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Improving Performance in Mining and Construction Projects: An Integrated Method Based on the Triple Constraint, Change and Risk Management with Normalized Databases

Mejora del Desempeño en Proyectos Mineros y de Construcción: Método Integral Basado en la Triple Restricción, Gestión de Cambios y Riesgos con Bases de Datos Normalizadas

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Abstract

Globally, construction projects, particularly in the mining industry, face growing challenges related to efficiency, sustainability, and resource management. In Peru, a key player in global mining production, these challenges are exacerbated by complex geographical and social conditions. This study presents a comprehensive project management methodology, called the Master Plan, designed to overcome the limitations of traditional approaches focused on the triple constraint, risk management, and change management. The article details the development of an advanced model based on normalized and standardized databases, structured into four stages: bidding, planning, monitoring and control, and performance evaluation. The method's validation is conducted through a case study of a mining project in Puno, Peru, where performance indicators such as the Cost Performance Index (CPI) and the Schedule Performance Index (SPI) were assessed. A comparison with eight mining projects demonstrates that the proposed model optimizes costs and timelines compared to traditional approaches. This research enhances project management in the mining and construction sectors, highlighting the importance of information integration and standardization, as well as proactive risk and change management.

Keywords: EAC; earned value; integrated method; project management; databases.

Resumen

A nivel global, los proyectos de construcción, especialmente en la industria minera, enfrentan crecientes desafíos relacionados con la eficiencia, la sostenibilidad y la gestión de recursos. En Perú, un actor clave en la producción minera mundial, estas dificultades se agravan por las complejas condiciones geográficas y sociales. Este estudio presenta una metodología integral de gestión de proyectos, denominada Master Plan, diseñado para superar las limitaciones de los enfoques tradicionales, centrados en la triple restricción, la gestión de riesgos y los cambios. El artículo describe el desarrollo de un modelo avanzado, basado en bases de datos normalizadas y estandarizadas, estructurado en cuatro etapas: licitación, planificación, seguimiento y control, y evaluación del desempeño. La validación del método se realiza mediante un caso de estudio en un proyecto minero en Puno, Perú, donde se evaluaron indicadores de desempeño, como el índice de desempeño de costos (CPI) y el índice de desempeño de cronograma (SPI). La comparación con ocho proyectos mineros demuestra que el modelo propuesto optimiza costos y tiempos en comparación con enfoques tradicionales. Esta investigación mejora la gestión de proyectos en los sectores de minería y construcción, destacando la importancia de la integración y estandarización de la información, así como una gestión proactiva de riesgos y cambios.

Keywords: EAC; valor ganado; método integral; gestión de proyectos; bases de datos.

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1. Introduction

Current studies reveal that projects face increasing challenges driven by the need to improve efficiency, ensure sustainability, and comply with strict management requirements (Unegbu et al., 2021); (Chowdhury et al., 2019); (Htoo et al., 2023). These challenges are further intensified in sectors such as construction and mining, where competitiveness in a saturated contractor market (Proaño et al., 2022), technical demands, and the optimization of economic resources are crucial for ensuring success. In Peru, one of the world's leading mineral producers, these challenges are exacerbated by geographic and social conditions (Fraser, 2021), emphasizing the need to adopt comprehensive and standardized methods to mitigate negative impacts (Ibrahim et al., 2019).

In this context, Earned Value Management (EVM) is a well-known technique for monitoring project progress and forecasting cost and duration (de Andrade et al., 2019). Its proper implementation could achieve savings ranging from 15% to 40% of the total project cost (Khodeir and El-Ghandour, 2019). Moreover, recent studies highlight the importance of early warning systems and cost indicators for dynamic control throughout the project lifecycle (Jingyi Dai and Dandan Ke, 2022); (Sou-Sen Leu et al., 2023); (Safapour and Kermanshachi, 2019). The implementation of integrated project management has proven to be a promising solution for significantly reducing and controlling project costs (Liu et al., 2020).

