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Project Performance Measurement using Statistical Process Control: A Case Study of Electro Magnetic Compatibility (EMC)–in Indonesian Enterprise

Hsiang-Ling Chen
Department of Industrial and System Engineering
Chung Yuan Christian University
Taoyuan City, Taiwan
achen@cycu.edu.tw

Wawan Tripiawan
Department of Industrial and System Engineering
Chung Yuan Christian University
Taoyuan City, Taiwan
g11102407@cycu.edu.tw

School of Industrial & System Engineering
Telkom University
Bandung, Indonesia
wawantripiawan@telkomuniversity.ac.id

Abstract

Managing projects to ensure optimal performance is a major challenge. As organizations prioritize efficiency and excellence in project execution, accurate performance measurement mechanisms become more important. This study uses statistical process control principles to explore how organizations can monitor and enhance project performance, using an anechoic chamber for Electro Magnetic Compatibility (EMC) as an example to illustrate these concepts. This specialized chamber serves as a critical environment for conducting electromagnetic compatibility testing, underscoring its pivotal role in ensuring the reliability and functionality of electronic equipment. Our investigation evaluates the project's performance, focusing particularly on cost and schedule management. Statistical Process Control (SPC) and Earned Value Management (EVM) methodologies are used to effectively monitor the project schedule's progress in this study. By leveraging EVM, we derive key performance metrics, including the Schedule Performance Index (SPI) and the Cost Performance Index (CPI). Subsequently, SPC analysis is employed to scrutinize SPI and CPI outputs, discerning whether these indices fall above or below the Center Line (CL), thus providing insights into project performance trends. Our findings provide a picture of project performance. SPI study shows three months of performance above the CL, six months around the CL, and three months below the CL. Similarly, CPI analysis shows three months above the CL, four months near the CL, and five months below the CL. Incorporating EVM and SPC techniques provides the project team with actionable insights, allowing proactive decision-making and efficient problem-solving. This comprehensive strategy enables stakeholders to optimize project results, resulting in greater success.

Keywords

Project Control, Performance measurement, Earned Value Management, Statistical Process Control.

Introduction

Smooth project execution is a must in project-based companies. There are two sides to a smooth project, namely success and performance. There is a difference between the success and performance of a project - a project may fail in terms of its management, but stakeholders may still consider it successful; conversely, a project may be well-managed in terms of time and cost, but it may not succeed in achieving the stakeholders' broader objectives. (Turner & Xue 2018). Measuring progress is crucial for successful project execution, though it is not sufficient on its own for effective project management and control (Orgut et al. 2015). A project schedule is controlled by monitoring project activities, assessing progress, and managing changes to the baseline schedule to achieve the plan.

Researchers and practitioners extensively use earned value management (EVM) to track project activities and costs and control the project. In EVM, Schedule Performance Indexes (SPI) and Cost Performance Indexes (CPI) are computed periodically during implementation (PMI 2017). EVMs are not the only way to track and manage project finances and schedule progress; statistical process control charts can also be used. An SPC chart could track cost performance indexes (CPIs) or schedule performance indices (SPIs) in a system development project. CPI or SPI could be plotted onto an SPC chart to help project managers assess if the overall project progress is on track and under control (Ng, J. J. 2018).

This study focuses on a project undertaken by an Indonesian Enterprise aimed at developing an Electro Magnetic Compatibility (EMC) – Anechoic Chamber. The EMC anechoic chamber encompasses both semi-anechoic chamber (SAC) and fully anechoic chamber (FAC) designs. SACs are equipped with absorbing materials on five sides and a metal reflecting surface on the ground, simulating an open test field to minimize external site and electromagnetic environment influences on tests (Guo et al. 2020). Given Indonesia's sizable population and corresponding high demand for electronic devices, the country imported $25.5 billion worth of electronic products in 2022, with electronics and telematics industry components constituting 53% of total imports, valued at $13 billion (IBP Journalist, 2023). The Indonesian government research institute, the Agency for the Assessment and Application of Technology (BPPT), announced plans to employ EMC as a screening tool for imported electronic devices, prioritizing partnerships and technology and engineering output utilization. BPPT, a non-departmental government institution under the Ministry of Research, Technology, and Higher Education's coordination, fulfills governmental technology assessment and application duties by relevant laws and regulations (BRIN 2024).

