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Journal homepage: http://journal.unj.ac.id/unj/index.php/jpensil/index

PROJECT DURATION FORECASTING METHODS USING EVM AND ESM FOR A DOUBLE-TRACK RAILWAY PROJECT IN COMPARISON

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P-ISSN: 2301-8437
E-ISSN: 2623-1085

ARTICLE HISTORY
Accepted:
30 July 2025
Revision:
19 September 2025
Published:
30 September 2025

ARTICLE DOI:
10.21009/jpensil.v14i3.59154

Abstract

The growing complexity of infrastructure projects, such as railway construction, necessitates precise tools to monitor progress and accurately predict completion times. Traditional methods often fail to capture real-time schedule dynamics, resulting in ineffective project management. This study employs earned value management (EVM) and earned schedule (ES) to predict the project duration for a double-track railway initiative. Performance metrics for scheduling, such as SPI and SPI(t), as well as forecasting tools, including EAC(t), IEAC, and IEAC(t), were analyzed over 28 weeks. The results demonstrate that SPI(t)-based methods offer more stable and realistic duration forecasts than conventional SPI-based approaches, particularly during periods of poor performance. IEAC values fluctuated sharply during the project's early and middle stages, exceeding 800 days, while IEAC(t) remained consistent, aligning closely with actual progress. After the implementation of contract addenda in Weeks 21 and 27, both indicators improved significantly. SPI and SPI(t) exceeded 1.0, and the forecasted completion date aligned closely with the original plan. The study concludes that the ES method improves schedule forecasting accuracy and provides better insight into project performance trends.

Keywords: Earned Value, Earned Schedule, Forecasting duration

Introduction

Railway transportation plays a critical role in supporting mobility and logistics in Indonesia. There has been consistent growth in passenger demand, with the Directorate of Railway Traffic and Transportation reporting over 416 million passengers in 2023 compared to less than 300 million the previous year. This growth has been accompanied by accelerated infrastructure development. The Directorate of Railway Infrastructure recorded the addition of 233 kilometers of double-track railways in Java and Sumatra from 2022 to 2023, including the strategic Wonokromo–Jombang segment. The Mojokerto-Sepanjang project, spanning km 49+500 to km 52+500, includes bridge construction, track work, and related civil infrastructure. It has a contractual duration of 847 calendar days (121 weeks).

Despite the project's structured planning, it encountered delays by Week 27, requiring two contractual addenda. While progress initially appeared to be ahead of schedule after the first addendum, consistent performance improvements were not evident. This situation highlights the limitations of conventional progress tracking methods, which often provide optimistic results that do not reflect the actual efficiency of project execution. Current performance monitoring approaches in Indonesian railway infrastructure projects rely heavily on physical progress indicators and simple schedule comparisons. These methods are insufficient for identifying hidden inefficiencies or predicting future risks. This creates a research gap regarding the use of advanced project control methods that can objectively measure cost and time efficiency. This study addresses this gap by applying Earned Value Management (EVM) in combination with Earned Schedule (ES). This approach offers a more accurate framework for evaluating performance than conventional monitoring methods.

Earned value management (EVM) is a recognized technique for monitoring project performance that integrates cost and schedule into a unified framework (PMI, 2021). Previous studies have confirmed its effectiveness in identifying delays and cost overruns (Chen et al., 2016; Bryde et al., 2018; Rachmawati et al., 2024). However, EVM also has critical shortcomings. Its time-based performance indicators, particularly the Schedule Performance Index (SPI), become difficult to interpret when projects exceed their planned completion date. Consequently, EVM often fails to accurately measure the actual pace of work or provide meaningful insights into schedule dynamics (Nkiwane et al., 2016; Mayo-Alvarez et al., 2022).

To address these weaknesses, researchers have proposed refinements such as the Earned Schedule (ES) method (Lipke, 2015) and Earned Duration Management (EDM)(Vanhoucke et al., 2015; Nurevita & Anondho, 2020; Votto et al., 2020). On the other hand, cost and time are influenced by order variation factors (Hindami et al., 2024). Material waste improves supervisory performance during project construction (Kurniawan et al., 2024). In particular, ES extends EVM by translating earned value metrics into time units rather than cost units. This enables more precise measurement of schedule adherence and project duration forecasts. In essence, ES "perfects" EVM by restoring the validity of schedule performance indicators and offering reliable insights into the efficiency with which work is progressing relative to time.

This study's novel approach combines EVM and ES to evaluate the performance of railway infrastructure projects. While EVM provides an integrated view of cost and schedule efficiency, ES addresses EVM's shortcomings in schedule measurement. Together, they produce a more accurate, holistic assessment of project performance over time. This methodological approach contributes to both practice and theory. Practically, it provides project stakeholders with a more reliable tool for making decisions and managing complex infrastructure projects. Theoretically, it strengthens the knowledge base by demonstrating how EVM and ES can be used together to improve performance evaluation frameworks.

Despite its widespread use, EVM has inherent weaknesses when applied to schedule analysis. The Schedule Performance Index (SPI), which relies on cost-based metrics, becomes increasingly unreliable as a project progresses, especially after the planned completion date has passed. This can lead to inaccurate interpretations of schedule adherence since EVM measures progress in monetary terms rather than time. To address this, Earned Schedule (ES) converts earned value into time-based measures, restoring the validity of SPI and related indicators. ES enables more accurate monitoring of schedule performance by ensuring that project evaluations reflect not only cost efficiency, but also the actual pace of work execution.

