THE USE OF STATISTICAL QUALITY CONTROL CHARTS IN MONITORING THE COST AND PROJECT DURATION OF A COLUMBARIUM CONSTRUCTION PROJECT UTILIZING CONCRETE COMPOSITE PANELS

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ABSTRACT. *Earned value (EV) is a popular method for monitoring and analyzing a project's performance and progress. In this study, the EV indices are used with Statistical Quality Control Charts to monitor the cost and schedule of a columbarium building project. As a result, the Earned Value has increased in value during the last nine (9) weeks. From week 2 through week 9, the construction project's Schedule Performance Index (SPI) and Cost Performance Index (CPI) are both greater than one. The assessment found that more work was accomplished than anticipated, and the project's actual cost did not exceed the projected cost. The study indicated that EV indices and SQC charts were effective tools for project monitoring.*

Key Words: Statistical Quality Control, Control Chart, Cost Performance Index, Schedule Performance Index, Earned Value Method

1. INTRODUCTION

A columbarium is a mausoleum that was popular in early imperial Rome and was named from its resemblance to a dovecot. Such tombs, which were either completely or partially subterranean, had niches (loculi) constructed in rows in the walls with pots (ollae) plunged into them to hold the dead's ashes (Richmond & Davies, 2015) [9]. A columbarium consists of a concrete wall (CHBs) with numerous recessed niches, often known as columbarium niches. The most common material used in the Philippine construction industry is concrete hollow blocks (CHB). According to Hasan et al. (2021) [4], hollow concrete block masonry walls are extensively used in developing and developed countries due to their good compressive strength, even though they have low flexural and tensile strength. Common columbarium construction and design involve the use of both CHB and reinforced concrete in accordance with the standards set forth in the National Building Code of the Philippines (PD 1096) and the Department of Health standards on columbarium design. However, the use of CHB and reinforced concrete entails poor bearing capacity, poor in seismic performance, longer construction times and higher labor costs.

With the growing number of projects in industries such as manufacturing, construction, and service, as well as the increasing complexity of managing and executing projects, project management expertise, standards, and methodologies are becoming increasingly vital. Knowledge management (KM) is the central know how for the construction industry. However, the delivery of construction projects is often plagued by schedule delays and cost overruns due to lack of working knowledge of project personnel. Hence, the need to appraise the practices of knowledge management in the construction industry has become all the more germane (Yap & Lock, 2017)[10]. The analytical results indicate the appropriateness of prioritizing the practice of the PMBOK® Guide in the construction industry (Chou & Yang, 2012)[2]. The most common tool to measure progress in terms of cost and time constraints in construction is called value management (PMBOK,2013)[5].

To be able to successfully address these realities would mean that success factors in the project should be elicited by the project management function in the whole project cycle (Thomson, 2011)[6]. This also calls for the need to examine the dynamic nature of emergent requirements of stakeholders which means that project managers must continually engage with stakeholders and consider this as an ongoing process.

Meredith and Mantel (2012)[7] present a discussion that is reasonably extensive regarding the approach in EVM: 1.) EVM can be estimated at several levels within the hierarchy of the work breakdown structure (WBS), such as at the level of the task, the work package, the stage, or the project. 2.) The particular calculations that are produced will vary over time, as they will depend on the monitoring point in time and be affected by this. 3.) When it comes to monitoring, it is often more efficient and effective to focus on the key indices, such as schedule performance index (SPI) and cost performance index (CPI), and the extent to which they stay within an agreed tolerance range, which is greater than 0.8 and less than 1.2. Examples of these indices include the schedule performance index (SPI) and the cost performance index (CPI). 4.) The power of the method lies in part in the visual representation of the important dimensions.

There are many examples of EVM being applied to a variety of different project scenarios that can be found in the relevant literature. One example that is representative of the norm is offered by De Marco and Narbaev (2013)[3], who uses the example of a project to rehabilitate an industrial facility to show how its application works. The discussion of the efficacy of various EVM-generated metrics in the early part of the paper. One example of this is the foresting value of calculating CEAC (cost estimate at completion) and TEAC (time estimate at completion) on the basis of current variances. You can find this and other examples in the section. This discussion is illustrative of a trend that may be found in certain areas of the research literature to build increasingly sophisticated and complicated dimensions for the purpose of assessing performance and forecasting it.