Given the project's significant scale, valued in billions of Indonesian Rupiah, meticulous oversight and monitoring are crucial to ensuring smooth operation and stakeholder alignment. Effective management is imperative to closely monitor project progress, maintain adherence to established standards, and meet stakeholder expectations. Employing Earned Value Management (EVM) enables project managers to monitor performance, identify schedule and budget deviations, and make informed decisions to mitigate risks and optimize resources. Additionally, leveraging Earned Value Analysis as a project monitoring tool offers insights into overall project health, enabling proactive issue mitigation. Complementing EVM, Statistical Process Control (SPC) allows project managers to discern performance trends, anticipate issues, and take proactive measures. Integration of Earned Value Management and Statistical Process Control ensures comprehensive, data-driven project oversight and management. Project managers can effectively monitor progress, identify potential issues, and make informed decisions to maintain performance within schedule and budget constraints. This study recommends adopting Earned Value Management (EVM) and Statistical Process Control (SPC) methodologies within project management practices.

This study aims to ensure smooth project execution in large-scale initiatives by exploring the integration of Earned Value Management (EVM) and Statistical Process Control (SPC) methodologies. Focusing on the development of an Electro Magnetic Compatibility (EMC) Anechoic Chamber by an Indonesian enterprise, the study highlights how EVM can monitor performance, track schedule and budget deviations, and inform decision-making, while SPC charts detect performance trends and anticipate issues. The findings suggest that combining EVM and SPC provides a comprehensive, data-driven approach to project management, enabling proactive oversight, early issue identification, and informed decisions to keep projects on track. The study recommends adopting these methodologies for enhanced project control and success.

2. Literature Review

Earned Value

Orgut et al. (2015). stated that several metrics and indicators are used to assess the performance of construction projects based on different approaches. The most commonly used performance assessment method in the construction industry is Earned Value Management (EVM). Due to certain shortcomings of EVM, other methods, such as the Earned Schedule Method (ESM) and Earned Duration Management (EDM), are viable alternatives. This paper assumes an understanding of EVM. For convenience, the terminology EVM uses to portray the project status and forecast final cost as follows:

Table 1. Project Performance Approaches

Method	Related Metrics	Calculation
Basic Property	Planned Value	PV
	Actual Cost	AC
	Earn Value	EV
Earn Value Management (EVM)	Cost Variance (CV)	$CV = EV - AC$
	Cost Performance Index (CPI)	$CPI = EV / AC$
	Schedule Variance (SV)	$SV = EV - PV$
	Schedule Performance Index (SVI)	$SVI = EV / PV$
Earn Schedule Management (ESM)	Earn Schedule (ES)*	$ES(t) = t + \frac{EV - PV(t)}{PV(t+1) - PV(t)}$
	Earn Schedule Performance Index ($SPI_{(t)}$)	$SPI(t) = \frac{ES(t)}{Actual\ Duration}$
Earn Duration Management (EDM)	Earned Duration (ED)**	$ED_i = BPD_i \times API_i$
	Earned Duration Index (EDI_i)***	$EDI_i = \frac{ED_i}{PD_i}$

* "*t*" stands for the time status for which ES is calculated, whereas "*t*+1" is for the following period.
** BPD_i stands for Baseline Planned Duration of scheduled activity *I*, whereas API_i is the Activity Progress Index, measured scheduled progress of an activity through whichever method is preferred in the project.
*** PD_i is for Planned Duration of an activity *i*

The Earn Value (EV) is developed to assist project teams in assessing and evaluating the project's progress and performance. For this purpose, it includes several indices and estimates. By definition, the EV of an activity measures completed work and represents the budgeted cost of work performed (PMI, 2017). Two extensively used indices in analyzing project success are the Schedule Performance Index (SPI) and Cost Performance Index (CPI) (Aliverdi et al., 2013). SPI, or Schedule Performance Index, is a conformance measure of actual progress made on schedule. SPI is measured as the ratio of Earned Value (EV) to Planned Value (PV), that is:

$$SPI = \frac{EV}{PV} \quad (1)$$

CPI, or Cost Performance Index, is a measure of budgetary conformance with the actual cost of work performed and is the most useful index for indicating the cumulative cost efficiency of a project. CPI is the ratio of Earned Value (EV) to Actual Cost (AC), that is:

$$CPI = \frac{EV}{AC} \quad (2)$$

The SPI index measures how efficiently the project team is using its time. An SPI value of less than 1 indicates that less work was completed than was planned, whereas a value greater than 1 indicates that more work was completed than was planned (PMI 2017). Likewise, the CPI index measures how effectively the project team uses its cost, and the value works similarly.