Based on Urgilés et al. (2019) the cost versus time S-curve parameters are shown in Figure 1. The first thing we need to know is that BAC is Budget at Completion, which is the total amount of money that's estimated to be needed to complete a project. The curves are referred to as PV (Planned Value), BCWS (Budgeted Cost for Work Scheduled), or ACWP (Actual Cost for Work Performed); BCWP (Budgeted Cost for Work Performed) or EV (Earned Value). The BCWS curve shows the projected cost versus project completion time. The ACWP curve shows the real cost as a function of time. Finally, the earned value is shown by the BCWP curve. The project is essentially earning the budgeted cost of these tasks as earned value as they are performed. These three S-curves are used to generate the EVM indicators. Schedule Variance (SV) is the calculated cost difference, BCWP - BCWS, whereas Cost Variance (CV) is BCWP - ACWP. A ratio is employed to determine the Schedule Performance Index (SPI) and the Cost Performance Index (CPI). The CPI is equal to BCWP/ACWP, yet, the SPI is determined by the ratio of BCWP to BCWS.

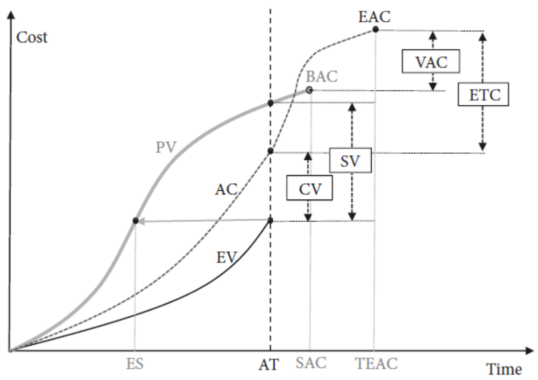

Figure 1. Cost/Time graph illustrating the primary ES parameters and EVM parameters (Urgilés et al., 2019)

In order to improve the estimation of the actual project duration and/or the implementation of more proactive and corrective measures during project execution, several of previous researchers target certain shortcomings or limitations of the EVM framework in general. One of them was Nizam & Elshannaway (2019), who presented the results of their research that the project's estimated cost, or BAC, is the endpoint of BCWS. In addition, BAC is the end-point for earned value (BCWP) (Ghanbari et al., 2017). It converges to the projected cost as the earned value gets closer to project completion. Once a project is delayed, BCWS equals BAC while BCWP gradually reaches the value (Martens & Vanhoucke, 2019). At project completion, the SPI ends at 1.0, but the SV must converge to 0.0. Lipke (2015) and Khamooshi & Abdi (2017) argued that EVM is a less appealing way to describe the project's scheduling status.

How have earned value metrics become so popular for monitoring a project's development and forecasting its future financial and temporal performance? (Jaber et al., 2020; Nguyen et al., 2019). In this section, we go into greater detail about how measurements are used to forecast the eventual duration of a project using various methods.. This method was also used by Batselier & Vanhoucke (2017) and Sackey et al. (2020) explains earned value management's applicability and considerations for project managers. Urgilés et al., (2019) evaluates the EVM technique's effectiveness in intricate hydroelectric power generation projects.. EVM and ES have been compared as project duration forecasting methods in a construction project (Batselier & Vanhoucke, 2015; Oktavitri & Tenriajeng, 2017; Tangtobing & Waty, 2023).

Lipke (2017) use statistical methods to forecast with earned value analysis. A well-established and mathematically sound way for inferring results is the application of statistical techniques. It has been shown in his earlier work that the statistical forecasting method for length performs rather well. To make things more convenient, the EVM language used to have forecast project completion dates using the following fundamental structure:

Duration Forecast = Time Spent + Projected Work Remaining
IEAC(t) = AT + (BAC – EV) / Work Rate ... (1)
IEAC(t) = AT + (BAC – EV) / SPI ... (2)
IEAC(te) = PD / SPI(te) ... (3)

(Lipke, 2015) where AT is an abbreviation for actual time, which is the duration since the PV and EV measurements were taken. The term 'work remaining' is frequently used to describe BAC-EV. The remaining work is converted to the anticipated time needed to do it by a factor called work rate.

The time estimate at completion (EACt) was predicted using the following formulas by Ballesteros-Pérez et al. (2019), Sackey et al. (2020), and Andreas et al. (2023):

EAC(t) = DAC / SPI, or EAC(t) = PD/SPI ... (4)

The DAC, or expected duration at completion, is determined by performance assumptions and represents the projected entire project time. Therefore, it can be said that DAC and PD are the same parameter. While Andreas et al. (2023) and Salsabilla & Andreas (2023) use EAC(t) with the difference form as follows:

EAC(t) = AT + ETS ... (5)
ETS = (AT – PD)/SPI ... (6)

But Saputra et al. (2024) argued that ETS is equal to Remaining Time divided by SPI, and EAS is Finish time plus ETS. The estimated time to schedule (ETS) is the anticipated amount of time needed to finish the remaining tasks. When work implementation deviates from the scheduled timeline, ETS is examined (Khesal et al., 2019).

The inability of EVM to accurately forecast project completion time since it evaluates schedule performance using cost factors rather than time characteristics (Vaibhava et al., 2020; Bryde et al., 2018). But as a result of the introduction of earned schedule (ES), an extension of EVM, to enhance the tracking of real project progress, the focus progressively switched to duration control (Cheng et al., 2021). The time from the beginning of the project to the point at which PV should have equalled the current amount of EV is known as the Earned Schedule (Nizam & Elshannaway, 2019). According to Lipke (2017) and Miguel et al. (2019), ES is a time duration measurement. In contrast to EVM, ES shows that it can explain cost performance in terms of time units. To put it another way, ES makes time-based schedule analysis easier to comprehend than EVM (Lipke, 2017). Using EV to calculate the PV time increment at which the cost value should occur yields the cumulative value of ES (Lipke, 2023). Figure 2 depicts the idea of an earned timetable.