Earned value management (EVM) is a methodology that combines scope, schedule, and resource measurements to assess project performance and progress. It is a commonly used method of performance measurement for projects. It integrates the scope baseline with the cost baseline, along with the schedule baseline, to form the performance baseline, which helps the project management team assess and measure project performance and progress. It is a project management technique that requires the formation of an integrated baseline against which performance can be measured for the duration of the project. The principles of EVM can be applied to all projects in any industry. EVM develops and monitors three key dimensions for each work package and control account: (1) *Planned value (PV)* is the authorized budget assigned to scheduled work. It is the authorized budget planned for the work to be accomplished for an activity or work breakdown structure component, not including management reserve. This budget is allocated by phase over the life of the project, but at a given moment, planned value defines the physical work that should have been accomplished. The total of the PV is sometimes referred to as the performance measurement baseline (PMB). The total planned value for the project is also known as budget at completion (BAC). (2) *Earned value (EV*) is a measure of work performed expressed in terms of the budget authorized for that work. It is the budget associated with the authorized work that has been completed. The EV being measured needs to be related to the PMB, and the EV measured cannot be greater than the authorized PV budget for a component. The EV is often used to calculate the percent complete of a project. Progress measurement criteria should be established for each WBS component to measure work in progress. Project managers monitor EV, both incrementally to determine current status and cumulatively or determine the long-term performance trends. (3) *Actual cost (AC)* is the realized cost incurred for the work performed on an activity during a specific time period. It is the total cost incurred in accomplishing the work that the EV measured. The AC needs to correspond in definition to what was budgeted in the PV and measured in the EV (e.g., direct hours only, direct costs only, or all costs including indirect costs). The AC will have no upper limit; whatever is spent to achieve the EV will be measured.

The SV and CV values can be converted to efficiency indicators to reflect the cost and schedule performance of any project for comparison against all other projects or within a portfolio of projects. The variances are useful for determining project status (PMBOK,2013)[5].

The study of Leu and Lin (2008) improved the assessment performance of traditional EV indices through the introduction of Statistical Quality Control Charts. Introducing Statistical Quality Control Charts in the monitoring of projects may improve the performance of EV indices in monitoring and assessing construction projects (Aliverdi et al., 2013).

In this study, the columbarium project is in the Divine Shepherd Memorial Gardens in Barangay Bulua, Cagayan de Oro City with a capacity of 108 niches and a floor area of 36 sq.m. The objective of this study is to assess the EV indices of the project cost and schedule of a columbarium construction project using Statistical Quality Control Charts. In this research, the standard deviation,mean and range of the CPI and SPI were taken to determine the lower and upper control limits of the project.

2. METHODOLOGY

In today's project management world, forward-thinking managers and leaders do not adhere to a single methodology, they become well-versed in many of them, and they learn how to mesh together various practices in order to accommodate whatever the project calls for.

The application of statistical methods to monitor a process in order to ensure that it provides conforming products or services is known as statistical process control (SPC). CPI and SPI indeces of the project have been taken and computed using the earned value project tracking method by the 2013 Project Management Body of Knowledge (PMBOK) of the Project Management Institute (PMI). The CPI and SPI indeces were further analyzed using Statistical Quality Control tools by looking into the Upper and Lower Control Limits of the project.

2.1 Data Gathering

The data were taken from the planned values for both the project cost and schedule which is based on the quotation submitted to a columbarium company. The actual construction data were provided as shown in Table-1 by the construction company involved in the implementation of the project.

Table-1: Planned Value and Actual Cost

Week No.	Planned Value (PV)	Actual Cost (AC)
1	₱210,511.11	₱278,437.50
2	₱210,511.11	₱141,036.00
3	₱210,511.11	₱323,446.00
4	₱210,511.11	₱102,434.18
5	₱210,511.11	₱102,434.18
6	₱210,511.11	₱66,449.50
7	₱210,511.11	₱98,937.10
8	₱210,511.11	₱82,178.00
9	₱210,511.11	₱141,317.19

2.2 Calculation of Earned Value

The study's main contribution is to provide a viable approach for monitoring statistically EV indicators and detecting any abnormalities by merging EV and statistical quality control charts. One of the most important benefits that the combination may provide is a better understanding of the behavior of EV indexes over time, which aids in monitoring project success and progress. The study's other contributions are in the manner of using statistical quality control charts to analyze project progress data. The EV of a project is calculated by multiplying the percentage complete by the total project budget.

2.3 Calculation of Schedule and Cost Variance

Schedule variance (SV) is a measure of schedule performance expressed as the difference between the earned value and the planned value. It is the amount by which the project is ahead or behind the planned delivery date, at a given point in time. It is a measure of schedule performance on a project. It is equal to the earned value (EV) minus the planned value (PV). The EVM schedule variance is a useful metric in that it can indicate when a project is falling behind or is ahead of its baseline schedule. The EVM schedule variance will ultimately equal zero when the project is completed because all of the planned values will have been earned. Schedule variance is best used in conjunction with critical path methodology (CPM) scheduling and risk management.

SV = EV – PV Eqn. (1)

Cost variance (CV) is the amount of budget deficit or surplus at a given point in time, expressed as the difference between earned value and the actual cost. It is a measure of cost performance on a project. It is equal to the earned value (EV) minus the actual cost (AC). The cost variance at the end of the project will be the difference between the budget at completion (BAC) and the actual amount spent. The CV is particularly critical because it indicates the relationship of physical performance to the costs spent. Negative CV is often difficult for the project to recover.

