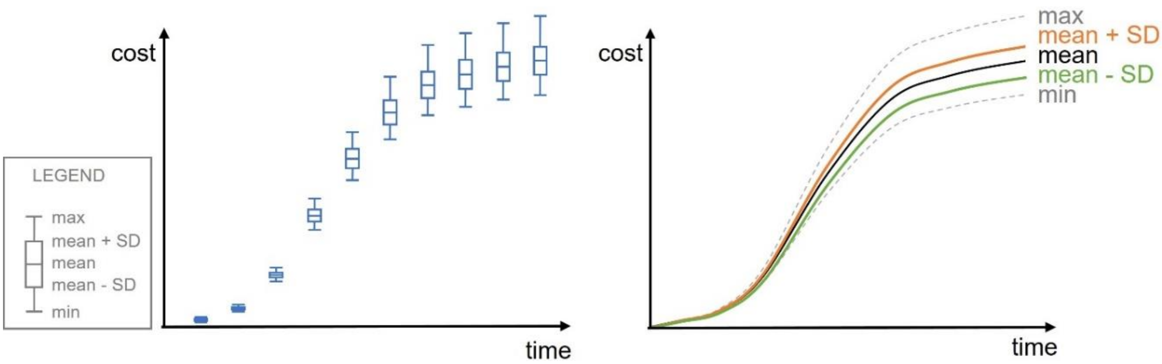

Fig. 5. *S-curve based on the uncertainty of the cost of activities*

In this figure, instead of the S-curve, we will see the creation of the S-area, which is between the probable line plus the standard deviation and the probable line minus the standard deviation. In this case, you will have a comparison with the real values with the five-mode S space, which is specified in Figure 6 and is as follows:

Mode 1: The earned value of the project is less than the standard deviation line, and this means that in addition to the uncertainties affecting the project, you had a more expensive implementation process than the plan, and the project is in an unfavorable state in terms of cost.

Mode 2: The earned value of the project is between the line of the most probable case and the reduced standard deviation line. This means that your management has been acceptable and the difference between execution and schedule is mainly due to the impact of project uncertainty.

Mode 3: The earned value is exactly on the line of the most probable state of the program, which has two meanings. First, the project management is in a favorable position in terms of cost, and secondly, the result of the positive and negative effects of uncertainties has made us stay exactly on schedule.

Mode 4: The earned value of the project is between the most probable line and the added standard deviation line. This means that your management has been acceptable and the difference between execution and schedule is mainly due to the impact of project uncertainty.

Mode 5: The earned value of the project is above the standard deviation line, which means that in addition to the uncertainties affecting the project, you had a lower execution cost than planned.

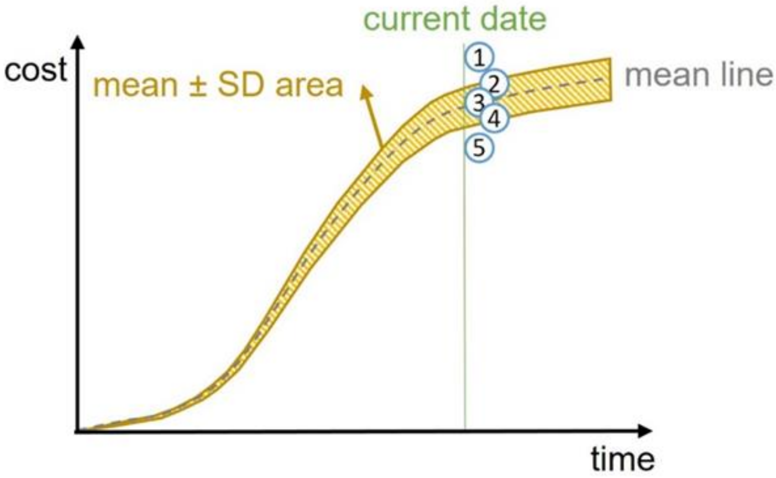

Fig. 6. Analysis of the state of earned value based on the S-area

5. CONCLUSION

The financial performance index shows the performance status of the project team, especially the project manager. Comparing the actual execution values with an absolute number makes minor deviations from the project team's performance plan to be unfavorable, if it is possible that these error values are outside of their negligence and are related to the uncertainties of the project implementation process.

If the cumulative uncertainty of the cost of activities is applied to the total cost of different time periods of the project, the ability to compare the performance based on the accepted period will be created, and the output of the indicators will be more consistent with the reality of the project team's efforts. As a result, management dashboards and project control reports will be less sensitive to minor deviations caused by uncertain factors.

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