ES presents differences in immediate units and measures them horizontally. As a result, SV is changed to SV(t), which shows how many time units the project has already surpassed its timeline. (Nadafi et al., 2019). To determine the actual performance of the project concerning its planned performance, ES converts EV into time units (Sheikhalishahi et al., 2022). Using ES, it is possible to create indicators that behave appropriately and similarly to cost indicators:

ES = C + I, where C = the nearest lower BCWS value at the location where the earned schedule value occurred, and I = additional value. It represents the proportion of the difference between the BCWP value and the lower BCWS value, as well as between the upper and lower BCWS values.

$$I=\frac{(BCWP-BCWSt)}{(BCWSt+1-BCWSt)} \quad \text{... (7)}$$

where BCWP = budgeted cost of work performed, BCWSt = lower limit of BCWS value based on BCWP in this period, BCWSt+1 = upper limit of BCWS value based on BCWP in this period. Then, ES = earned schedule value, AT = actual time.
Schedule Variance : SV(t) = ES – AT ... (8)
Schedule Performance Index : SPI(t) = ES/AT ... (9)(Lipke, 2017b)

The efficiency with which the PD is attained about the time invested is described by the SPI(t) index. The schedule performs satisfactorily when SPI(t) is 1.0 or more. It is necessary to look into and fix performance issues when the indicator value is less than 1.0. The same is true for SV(t), where performance is ahead of schedule when the value is positive and behind schedule when the value is negative.

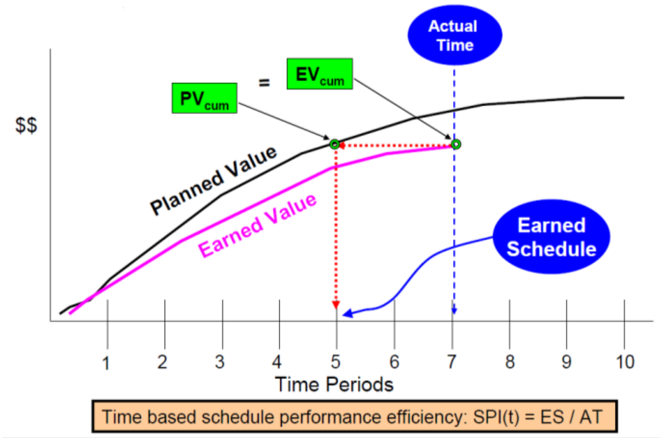

Figure 2. Earned Schedule Concept (Lipke, 2015)

Figure 2 illustrates the concept by (Lipke, 2015). The EV should have been accumulated at the moment that the ES measure indicated. PV equals the total EV at this location on the PMB (Performance Measurement Baseline), per the diagram. In the schedule, what is "earned" is determined by the vertical line that connects the point on the PMB to the time axis. The duration between the beginning of the project and the intersection of the time axis is known as the ES.
A formula for project duration predictions is offered by:
EAC(t) = AD + PDWR, ... (10)
PDWR = PD – ES, ... (11)

where EAC(t) is the projected duration at completion, PDWR is the planned length of work left, and AD is the actual duration. It refers to the project's real duration at the present time instance using the AD metric. Additionally, any forecasting metric for the full project period can be referred to using the EAC(t) measure (keep in mind that the literature typically refers to the cost estimate at completion using the term EAC - without (t)). Additionally, the part that needs to be estimated is the PDWR metric. and is highly contingent on the specifics and current status of the project (Ballesteros-Pérez et al., 2019).

de Andrade et al. (2019) recently presented the earned schedule method for project duration forecasting, which builds on Lipke (2017) work. He has used a portfolio of six projects to show that the earned schedule concept is feasible, as well as a small but important initiative to develop software for information technology. The earned schedule duration forecasting formula by Lipke (2017) is:
IEAC(t)ES = PD / SPI(t) = AD + (PD – ES)/PF(t) ... (12)
where PF(t) = Time-Based Performance Factor.

Additionally, the ES program, offered by Lipke (2017), can calculate the performance efficiency needed to finish the project by the target duration (TD) or the projected or estimated duration (ED). The following is the definition of the to-complete schedule performance index (TSPI):
TSPI = (PD – ES) / (TD or ED – AT) ... (13)

In addition, Khamooshi et al. (2021) and Wauters & Vanhoucke (2016) forecasted the final duration of ES using a similar method: by using IEAC(t)es = PD/SPI(t), the final duration is predicted, where PD is the project's projected duration and IEAC(t)es stands for Independent Estimate at Completion (time). A recent TSPI study utilising actual data has demonstrated that there is virtually little chance of finishing the project on schedule when the indicator value is more than 1.10 (Lipke, 2016). Furthermore, Lipke (2020) use the schedule performance impact from rework by earned schedule compared with earned value method. The same approach was employed by Chen et al. (2016) and Mahmoudi et al. (2021) in construction projects.

Research Methods

The research employed a case study approach, focusing on the Wonokromo–Jombang double-track railway project, which is expected to be completed within 121 weeks. Data from weeks one to 28 were analyzed to assess schedule performance. To assess project progress, the analysis employed earned value and earned schedule techniques, applying revised BAC values after two contractual addenda were made. Data were collected from secondary project documents, including weekly progress reports. These documents were then processed to calculate schedule performance indicators. The method of data analysis entailed contrasting earned value, planned value, and real time to determine schedule variance and forecast project duration.