CV= EV – AC Eqn. (2)

2.4 Developmet of SQC Control Charts

The schedule performance index (SPI) is a measure of schedule efficiency expressed as the ratio of earned value to planned value. It measures how efficiently the project team is using its time. It is sometimes used in conjunction with the cost performance index (CPI) to forecast the final project completion estimates. Since the SPI measures all project work, the performance on the critical path also needs to be analyzed to determine whether the project will finish ahead of or behind its planned finish date. The SPI is equal to the ratio of the EV to the PV.

SPI = EV/PV Eqn. (3)

The cost performance index (CPI) is a measure of the cost efficiency of budgeted resources, expressed as a ratio of earned value to actual cost. It is considered the most critical EVM metric and measures the cost efficiency for the work completed. The CPI is equal to the ratio of the EV to the AC. The indices are useful for determining project status and providing a basis for estimating project cost and schedule outcome.

CPI = EV/AC Eqn. (4)

3. RESULTS AND DISCUSSION

3.1 The Earned Value

Table-2 show the project tracking-earned value of the conducted project using composite panel for nine (9) weeks period. The first week and the third week show that the Actual Cost (AC) surpasses the Planned Value (PV). However, the proceeding weeks show a lower Actual Cost when compared to the Planned Value. In result, the Earned Value provides an overwhelming cost that amounted to 1,894,600 pesos in the period of nine(9) weeks.

3.2 The Schedule Variance (SV) and the Cost Variance (CV)

The Schedule Variance (SV), Cost Variance (CV), Schedule Performance Index (SPI) and the Cost Performance Index (CPI) were also calculated. Figure-1 below is a graph of the Planned Value (PV), Actual Cost (AC) and the Earned Value(EV). The PV is allocated by phase over the life of the project, but at a given moment, planned value defines the physical work that should have been accomplished.

Table-2: Earned Value

Week No.	Planned Value (PV)	Actual Cost (AC)	Earned Vaue (EV)
1	₱210,511.11	₱278,437.50	₱0.00
2	₱210,511.11	₱141,036.00	₱236,825.00
3	₱210,511.11	₱323,446.00	₱473,650.00
4	₱210,511.11	₱102,434.18	₱710,475.00
5	₱210,511.11	₱102,434.18	₱947,300.00
6	₱210,511.11	₱66,449.50	₱1,184,125.00
7	₱210,511.11	₱98,937.10	₱1,420,950.00
8	₱210,511.11	₱82,178.00	₱1,657,775.00
9	₱210,511.11	₱141,317.19	₱1,894,600.00

The AC needs to correspond in definition to what was budgeted in the PV and measured in the EV (e.g., direct hours only, direct costs only, or all costs including indirect costs). The EV being measured needs to be related to the PMB, and the EV measured cannot be greater than the authorized PV budget for a component. The EV is often used to calculate the percent complete of a project. Progress measurement criteria should be established for each WBS component to measure work in progress. As per scheduled project of nine (9) weeks, the earned value showed an increasing value as time progresses with the use of the concrete composite panels materials.

Table-3: Schedule Variance and Cost Variance

Week No.	Schedule Variance (SV)	Cost Variance (CV)
1	-₱210,511.11	-₱278,437.50
2	₱26,313.89	₱95,789.00
3	₱263,138.89	₱150,204.00
4	₱499,963.89	₱608,040.82
5	₱736,788.89	₱844,865.82
6	₱973,613.89	₱1,117,675.50
7	₱1,210,438.89	₱1,322,012.90
8	₱1,447,263.89	₱1,575,597.00
9	₱1,684,088.89	₱1,753,282.81