One of the main challenges in project management lies in the limited visibility of traditional methods, a situation exacerbated by a changing environment that demands agile and timely responses (Jiang, 2021); (Yang et al., 2023). Budget deviations and inevitable changes in activities are common and affect project performance (Hussein and Moradinia, 2024); (Efe and Deminors, 2019). These complexities make projects more susceptible to failure and foster the emergence of risks (Zaneldin and Ahmed, 2024), which amplifies management issues. Effectively addressing this problem requires a systematic and robust approach to identifying potential risks (Eaton et al., 2018), enabling their classification by risk factors and the determination of actions that should be mitigated or avoided (Mahamid, 2024).

Although numerous studies on EVM exist due to its widespread adoption (Salari et al., 2014); (Pourrahimian et al., 2024); (Sutrisna et al., 2020), significant gaps persist regarding its effective implementation in construction projects, particularly due to the lack of specific adaptations for contexts (Aramali et al., 2021); (Soetjipto et al., 2024); (Son et al., 2023). Furthermore, the literature on cost information management and the use of modeling tools for lifecycle project management remains insufficient (Tran, 2020); (Ngo et al., 2022).

The main objective of this study is to develop and implement a comprehensive project management method for the construction sector, specifically within the mining industry in Peru. To achieve this, an advanced model is proposed, designed based on best practices and an adaptive approach (Ottaviani et al., 2024). Through a case study, the proposed method's effectiveness will be validated using key performance indicators (KPIs) that enable dynamic tracking and timely adjustments (Netto et al., 2020). Finally, a comparison with traditional methods will be conducted using quantitative analysis, highlighting the significant contribution of the proposed model to project management in the construction sector within the mining industry in Peru.

2. Literature review

Earned Value Management (EVM) is a method used to integrate and assess project performance in terms of scope, cost, and time (Zahoor et al., 2022). This approach enables continuous tracking of project progress, providing key indicators that measure the impact on schedules and costs as the project advances (Nejatyan et al., 2023); (da Silva et al., 2019). The literature on EVM primarily falls into two categories: the development of metrics to measure project performance and the analysis of benefits derived from its application in various project contexts (Eid et al., 2024). However, empirical research on its practical implementation in real-world scenarios remains limited (Olawale and Sun, 2013), particularly when addressing changes and risks throughout the various project phases (Moshtaghian et al., 2020). According to (Shah et al., 2023), cost estimation, risk management, and resource allocation are key elements for the implementation and optimization of project management, as they play a crucial role in delivering value.

(Barrientos et al., 2022) Analyzed EVM metrics, including Planned Value (PV), Earned Value (EV), Actual Cost (AC), Cost Performance Index (CPI), Schedule Performance Index (SPI), and Estimate at Completion (EAC). Their study evaluated the stability of 15 deterministic cost prediction methods using the simulation of 4,100 artificial projects with different topological structures. The research showed that projects became more stable when they reached between 70% and 80% completion. Meanwhile (Sohrabi and Noorzai, 2024) developed a case-based reasoning model to assess risks during the review phase. By examining 68 water-related projects, they integrated EVM metrics with economic, natural, and

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technical risk factors to quantify uncertainties. The model demonstrated improved predictions by considering these uncertainties in the decision-making process.

(Chen, 2022) addressed a growing challenge in construction project management: handling large volumes of data. With the increasing complexity and scale of projects, data collection and classification have become critical issues. The study proposed the application of Big Data and the development of construction project management software. Results showed that with a higher number of nodes, operational efficiency remained high and stable, positioning the system as a key tool in modern cost management and promoting the company's sustainable development. Similarly, (You and Wu, 2019) highlighted the difficulties of processing Big Data in construction projects, particularly inaccurate manual inputs and delayed data collection. They proposed a big data infrastructure for companies in the sector, which improved business processes by extracting value from historical data, contributing to early risk detection, and assessing business performance.

Furthermore, (Javanmardi et al., 2023) identified the OPDCA cycle (Observe, Plan, Do, Check, Act) as a strategy to improve workflow reliability in construction projects. The results revealed that the "Check" and "Plan" stages have the greatest impact on reliability, while "Act" has the least, underscoring the importance of balancing planning and control in project execution. (Montesinos et al., 2020) Analyzed the Deming Cycle (Plan, Do, Check, Act) in inventory management at an LP gas plant. They observed an improvement in the area's performance, from 2.64% in 2016 to 4.04% in 2018, demonstrating the effectiveness of the approach in fostering continuous improvement. The method's replicability in other sectors highlights its potential for optimizing processes in various industries, including construction.