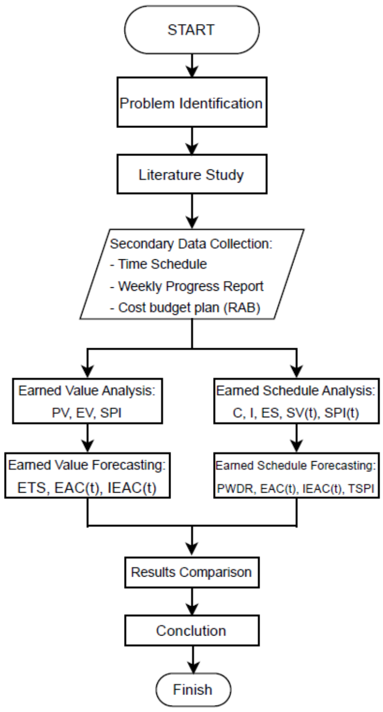

Figure 3. Research Methods

The analysis was conducted in two stages. First, the Earned Value Management (EVM) method was applied to calculate indicators such as Planned Value (PV), Earned Value (EV), and Schedule Performance Index (SPI). These metrics integrate cost and schedule to evaluate efficiency, yet they are still expressed in monetary terms. Next, the Earned Schedule (ES) method was employed to convert earned value into time units. This involved calculating the earned schedule (ES), schedule variance in time (SV(t)), and schedule performance index in time (SPI(t)). These calculations provide a more direct assessment of schedule adherence and delays.

After the analysis was completed, forecasting techniques were applied to estimate the project's completion performance. In the EVM approach, the following were calculated: Estimate to Complete (ETS), Estimate at Completion (EAC(t)), and Independent Estimate at Completion (IEAC(t)). The ES approach yielded additional forecasting metrics, such as Planned Work Duration Remaining (PWDR), EAC(t), IEAC(t), and To-Complete Schedule Performance Index (TSPI). The results from both methods were then compared to highlight the differences between cost- and time-based evaluations. This demonstrated how the ES approach enhances the accuracy of the EVM method for assessing project performance and predicting schedule outcomes.

Research Methods

In order to assess the project's success over time and, specifically, to assess the degree of precision in the time performance prediction, this research is taken as a case study, namely the Wonokromo – Jombang double track railway project. The project was analysed from week 1 to week 28 because within this timeframe there were two contract addenda that allowed the project schedule's performance to undergo significant changes. The BAC used is the contract value after the two addenda occur. Note that the schedule performance analysis in the first 20 weeks does not use the initial contract value, and between weeks 21 and 25 does not use the first addendum value. This project's BAC value we use is Rp 52,607,777,000. For example, the calculation process for week 10 is as follows:

Planed Value = Cumulative Planning Progress x BAC
= 3.499% x Rp 52,607,777,000
= Rp1.840.706.243,62

Earned Value = Cumulative Actual Progress x BAC
= 1.023% x Rp 52,607,777,000
= Rp 538,410,355.91

Schedule Variance = Earned value – Planed Value
= Rp 538,410,355.91 – Rp1.840.706.243,62
= – Rp 1,302,295,887.72

SPI = EV / PV = Rp 538,410,355.91 / Rp1.840.706.243,62 = 0.293

Table 1. Earned value result analysis

Month	Cumulative Planning Progress (%)	Planed Value		Cumulative Actual Progress (%)	Earned Value		Schedule Variance		SPI
APRIL	0.010%	Rp	5,456,341.52	0.029%	Rp	15,021,830.64	Rp	9,565,489.11	2.753
	0.334%	Rp	175,680,645.87	0.150%	Rp	78,993,660.87	-Rp	96,686,985.00	0.450
MAY	0.334%	Rp	175,680,645.87	0.150%	Rp	78,993,660.87	-Rp	96,686,985.00	0.450
	0.334%	Rp	175,680,645.87	0.150%	Rp	78,993,660.87	-Rp	96,686,985.00	0.450
	0.700%	Rp	368,043,552.21	0.389%	Rp	204,439,776.30	-Rp	163,603,775.91	0.555
	0.875%	Rp	460,365,512.86	0.549%	Rp	289,020,892.07	-Rp	171,344,620.78	0.628
JUNE	1.324%	Rp	696,620,162.97	0.710%	Rp	373,602,007.85	-Rp	323,018,155.12	0.536
	2.071%	Rp	1,089,653,657.87	0.871%	Rp	458,183,123.62	-Rp	631,470,534.24	0.420
	2.786%	Rp	1,465,593,058.48	0.970%	Rp	510,424,239.66	-Rp	955,168,818.81	0.348
	3.499%	Rp	**1,840,706,243.62**	**1.023%**	Rp	**538,410,355.91**	-Rp	**1,302,295,887.72**	**0.293**
JULY	4.158%	Rp	2,187,463,155.48	1.070%	Rp	563,091,380.75	-Rp	1,624,371,774.74	0.257
	4.848%	Rp	2,550,313,699.18	1.074%	Rp	565,148,925.77	-Rp	1,985,164,773.41	0.222
	5.635%	Rp	2,964,267,747.28	1.078%	Rp	567,206,470.80	-Rp	2,397,061,276.48	0.191
	6.422%	Rp	3,378,221,795.38	1.082%	Rp	569,264,015.83	-Rp	2,808,957,779.55	0.169
	7.111%	Rp	3,741,072,339.08	1.140%	Rp	599,956,320.62	-Rp	3,141,116,018.45	0.160
AUGUST	7.801%	Rp	4,103,922,882.77	1.199%	Rp	630,648,625.41	-Rp	3,473,274,257.36	0.154
	8.491%	Rp	4,466,773,426.47	1.492%	Rp	784,702,156.47	-Rp	3,682,071,270.00	0.176