3. Project Process Control

Project control measures progress identifies deviations, and takes corrective actions (Song 2022). It involves defining performance standards, evaluating actual performance, and implementing corrective actions (Pellerin & Perrier 2019). Success is measured by achieving project schedule and budget objectives. The project is monitored by comparing actual performance against the planned baseline schedule. Performance data are collected, and measures such as the Cost Performance Index (CPI) are computed.

Statistical process control (SPC) is a method widely used in manufacturing environments to monitor and enhance process efficiency by employing statistical methods to ensure the production of specification-conforming products with minimal waste (Jamadar 2020; Parkash et al. 2013). It involves tools like run charts, control charts, and a focus on continuous improvement, making it a standard for visualizing and controlling processes based on sample measurements (Jamadar 2020). SPC is crucial for achieving continuous quality and productivity improvements within organizations, emphasizing the systematic implementation of SPC as a key step toward total quality control (Aly & Murti 2014). Decision-making in SPC is human-driven, relying on wisdom and experience to interpret results and implement necessary improvements (Parkash et al. 2013).

Statistical Process Control (SPC) methodologies have been applied in various projects to measure performance. For instance, a study introduced a Computer-based SPC (CSPC) for analyzing manufacturing processes, like in a Coca-Cola bottling company, to enhance productivity (Ifekoya & Simolowo 2018). Another research validated the process capability of a new Bead Grommet machine in a tire manufacturing company using SPC, aligning with industry standards (Ruswanto & Hernadewita 2018). Moreover, SPC has been utilized in healthcare organizations to monitor perioperative system performance, such as operating room turnaround time, effectively identifying process improvements or deteriorations over time (Apreda et al. 2015). These studies collectively showcase the versatility and effectiveness of SPC in measuring and enhancing performance across different project scenarios.

SPC, a statistical method used to assess and enhance process output quality, plays a pivotal role in improving project outcomes. Through SPC implementation, process capability and output quality can be enhanced, yielding favorable project results. SPC establishes tolerance limits on Earned Value Analysis (EVA) metrics in project management, aiding in the identification of out-of-control performance levels with a certain confidence level. This capability is instrumental in facilitating corrective actions during project execution (Pellerin & Perrier 2019). Typically depicted as Control Charts, SPC visually represents quality characteristic monitoring over time, utilizing a center line and upper and lower control limits. Control chart construction necessitates average value determination (center line), standard deviation, and extreme value calculation (upper and lower control limits) (Băncescu 2016). In project performance measurement, statistical process control plays a critical role, enabling real-time monitoring and analysis of key performance indicators. This approach will help project managers with invaluable insights into project progress and highlight areas requiring corrective measures.

Leu & Lin (2008); Lipke et al. (2009); Aliverdi et al. (2013); and Băncescu (2016), suggest integrating Earned Value Management (EVM) with Statistical Process Control (SPC) to better control project schedules. They use control charts, a tool within SPC, to monitor the Schedule Performance Index (SPI) and identify when project schedules deviate from the planned trajectory. The integration of EVM with SPC provided promising results, offering a more detailed understanding of project performance and enabling early detection of deviations, which could lead to proactive corrective actions.

Project managers can analyze performance data using Statistical Process Control (SPC) charts. By identifying patterns and trends in project performance, they make informed decisions and take proactive measures to improve project outcomes. Data can be analyzed quarterly with SPC charts to determine any changes in a process. In this way, special causes of variations, such as overtime or over budget, can be identified and addressed, and corrective action can be taken to restore the project's performance. Additionally, SPC helps identify and distinguish between common causes (inherent to the process) and special causes of variation. This can help project managers detect variances from the project plan, such as delays or cost overruns, early on. Furthermore, SPC provides project managers with a concise and graphical representation of the project's performance over time. This makes it easier to visualize a project's progress and identify areas for improvement.