3. Research Methods

The methodological approach adopted in this article focused on the development and implementation of a comprehensive method designed to effectively address three key variables in project management: scope, cost, and time, commonly referred to as the triple constraint or the iron triangle (Project Management Institute, 2017). In addition to these fundamental variables, two other highly relevant elements were incorporated: change management and risk assessment. The inclusion of these two complementary variables was crucial for improving the analysis of project projections, providing a more comprehensive view of its evolution and potential challenges. These aspects represent significant challenges that the management team must face throughout the project lifecycle (Essam and Waleed, 2024).

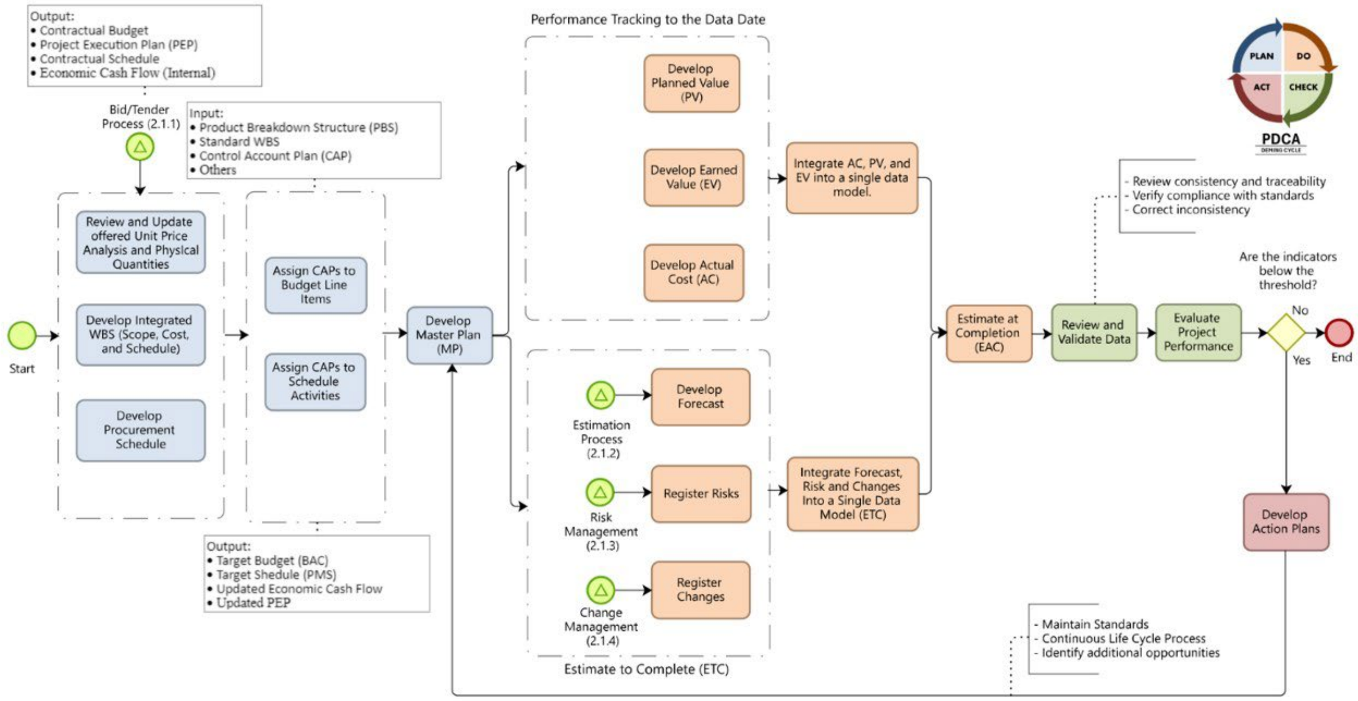

Figure 1. Process Map for Integrated Project Management.