	9.226%	Rp	4,853,423,146.25	3.057%	Rp	1,608,134,452.57	-Rp	3,245,288,693.68	0.331
	9.953%	Rp	5,235,830,634.91	6.763%	Rp	3,558,051,073.53	-Rp	1,677,779,561.38	0.680
SEPTEMBER	10.638%	Rp	5,596,478,474.55	8.369%	Rp	4,402,620,182.40	-Rp	1,193,858,292.15	0.787
	9.476%	Rp	4,985,075,118.69	10.713%	Rp	5,636,114,306.56	Rp	651,039,187.88	1.131
	10.579%	Rp	5,565,149,105.00	11.679%	Rp	6,143,980,586.88	Rp	578,831,481.89	1.104
	11.652%	Rp	6,129,779,091.43	13.175%	Rp	6,931,199,845.59	Rp	801,420,754.16	1.131
	12.718%	Rp	6,690,818,875.90	14.445%	Rp	7,599,232,780.30	Rp	908,413,904.40	1.136
OCTOBER	14.048%	Rp	7,390,421,157.82	15.898%	Rp	8,363,691,919.85	Rp	973,270,762.03	1.132
	15.595%	Rp	8,204,084,858.84	18.831%	Rp	9,906,466,714.54	Rp	1,702,381,855.70	1.208
	20.100%	Rp	10,574,278,792.26	20.727%	Rp	10,904,130,330.61	Rp	329,851,538.35	1.031
	21.323%	Rp	11,217,678,661.84	22.912%	Rp	12,053,383,124.94	Rp	835,704,463.10	1.074

Using week 10 in the calculation example above, the EV is Rp 538,410,355.91. EV represents the value of completed work in budgeted terms. This differs from ACWP, which is the actual money spent. ACWP is based not only on completed work but also on indirect costs. Since ACWP is greater than EV, the project is over budget for the amount of work accomplished. However, when ACWP < EV, the opposite is true.

Project performance analysis based on schedule variance (SV) and schedule performance index (SPI), as displayed in Table 1, shows an obvious trend of initial delays followed by gradual improvement. From Week 1 to Week 20, SPI values consistently remained below 1.0, indicating that the project was progressing more slowly than planned. The worst performance occurred around Weeks 13 to 16, when the SPI dropped to 0.154 and the SV reached over Rp -3.4 billion, reflecting significant schedule delays. These results suggest that the original execution plan was not being met due to various implementation issues on-site.

A turning point occurred in Week 21 when the first contract addendum was enacted. From that point on, the SPI values steadily climbed, surpassing 1.0 in Week 22 and continuing to improve in subsequent weeks. This indicates that the corrective measures introduced by the addendum effectively realigned the project schedule. By Week 27, when the second contract addendum was implemented, the SPI had stabilized above 1.0, and the SV had turned consistently positive. By the end of Week 28, the project had achieved an SPI of 1.074 and a positive SV of over Rp 835 million, indicating that it was ahead of the revised schedule. This analysis shows that contract adjustments significantly impact schedule performance and that earned value metrics, particularly SPI, are valuable for evaluating and forecasting the progress of civil infrastructure projects.

To validate this result, we also calculated the Independent Estimate at Completion (IEAC) using the formula IEAC = PD/SPI. This yielded an estimate of approximately 413.7 weeks. The slight difference between EAC(t) and IEAC reflects the EAC(t) method's consideration of actual time consumed. These results both reinforce that the current project is significantly behind schedule and that immediate corrective action is necessary to make progress and minimize further delays. These calculations demonstrate the effectiveness of SPI-based forecasting in providing early warnings and helping project managers make data-driven decisions. For example, the calculation process for week 10 is as follows:

ETS = (PD-AT)/SPI = (121 – 10)/0.293 = 379.5
EAC(t) = AT+ETS = 10 + 379.5 = 389.5
IEAC = PD/SPI = 121/ 0.293 = 413.7

Table 2. Earned value duration forecasting

Month	AT	ETS = (PD-AT)/SPI	EAC(t) = AT+ETS	IEAC = PD/SPI
APRIL	1	43.6	44.6	44.0
	2	264.7	266.7	269.1
MAY	3	262.4	265.4	269.1
	4	260.2	264.2	269.1
	5	208.8	213.8	217.8
	6	183.2	189.2	192.7

Month	AT	ETS = (PD-AT)/SPI	EAC(t) = AT+ETS	IEAC = PD/SPI
JUNE	7	212.6	219.6	225.6
	8	268.7	276.7	287.8
	9	321.6	330.6	347.4
	10	379.5	389.5	413.7
JULY	11	427.3	438.3	470.1
	12	491.9	503.9	546.0
	13	564.4	577.4	632.4
	14	635.0	649.0	718.1
	15	661.0	676.0	754.5
AUGUST	16	683.3	699.3	787.4
	17	592.0	609.0	688.8
	18	310.9	328.9	365.2
	19	150.1	169.1	178.1
SEPTEMBER	20	128.4	148.4	153.8
	21	88.4	109.4	107.0
	22	89.7	111.7	109.6
	23	86.7	109.7	107.0
	24	85.4	109.4	106.5
OCTOBER	25	84.8	109.8	106.9
	26	78.7	104.7	100.2
	27	91.2	118.2	117.3
	28	86.6	114.6	112.6

Using SPI, we examined the project's time performance, based forecasting to estimate the remaining (ETS) and total (EAC(t) and IEAC) durations required to complete the project. As shown in Table 2, SPI values consistently declined in the early phase (Weeks 1–10), dropping to 0.293 by Week 10. Consequently, the estimated time to complete the project (ETS) increased significantly, reaching 379.5 weeks. This resulted in an EAC(t) of approximately 389.5 weeks and an IEAC of 413.7 weeks. Assuming performance continued at that pace, these values indicate a projected delay of over 260 weeks compared to the original 121-week plan.