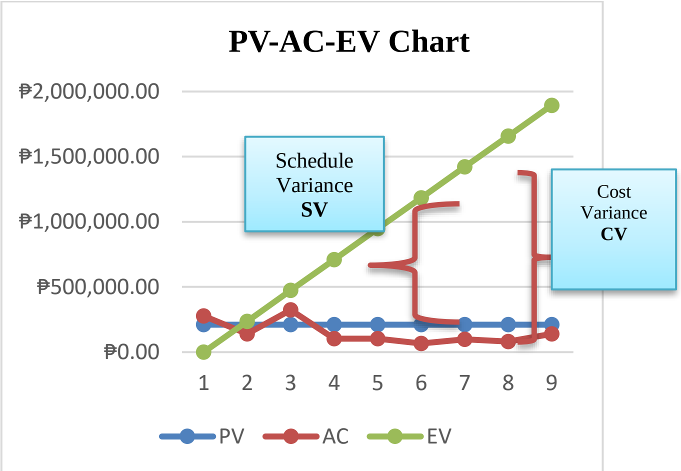

Figure-1: EV-AC-PV Graph

3.3 Calculation of Schedule Performance Index and Cost Performance Index

Two widely used indices in evaluating project progress are Schedule Performance Index (SPI) and Cost Performance Index (CPI). An SPI value less than 1.0 indicates less work was completed than was planned. An SPI greater than 1.0 indicates that more work was completed than was planned. Since the SPI measures all project work, the performance on the critical path also needs to be analyzed to determine whether the project will finish ahead of or behind its planned finish date. A CPI value of less than 1.0 indicates a cost overrun for work completed. A CPI value greater than 1.0 indicates a cost underrun of performance to date. The indices are useful for determining project status and providing a basis for estimating project cost and schedule outcome. Table-2 shows the CPI and SPI values and its corresponding mean and range values. In this study, the SPI and CPI mean value is 7.066 which is more than 1.0. Thus, it indicates a more work completed than was planned.

Table-4: CPI and SPI

Week No.	CPI	SPI	Mean or X-Bar	Range
1	0.68	0.90	0.790	0.220
2	1.68	1.13	1.405	0.550
3	1.46	2.25	1.855	0.790
4	6.94	3.38	5.160	3.560
5	9.25	4.50	6.875	4.750
6	17.82	5.63	11.725	12.190
7	14.36	6.75	10.555	7.610
8	20.17	7.88	14.025	12.290
9	13.41	9.00	11.205	4.410
			7.066	**5.152**

The SQC chart is used in this study to determine the acceptability of the data. The Lower Control Limit value is 3.310 while the Upper Control Limit value is 10.822. Some data were out of control as shown in Figure-2 and Figure-3.

Eqn. (5)

$$\text{Upper control limit (UCL)} = \bar{\bar{x}} + A_2\bar{R}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{x}} - A_2\bar{R}$$

Eqn. (6)

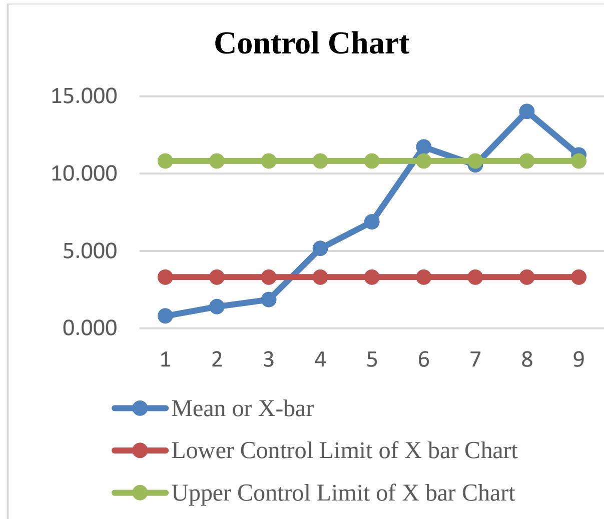

Figure-2: Control Chart of SPI and CPI-X Bar(Mean)

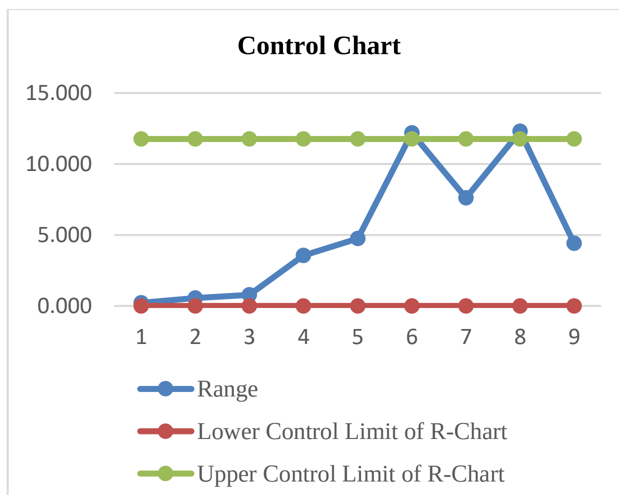

Figure-3: Control Chart of SPI and CPI (Range)

CONCLUSION

The Earned Value showed a positive effect with the use of composite panel in this study. The project's present status is tracked, and the long-term performance trends are calculated. As a result, the Earned Value has increased in value during the last nine (9) weeks. From week 2 through week 9, the construction project's Schedule Performance Index (SPI) and Cost Performance Index (CPI) are both greater than one. The assessment found that more work was accomplished than anticipated, and the project's actual cost did not exceed the projected cost. The study indicated that EV indices and SQC charts were effective tools for project monitoring.

RECOMMENDATION

To compare the acceptability of traditional CHB and a concrete composite panel (CCP) employing SQC in order to assist the building industry.

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