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In this context, the study object focused on the design and implementation of a comprehensive project management method specifically tailored to the demands of the construction and mining sectors. The proposed model is based on the use of standardized databases and is structured into four key stages: a) bidding process, b) planning, c) monitoring and control, and d) performance evaluation and development of an action plan (Figure 1). These stages follow the PDCA (Plan-Do-Check-Act) cycle, also known as the Deming cycle (Montesinos et al., 2020), aimed at optimizing quality in business management. Furthermore, the model is grounded in the best practices recommended by AACE International, in accordance with the guidelines established in its Skills & Knowledge of Cost Engineering, which outlines the fundamental principles of the Earned Value Management methodology (AACE International, 2015).

To achieve the main objective of this study, the implementation of a comprehensive methodological approach is proposed, aimed at optimizing the interaction and convergence of the three fundamental pillars of project management: scope, cost, and time. This approach also incorporates risk assessment and change management, ensuring that all these elements are recorded and stored in a unique, normalized, and standardized data model. The proposal addresses one of the main challenges in project management: the lack of traceability of information and data consistency (Wolf and Specker, 2024). These issues are particularly evident in the data collection process required to calculate the actual costs of the resources used (AC), evaluate the actual progress of activities (Xingjun, 2021), and, critically, determine the estimate at completion (EAC) of the project.

3.1 Proposal for an Integrated Management Method

The developed model begins with the bidding process or kickoff stage, during which the project's key documents are established, such as budgets or capital expenditures (CapEx), preliminary schedules, and the work plan, among others. Subsequently, the planning phase follows, involving a thorough evaluation of all collected information and an analysis of the project's main determining factors. During this stage, all necessary updates are made, focusing primarily on the verification of scope, unit prices, and quantities. This information is then integrated into a single, normalized, and standardized data model.

To facilitate the integration and standardization of the planning phase, a Control Account Plan (CAP) was designed to define the control points where scope, cost, and time converge. This plan allows for the collection of the necessary data to evaluate the performance of different work packages (Figure 2). CAPs were assigned to all CapEx items and each activity in the schedule, ensuring that each one was linked to a unique CAP. The outcome of the planning phase concluded with the development of a standardized database known as the "Master Plan" or project master plan.

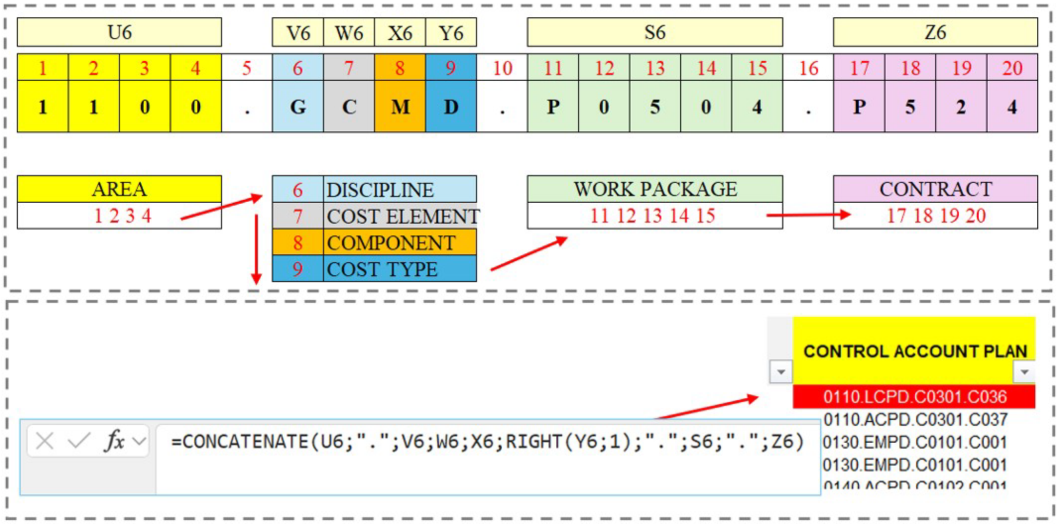

Figure 2. Development of the Control Account Plan (CAP).

After the planning phase, the monitoring and control phase is carried out, constituting one of the most extensive stages of the proposed methodology. During this phase, all the necessary information is collected to assess the progress of activities and the associated project costs. Additionally, all approved changes or Project Deviation Notices (PDN) are incorporated, as well as potential changes or trends (Figure 3). Both the

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PDNs and trends are stored in a standardized database, and each change record is assigned a unique CAP, ensuring proper integration with the cost management model and facilitating the periodic collection of information for subsequent analysis within the established data model.