Performance hit rock bottom between Weeks 13 and 16, with the SPI dropping below 0.2 and the IEAC peaking at 787.4 weeks. After the first contract addendum was implemented in Week 21, however, the SPI began to improve, resulting in a sharp decline in both the ETS and the EAC(t) values. This recovery trend continued, and by Week-27, when the second contract addendum was introduced, the SPI had risen to 1.031 and the EAC(t) had dropped to 118.2 weeks, nearly aligning with the original plan. By Week-28, the SPI had risen to 1.074, the EAC(t) had dropped to 114.6 weeks, and the IEAC had dropped to 112.6 weeks. These results indicate that the project had not only recovered but was also on track to finish slightly ahead of the revised schedule. These results confirm that using SPI for schedule forecasting can effectively identify early delays and measure the success of corrective actions, such as contract addenda.

Subsequently, we use ES to analyse the schedule performance. Next, determine the value of C, which is the closest lower value of BCWS at the point where the earned schedule value occurs. Next, get the value of I, an extra value that is the ratio of the BCWP value difference to the BCWS bottom value difference to the BCWS top and bottom value difference. Let's take week 10, for example. In week 10, the BCWP value is Rp 538,410,356, while the closest BCWS value below this value is in week 6, because it is Rp 460.365.513. If we used week 7, its BCWS is greater than week 10 BCWS. So, so the value of C is 6.

$$I = \frac{(BCWP - BCWSt)}{(BCWSt+1 - BCWSt)}$$

$$= \frac{(\text{Rp } 538{,}410{,}356 - \text{Rp } 460.365.513)}{(\text{Rp}696.620.163 - \text{Rp } 460.365.513)}$$

$$= 0.330$$

$$ES = C + I \qquad = 6 + 0.330 = 6.330$$

SV(t) = ES – AT = 6.330 – 10 = -3.670
PSI(t) = ES / AT = 6.330 / 10 = 0.633

Table 3. Earned schedule result analysis

Month	AT	C	I	ES = C + I	SV(t)	SPI(t)
APRIL	1		0.054	1.054	0.054	1.054
	2	1	0.432	1.432	-0.568	0.716
MAY	3	1	0.432	1.432	-1.568	0.477
	4	1	0.432	1.432	-2.568	0.358
	5	4	0.150	4.150	-0.850	0.830
	6	4	0.589	4.589	-1.411	0.765
JUNE	7	5	0.060	5.060	-1.940	0.723
	8	5	0.976	5.976	-2.024	0.747
	9	6	0.212	6.212	-2.788	0.690
	10	**6**	**0.330**	**6.330**	**-3.670**	**0.633**
JULY	11	6	0.435	6.435	-4.565	0.585
	12	7	-0.335	6.665	-5.335	0.555
	13	7	-0.329	6.671	-6.329	0.513
	14	7	-0.324	6.676	-7.324	0.477
	15	7	-0.246	6.754	-8.246	0.450
AUGUST	16	7	-0.168	6.832	-9.168	0.427
	17	7	0.224	7.224	-9.776	0.425
	18	9	0.380	9.380	-8.620	0.521
	19	14	0.496	14.496	-4.504	0.763
SEPTEMBER	20	16	0.823	16.823	-3.177	0.841
	21	20	-0.065	19.935	-1.065	0.949
	22	21	1.998	22.998	0.998	1.045
	23	22	2.419	24.419	1.419	1.062
	24	23	2.619	25.619	1.619	1.067
OCTOBER	25	24	2.391	26.391	1.391	1.056
	26	25	3.092	28.092	2.092	1.080
	27	26	1.139	27.139	0.139	1.005
	28	27	2.299	29.299	1.299	1.046

According to the ES analysis in Table 3, the project experienced consistent delays from Week 1 to Week 20. This is reflected by the negative SV(t) values and the SPI(t) consistently being below 1.0. For example, in Week 10, the SPI(t) was 0.63 and the SV(t) was -3.67, meaning the project was nearly four weeks behind schedule. The lowest SPI value, 0.42, occurred in week 17, highlighting the severity of the delay. However, a notable improvement began in Week 21 following the implementation of the first contract addendum. From that point on, the SPI gradually increased, reaching values above 1.0. This indicates that the project was progressing faster than the revised plan.

The positive trend continued steadily through week 27, when the second contract addendum was implemented. Following this adjustment, the SPI(t) stabilised between 1.01 and 1.07, while the SV(t) consistently remained positive. This demonstrated that the project was not only recovering but also catching up to the revised timeline. By week 28, the earned schedule (ES) reached 29.299 weeks, with the schedule performance index (SPI) at 1.05 and the schedule variance (SV) at +1.30. These results indicate that the project was more than a week ahead of the revised schedule. These results demonstrate that earned schedule metrics provide clearer insight into schedule performance than traditional cost-based EVM indicators, particularly for projects with dynamic timelines adjusted through contract addenda.

After performing a schedule analysis using the earned schedule, next, based on current progress patterns, the remaining time and total duration needed to finish the project were estimated. With a PD of 121 weeks and an assumed TD equal to the PD, several forecasting metrics were calculated. The Planned Duration of Work Remaining (PDWR) was found to be

114.67 weeks. This value was derived from the difference between the PD and the ES, which was 6.33 weeks at the tenth week of observation.