Control charts help distinguish between common causes and assignable causes. An assignable cause signifies that a process is out of control (Mulcahy 2013). For an out-of-control process, a data point that can be the *i*th sample mean X_i, is under the Lower Control Limit (LCL) ($\overline{X}_i < LCL$) or it is above the Upper Control Limit (UCL) ($\overline{X}_i > UCL$).

The center line is calculated as an average of the sample means and consists of the mean parameter value of each period (Bauch & Chung, 2001). The following formula then calculates the mean parameter value of each period:

$$CL = \bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad (3)$$

The Upper Control Limit and the Lower Control Limit is calculated with the following formula,

$$UCL = \bar{X} + 3 * \sigma \quad (4)$$

$$LCL = \bar{X} - 3 * \sigma \quad (5)$$

Where

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}} \quad (6)$$

σ is a standard deviation from the project data. It quantifies the extent to which individual data points deviate from the mean of the dataset, in this case is the project data. A smaller standard deviation indicates that data points tend to be closer to the mean ($\bar{X}$), while a larger standard deviation suggests that data points are more widely spread out from the mean ($\bar{X}$).

Based on (Băncescu 2016), the $\bar{X}$ chart is best suited for monitoring individual observation because this can be used to monitor project performance variables normally distributed during a review period. SPI and CPI data represent individual observations gathered at review periods, e.g., every month). Aliverdi et al. (2013) used an $\bar{X}$ chart to monitor individual observations due to the quantifiability of SPI and CPI indexes, their ability to take continuous values, and the limited number of measurements (samples) available, typically once per week or month.

4. Result and Discussion

4.1 Project Data

The study's computational section uses real data from a Project Chamber 10m with multiple serial activities. Project Chamber 10m consists of 9 work packages, as seen in Table 2. The entry data consists of 12 observations about the project's schedule progress. Data were collected and reported monthly using the SPI and CPI indicators.

Table 2.Work Package in Chamber 10m Project

Work Package	Task no.	Weight
Purchase Order (PO)	A	20%
Design	B	2%
Production	C	20%
FAT	D	1%
TOT	E	1%
Training	F	1%
Delivery	G	36%
Installation & Validation	H	17%
Functional Test	I	2%
Total		100%

Table 2 illustrates the distribution of effort and resources across various tasks in the Chamber 10m Project, highlighting that delivery and production are the most resource-intensive phases, while other tasks such as FAT, TOT, and training require relatively less effort.

Performance measures are shown in Table 3 for each task in 12 months of the project, including PV, EV, and AC. Planned Value (PV) indicates that some tasks have already been done or completed in the previous time unit. For example, Task number A was scheduled to be completed within three months but can be finished within only two months. Task C, which was scheduled to be completed by the eleventh month, was also able to be completed in the ninth month instead of the eleventh. In addition, this performance measurement is measured in Indonesian rupiah units (in millions), according to the location where the Chamber 10m project is taking place.

Table 3. Performance Measurement of the Chamber 10m project

Task No	Measure	Performance Period											
		1	2	3	4	5	6	7	8	9	10	11	12
A	PV	403.15	19149.91	604.73									
	EV	605.24	18918.56										
	AC	475	7642										
B	PV		413.23	1159.07	443.471								
	EV		408.57	1104.98	438.82								
	AC		17	756	17								
C	PV		1310.25	806.31	3023.67	3124.46	3930.77	3527.61	2519.72	1733.57	141.10	40.31	
	EV		1269.04	780.95	2928.57	3904.76	3904.76	3319.04	3319.04	97.62			
	AC		3736	1344	2026	3875	3700	3150	9824	500			
D	PV								503.94	503.95			
	EV								488.09	488.09			
	AC								100	301			
E	PV									1007.89			
	EV									976.19			
	AC									532			
F	PV										503.94		503.94
	EV										488.09		488.09
	AC										158		276
G	PV							3023.67	6047.34	6047.34	15622.3	5241.02	302.36
	EV						117.14	2147.61	5661.90	1757.142	14642.85	10738.09	78.09
	AC						175	2100	349	718	16739	14226	3821
H	PV									2015.78	3023.67	4031.56	8063.12
	EV									1903.57	2635.71	4392.85	7663.09
	AC									719	2087	736	16364
I	PV												2015.78
	EV												1952.38
	AC												1156

In million Indonesian Rupiah (IDR)

4.2 Overall Project Measurement Result

As shown in Table 4, the overall project measurements include PV per period, PV cumulative, EV per period, EV cumulative, AC per period, and AC cumulative. SPI and CPI are calculated based on this data.