Item	PDN #	Title	Contractor	Identification Date	Work Package (WP)	PDN Type	Justification	(1) Baseline	(2) PDN Amount	(3) = (1) + (2) Current Budget
1	PDN-B2-EJ-001	Electrical panels	ABB	30-Nov-18	P0313	Tipo II	Not Applicable	545,091	-362,423	182,668
18	PDN-B2-EJ-018	Cost synergy in the construction of the pipeline bridge	TBD	26-Dic-18	C4102 / C4103	Tipo II	Not Applicable	867,032	-297,076	569,956
19	PDN-B2-EJ-019	Boilemaking (savings contribution)	TBD	26-Dic-18	P0209	Tipo II	Not Applicable	342,183	-180,000	162,183
20	PDN-B2-EJ-020	Installation of doors and gates in the flotation building	FGA	26-Dic-18	C3304	Tipo I	Omission	479,395	132,231	611,627
21	PDN-B2-EJ-021	Incrased costs in micellaneous works	EPCM EXPERTS	26-Dic-18	C105	Tipo I	Underestimation	261,753	60,096	321,849
22	PDN-B2-EJ-022	Electrical rooms and capacitor bank	ABB SA	6-Ene-19	P0110 / P0301	Tipo I	Underestimation	3,710,434	35,119	3,745,553
25	PDN-B2-EJ-025	Process pums	VULCO	6-Ene-19	P0204	Tipo I	Underestimation	1,900,000	30,822	1,930,822
26	PDN-B2-EJ-026	Higher costs in the reloction works of 10KV line	INGELMEC	6-Ene-19	C0301	Tipo I	Underestimation	507,739	26,073	533,812
								43,642,988	1,458,758	45,101,746

Figure 3. Change Management: Approved PDNs.

Construction and mining projects are exposed to a significant number of risks, requiring a solid and systematic management approach to ensure their success (Eaton et al., 2018). Like change management, identified risks are recorded in a standardized database (Figure 4), where each risk entry is uniquely linked to a Work Breakdown Structure (WBS) element, ensuring its integration into the model. The final stage of the proposed model includes monitoring and control, as well as the development of action plans to address deviations that arise during the project lifecycle, within an iterative process.

Risk Id	Risk Event	Most Likely Cost	Probability Occurrence	Risk Impact	Current Month Value P8	Minimum Impact (Optimisti	Maximum Impact (Pessimisti	PERT Distribution	Occurrence Distribution	Impact if It Occurs
3	Mechanical system engineering of the dam	$ 330,656	100%	$ 330,656	$ 368,301	$ 320,736	$ 360,415	$ 341,448	1	$ 341,448
59	Potential higher costs in commissioning 3	$ 340,000	70%	$ 238,000	$ 271,470	$ 289,000	$ 459,000	$ 346,052	0	$ -
77	Lower costs incurred in pre-operations scope	$ (350,000)	50%	$ (175,000)	$ (194,297)	$ (381,500)	$ (339,500)	$ (344,848)	0	$ -
88	Drains and channels for infiltration water collection	$ 300,000	100%	$ 300,000	$ 341,940	$ 255,000	$ 405,000	$ 313,155	1	$ 313,155
100	Potential cost overruns in the construction of the final channel	$ 911,481	80%	$ 729,185	$ 815,968	$ 820,333	$ 1,093,777	$ 870,881	1	$ 870,881
154	Vendor assistance	$ 260,000	100%	$ 260,000	$ 291,621	$ 234,000	$ 312,000	$ 270,998	1	$ 270,998
159	Construction works for the plant and pulp preparation	$ 680,000	100%	$ 680,000	$ 774,847	$ 578,000	$ 918,000	$ 756,976	1	$ 756,976
161	Energy savings in commissioning 2 and 3 works	$ (350,000)	70%	$ (245,000)	$ (274,379)	$ (393,750)	$ (332,500)	$ (344,650)	0	$ -
		$2,122,137	Contingency =	$2,117,841	$2,395,471		without occurrence	5,190,239	with occurrence	5,533,684

Figure 4. Modeling of Risks and Uncertainties.