The estimated at completion (EAC(t)) was calculated as the sum of the actual duration (AD) and the planned duration remaining (PDWR), resulting in 124.67 weeks. This indicates that, if the current performance trend continues, the project is expected to finish 3.67 weeks later than originally planned. Meanwhile, the independent estimate at completion (IEAC(t)) is calculated using the schedule performance index (SPI(t)) value of 0.633, resulting in a projected duration of 191.14 weeks. This shows a more pessimistic outlook if performance remains at this low efficiency level. However, the to-complete schedule performance index (TSPI) was calculated at 1.033, suggesting that slight improvements in schedule performance are needed to meet the original target. These findings underscore the importance of continuous monitoring and proactive management to align the project schedule with its objectives. For example, the calculation process for week 10 is as follows:

PWDR = DP – ES = 121 – 6.330 = 114.670
EAC(t) = AD + PWDR = 10 + 114.670 = 124.670
TSPI = (PD – ES) / (TD – AT)
= (121 – 6.330) / (121 – 10)
= 1.033

Table 4. Earned schedule duration forecasting

Month	AD	PWDR	EAC(t)	IEAC(t)	TSPI
APRIL	1	119.946	120.946	0.000	1.000
	2	119.568	121.568	168.994	1.005
MAY	3	119.568	122.568	253.491	1.013
	4	119.568	123.568	337.988	1.022
	5	116.850	121.850	145.801	1.007
	6	116.411	122.411	158.198	1.012
JUNE	7	115.940	122.940	167.384	1.017
	8	115.024	123.024	161.971	1.018
	9	114.788	123.788	175.309	1.025
	10	**114.670**	**124.670**	**191.143**	**1.033**
JULY	11	114.565	125.565	206.844	1.042
	12	114.335	126.335	217.838	1.049
	13	114.329	127.329	235.806	1.059
	14	114.324	128.324	253.746	1.068
	15	114.246	129.246	268.727	1.078
AUGUST	16	114.168	130.168	283.366	1.087
	17	113.776	130.776	284.741	1.094
	18	111.620	129.620	232.196	1.084
	19	106.504	125.504	158.600	1.044
SEPTEMBER	20	104.177	124.177	143.849	1.031
	21	101.065	122.065	127.463	1.011
	22	98.002	120.002	115.750	0.990
	23	96.581	119.581	113.967	0.986
	24	95.381	119.381	113.353	0.983
OCTOBER	25	94.609	119.609	114.622	0.986
	26	92.908	118.908	111.988	0.978
	27	93.861	120.861	120.380	0.999
	28	91.701	119.701	115.636	0.986

The project's time performance forecast, based on the Earned Schedule approach, offers a clearer view of progress and future expectations in Table 4. During the first ten weeks, the SPI(t) values remained consistently below 0.75, indicating schedule inefficiencies. By week 10, SPI(t) dropped to 0.633 while IEAC(t) sharply increased to 191.143 weeks, well beyond the planned 121-

week duration. This suggests that if poor performance continued, the project could be delayed by more than a year. However, the To-Complete Schedule Performance Index (TSPI) was 1.033 by week 10, suggesting that moderate efficiency improvements could put the project back on schedule.

After the first contract addendum was implemented in Week 21, the SPI(t) steadily improved and surpassed 1.0 in Week 22. By Week 28, SPI(t) had reached 1.046, while TSPI had declined slightly to 0.986. This suggests that the project was performing ahead of the revised schedule and could potentially be completed sooner than planned. The convergence of EAC(t) and IEAC(t) toward the original PD indicates a more stable forecast. These trends confirm that corrective actions, such as schedule acceleration or resource reallocation, effectively improved the project's time performance. The consistent increase in ES values reflects the growing earned progress in time units and reinforces the reliability of the Earned Schedule as a forecasting tool for civil infrastructure projects.

Figure 4 illustrates the project's schedule performance from both cost-based and time-based perspectives by comparing SPI and SPI(t) over 28 weeks. Initially, in Week 1, the SPI value spiked to 2.75, while the SPI(t) value started close to 1.0. However, both indicators declined significantly in subsequent weeks, reflecting early-stage underperformance. From weeks 4 to 17, both SPI and SPI(t) remained consistently below 0.7, with SPI dropping below SPI(t). This indicates that cost-based progress lagged further behind time-based expectations.

A turning point was observed starting in Week 18, when both indices began to rise steadily. The recovery trend became more pronounced after Week 21, which coincided with the implementation of the first contract addendum. From Week 22 onward, both SPI and SPI(t) consistently exceeded 1.0, indicating that the project was progressing ahead of the revised schedule. From Week 23 to Week 28, the two indicators converged closely, suggesting that actual progress aligned well with time and cost performance. This confirms that the mid-project corrective actions were effective in improving productivity and schedule adherence. Additionally, the comparison shows that, being time-based, SPI(t) provides a more stable and earlier reflection of schedule trends than SPI, which can fluctuate more sharply and may lag in reflecting real progress.

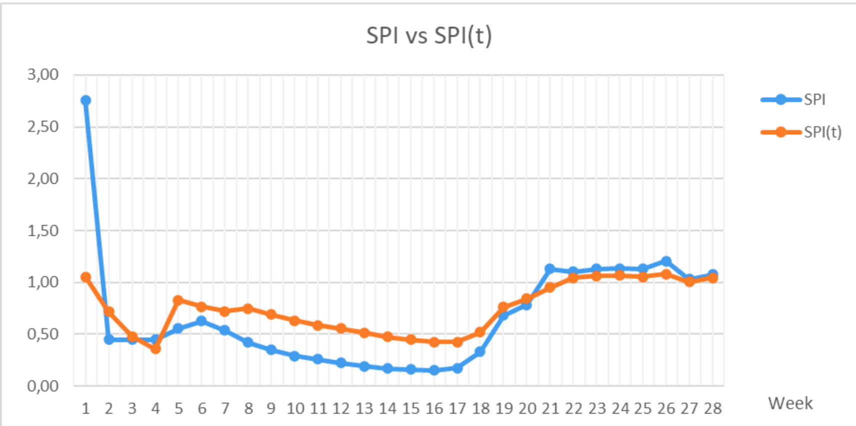

Figure 4. SPI vs SPI(t) Graph.