Table 4. Performance Measurement per period and cumulative of the Chamber 10m project

Measure		Performance Period											
		1	2	3	4	5	6	7	8	9	10	11	12
Total Project	PVper	403.156	20873.4	2570.12	3467.142	3124.459	3930.771	6551.285	9071.01	11308.53	19291.01	9312.904	10885.21
	PVcum	403.156	21276.56	23846.68	27313.82	30438.28	34369.05	40920.33	49991.34	61299.87	80590.88	89903.79	100789
	EVper	605.2378	20596.18	1885.937	3367.391	3904.76	4021.903	5466.664	9469.043	5222.617	17766.66	15130.95	10181.66
	EVcum	605.2378	21201.42	23087.36	26454.75	30359.51	34381.41	39848.08	49317.12	54539.74	72306.39	87437.34	97619
	AC per	475	11395	2100	2043	3875	3875	5250	10273	2770	18984	14962	21617
	ACcum	475	11870	13970	16013	19888	23763	29013	39286	42056	61040	76002	97619

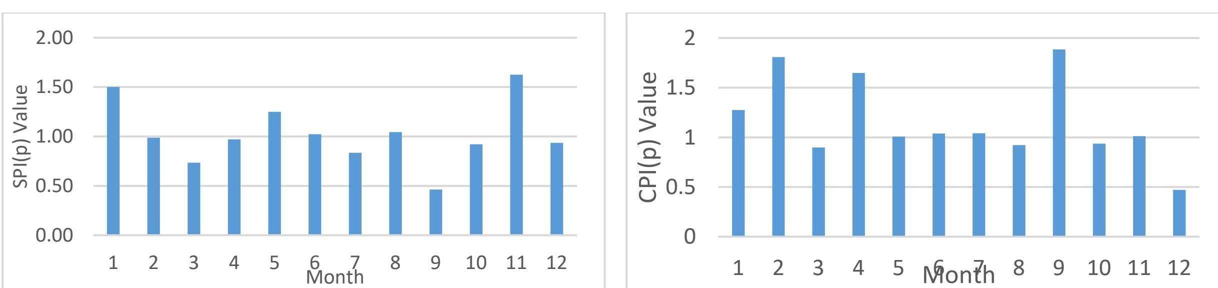
4.3 SPI and CPI Calculation Result

From the Chamber 10m project data, the SPI and CPI measurements have been calculated over 12 months. Applying the formulas (1) and (2), Table 5 shows the calculation results for SPI and CPI. The result shows the variation in SPI and CPI value, resulting from the variation in PV, EV, and AC that is mentioned in Table 3. It shows that the project team employed available time inefficiently in months 2, 3, 4, 7, 9, 10, and 12, where the SPI value is less than 1, but more efficiently in subsequent months. The overall SPI value for the project has the lowest efficiency in month 9 (SPI=0.4618) and the peak efficiency in months 1, 5, and 11 – with SPI values of 1.5012, 1.2497, and 1.6247, respectively. Furthermore, for the CPI value, the cost is over the budget in the first 2 months of the project but more effective in subsequent months. This can happen because the earlier time in the project, the project team needs to purchase the material for the chamber.

Table 5. SPI and CPI Measurement of the Chamber 10m project

Period	SPI	CPI
1	1.5012	1.2742
2	0.9867	1.8075
3	0.7338	0.8981
4	0.9712	1.6482
5	1.2497	1.0077
6	1.0232	1.0379
7	0.8344	1.0413
8	1.0439	0.9217
9	0.4618	1.8854
10	0.9210	0.9359
11	1.6247	1.0113
12	0.9354	0.4710

The chart labeled "SPI values for 12 months" presents a bar graph that illustrates the Schedule Performance Index (SPI) values over 12 months. The SPI is a key metric used in project management to measure how efficiently the project is adhering to its planned schedule.



(a) SPI values for 12 months (b) CPI values for 12 months

Figure 1. Performance monitoring scheme, where project cost and schedule performance were monitored over 12 months. a) SPI values for 12 months, b) CPI values for 12 months

The chart labeled "CPI values for 12 months" displays a bar graph showing the Cost Performance Index (CPI) over 12 months. The CPI is a key metric in project management used to measure the cost efficiency of the project, where a CPI above 1.0 indicates cost efficiency, and a CPI below 1.0 suggests cost overruns.

4.4 Control Chart Result

To create the control chart, we calculate the center line (CL), upper control limit (UCL), and lower control limit (LCL) based on the results in Table 5. Table 6 demonstrates the outcomes of applying formulas (3), (4), (5), and (6) to the set of SPI data mentioned above.

Table 6. Control chart element calculation for SPI and CPI

Performance Index	Control chart element	Value calculated
SPI	Center Line (CL)	1.02
	Upper control limit (UCL)	1.93
	Lower control limit (LCL)	0.12
CPI	Center Line (CL)	1.16
	Upper control limit (UCL)	2.36
	Lower control limit (LCL)	0.00

The average value of the SPI (Schedule Performance Index) being over 1 indicates that, an average SPI (Schedule Performance Index) value over 1 indicates that the project is ahead of schedule. This means that, overall, the project is progressing more rapidly than planned. The acceptable range of variation for the schedule performance data, from 0.12 and 1.93, suggests that deviations from the planned schedule are within an acceptable range. Values falling within this range indicate that the project is generally maintaining its schedule efficiency without significant delays or accelerations. Similarly, the average value of the CPI (Cost Performance Index) being over 1 indicates that, on average, the project is under budget. This means that, overall, the project is spending less than planned to achieve its objectives. The acceptable range of variation for the cost performance data, between 0.00 and 2.36, indicates that deviations from the planned budget are also within an acceptable range. Values falling within this range suggest that the project is generally managing its costs efficiently, with expenses being controlled within reasonable limits.

The control chart is designed and used for process monitoring the entire data set, all 12 observations from Table 5. The results are presented in Figure 2.

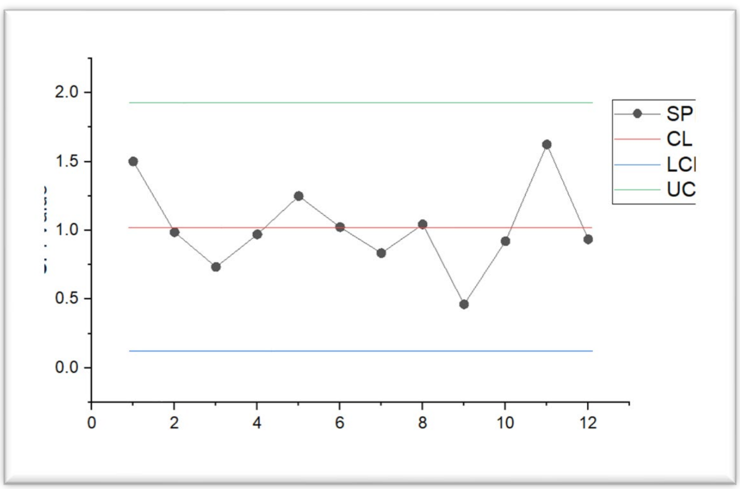


Figure 2. Control chart for SPI

The results show that during the first two months of the project, the SPI indicator was below the center line but still above the lower control limit, where the $PV > EV$, resulted in abnormally slow job progress. This happens because in the second and third months of the project, the main activity is Design and Production which are dependent on the availability of the material. Also, the SPI goes below the center line in months 6-7 and 8-9. This happened because, in that month, the project team was required to start delivering chamber components to the project location, and also continue the production process. However, production progressed exceptionally quickly in month 11 of the project, where the $PV < EV$, as they focused on Delivery, Installation & Validation, and Functional Test activity.