Figure 5 shows a comparison between IEAC (independent estimate at completion using cost-based SPI) and IEAC(t) (time-based SPI(t)). This comparison highlights significant differences in project duration forecasting accuracy over time. In the early weeks (Weeks 1–3), both IEAC and IEAC(t) increased sharply, reflecting schedule inefficiencies. However, IEAC values were much more volatile, peaking dramatically between weeks 10 and 17 at over 800 days. This suggests that the cost-based SPI method (IEAC) may overestimate project delays, particularly during periods of poor performance.

In contrast, the IEAC(t) displayed a more stable and gradual trend. It peaked at around 347 days and maintained a relatively consistent range throughout the mid-project period. This demonstrates that SPI(t)-based forecasting provides a smoother and more reliable projection of project duration. After Week 18, both indicators dropped significantly, especially IEAC, due to improvements in performance and the implementation of the first contract addendum in Week 21. From week 22 onward, IEAC and IEAC(t) converged around 110–120 days, closely aligning with the original planned duration. This convergence suggests that the corrective measures were effective and the project will likely finish on time. This comparison shows that IEAC(t) is a more stable and realistic forecasting tool, particularly for projects with fluctuating performance.

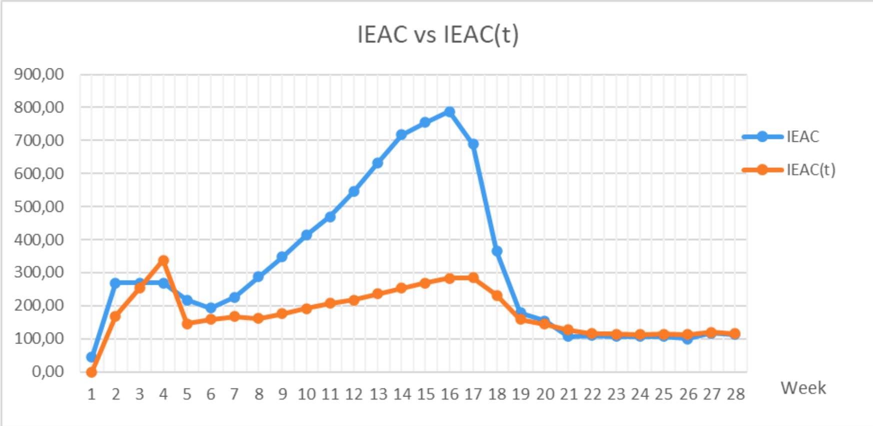

Figure 5. IEAC vs IEAC(t) Graph.

The findings confirm that using a combination of Earned Value Management (EVM) and Earned Duration Management (EDM) provides a more accurate and reliable assessment of project performance than relying solely on traditional cost-based indicators. While early project performance suffered from significant schedule inefficiencies, the analysis showed that corrective actions and contractual addenda improved time performance, as reflected in SPI(t) and IEAC(t). These results underscore the importance of incorporating time-based performance analysis in railway infrastructure projects, where delays can result in substantial economic losses and operational disruptions.

In line with recent studies, the findings of this research reinforce the growing consensus that traditional Earned Value Management (EVM) has inherent weaknesses when applied to projects with dynamic schedules and frequent scope adjustments. Batselier & Vanhoucke (2015) and Lipke (2015) argue that cost-based indices, such as SPI, often lag in reflecting actual schedule performance. This aligns with the observation in this study that SPI underestimates progress during recovery periods. Furthermore, Mayo-Alvarez et al. (2022) and Nurevita & Anondho (2020) demonstrate that EDM, through SPI(t) and IEAC(t), provides earlier and more stable warnings of schedule risks. This pattern is clearly evident in the Wonokromo–Jombang case. Recent railway infrastructure studies (e.g., Votto et al., 2020; Hindami et al., 2024) also emphasize that complex transportation projects benefit from methodologies that capture real-time duration performance instead of relying solely on cost-based progress indicators. Situating this research within these findings shows that combining EVM and EDM validates prior studies' conclusions and extends them by demonstrating their practical application in a large-scale, live railway project. This strengthens the methodological relevance of EDM as a complement to EVM, especially in high-risk infrastructure contexts where delays have wide socioeconomic consequences

Conclusion

This study concludes that the Earned Schedule (ES) method, specifically the SPI(t) and IEAC(t) indicators, is a more stable and reliable approach for forecasting project duration than traditional EVM methods based on SPI. Findings show that SPI produces volatile and often exaggerated delay predictions, especially during poor performance. In contrast, SPI(t) realistically reflects schedule trends and responds earlier to performance improvements. The ES method successfully captured the impact of contract adjustments in Weeks 21 and 27. After each addendum, SPI(t) and IEAC(t) demonstrated significant performance recovery. Using SPI(t)-based forecasting enables better anticipation of project schedule outcomes and supports more accurate and timely managerial decisions. Thus, this research makes an important contribution to the development of schedule forecasting tools for civil infrastructure projects, particularly long-duration railway construction projects.

In light of these findings, project managers are encouraged to adopt ES metrics alongside traditional EVM approaches to enhance the precision of time performance monitoring. Future research should explore integrating ES with machine learning or adaptive control systems to enable real-time forecasting and decision-making. Additionally, testing the ES method in different types of infrastructure projects could validate its effectiveness further and expand its application.

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