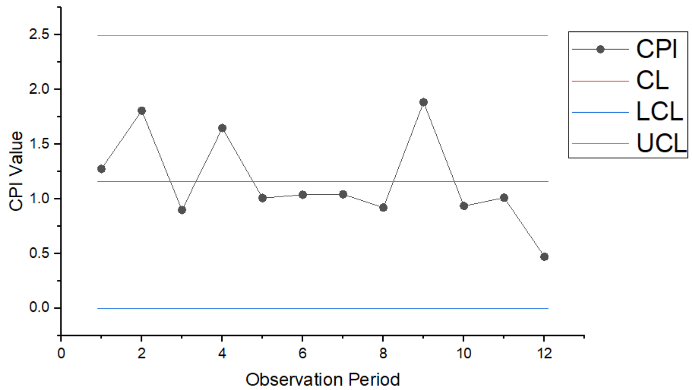


Figure 3. Control chart for CPI

As for the CPI, the results show that during the first two months of the project, the CPI indicator was above the center line but still under the upper control limit, where the $EV > AC$, resulting in the progress being effective and budget-wise. Also, in months 4 and 9, the CPI indicator was above the center line but still under the upper control limit. In months 5, 6, 7, and 11, the CPI value is nearly in Center Line (CL), indicating that a project progress is most likely on budget. However, in months 3, 8, 10, and 12, the CPI value of the project is under the Center Line, and less than 1 where the $EV < AC$, indicates that the project progress is over budget.

5. Conclusion

The application of Statistical Process Control (SPC) techniques, particularly through the utilization of Schedule Performance Index (SPI) and Cost Performance Index (CPI) analysis from the Earned Value Management (EVM) approach, has provided valuable insights into the dynamics of our project's schedule progress and budgetary performance. Using Statistical Process Control methods, we constructed a control chart with computed center lines and control limits derived from 12 observations of the SPI indicator. This rigorous approach enabled the team to promptly detect deviations from the project timeline and facilitated targeted interventions to address underlying issues or capitalize on emerging opportunities.

Moreover, utilizing the SPI provided valuable insights into the project's performance dynamics. The initial months witnessed a slower pace of progress, prompting a detailed examination of individual activities to identify bottlenecks and inefficiencies. Subsequent interventions based on these findings resulted in gradual improvements, reflected in the SPI rising above the center line in certain intervals. However, the notable surge in progress during months 10 and 11 underscored the project's resilience and adaptability. This rapid advancement demonstrated the team's capacity to overcome challenges and hinted at the project's potential for overall success.

Similarly, the analysis of the CPI shed light on the project's budgetary performance over time. While periods of cost efficiency were observed during the project's inception and at intermittent stages, indicating effective resource utilization, challenges with budget management surfaced during other phases. During certain months, the CPI values falling below the center line and below 1 signaled over-budget progress, necessitating corrective measures to realign expenditures with planned targets. In essence, the combined insights from SPI and CPI analysis facilitated proactive decision-making and empowered the project team to navigate challenges effectively and capitalize on opportunities, ultimately enhancing the project's chances of success.

Incorporating SPC principles into the project management approach enabled the team to make informed decisions and take proactive steps to ensure project success. Moving forward, the insights gleaned from this analysis will serve as a foundation for continuous improvement, guiding the efforts to enhance project efficiency and effectiveness in future endeavors. By applying SPC principles, the project team remains committed to achieving its project objectives and delivering value to stakeholders.

Future research could investigate the integration of advanced predictive analytics with SPC and EVM techniques to improve early identification of potential project deviations. The use of machine learning algorithms could enable real-time data analysis and predictive modeling, allowing for more accurate and timely interventions. Moreover, extending the study to encompass a wider variety of projects across different industries could help confirm the effectiveness of these methodologies in various settings. Additional research could also examine the influence of team dynamics and external factors on SPI and CPI fluctuations, providing a more comprehensive view of project performance. Finally, refining control limits and center lines using larger datasets and longer project timelines could enhance the precision of SPC charts, leading to even more effective project management practices.

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Biographies

Angela Hsiang-Ling Chen is a Associate Professor of Operations and Logistics Management at Chuang Yuan Christian University's Department of Industrial and Systems Engineering, Taiwan. Her research studies project operations, logistics, and human resource management decision-making. Her current research focuses on retail distribution and channel management, CRM in public transportation systems, and sustainability in human capital management.

Wawan Tripiawan is a PhD Student at the Department of Industrial and System Engineering, Faculty of Engineering, Chung Yuan Christian University, Taoyuan - Taiwan. His major is Industrial Engineering. His present research interests are in the field of Project Management.