3.2 Validation Through a Case Study

The proposed model was implemented in a large-scale project within the mining sector, specifically in the construction of a mineral processing plant. The project was carried out in the Puno region, located in southern Peru, and was managed by one of the country's leading mining companies, recognized as a global leader in the tin market. Through an experimental approach, the project's key performance indicators (KPIs) were measured, including the Cost Performance Index (CPI) and the Schedule Performance Index (SPI), to assess the effectiveness of the proposed model.

3.3 Comparison with Traditional Approaches

A quantitative evaluation of the performance of the new model was conducted in comparison to traditional project management methods. For this purpose, recognized metrics from the literature, such as Earned Value Management (EVM) and PERT analysis, were employed. In this context,

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eight medium-scale mining projects located in Peru were selected, where the CPI and SPI were compared. Additionally, the integrated Cost and Schedule Index (CSI) was evaluated, incorporating a dispersion analysis for the CSI to assess the variability of the results obtained and provide a more comprehensive view of the proposed model.

4. Results and Discussion

The implementation of advanced management methods in mining projects represents a relatively unexplored area within the field of project management. Most projects of this nature are managed using traditional approaches, which often fail to adequately integrate the three fundamental elements: cost, time, and scope (Kasprowicz and Starczyk-Kołbyk, 2024). The results obtained in this research demonstrate the effectiveness of the proposed methodology in improving the overall performance of the project. This is reflected in the increase in key performance indicators (KPIs), measured through the earned value methodology and aligned with best practices in project management. To validate these results, the planning, monitoring, and control of the project were carried out by applying this methodology to a case study of a mining project, which was developed from June 2017 until its completion in December 2019.

4.1 Project Planning

The results obtained at the end of the project planning phase include the creation of a key control tool known as the Master Plan. (Table 1) presents an excerpt of the Master Plan prepared for the project under study, which integrates information from the 435 Control Account Plans (CAPs) developed, and distributed across a total of 5,787 records. For each record, the associated costs were documented and linked to the corresponding scheduled activities using the Activity ID in the Primavera P6 software.

The budgeted cost for the project's work packages (Work Package Cost Estimates, WPCE), recorded in the Master Plan, amounts to 158.69 million US dollars (US$ M), which corresponds to direct and indirect costs. Additionally, the contingency reserve for this project was 11.79 US$ M, bringing the total CapEx to 170.47 US$ M. Furthermore, the budget request submitted to management also included an escalation cost of 8.31 US$ M, resulting in a total Budget at Completion (BAC) of 178.79 US$ M.

(Figure 5) shows that the largest percentage of the total requested budget (178.79 US$ M) corresponds to the Construction phase, accounting for 35%, followed by Procurement, at 27%. The phases with the lowest costs are Escalation, at 5%, and Engineering, at 6%. This analysis made it possible to identify the costliest components and prioritize efforts to control them, thus avoiding deviations that could impact the project.

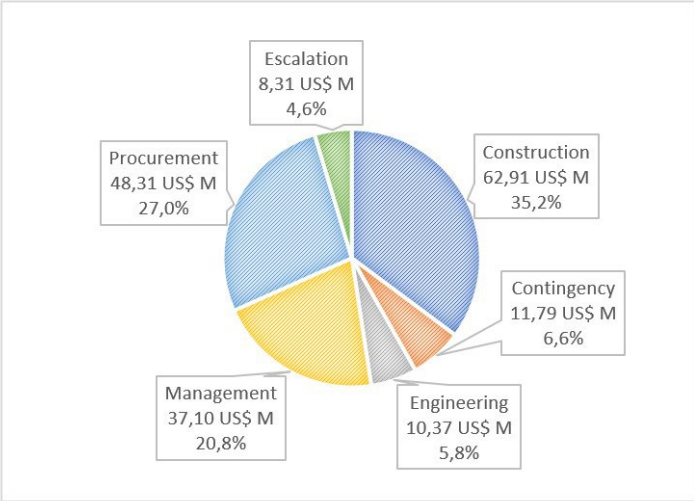

Figure 5. Total Cost Distribution by Phase.

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Table 1. Project Master Plan.

ID	Description	Control Account Plan (CAP)	ID Activity (P6)	Start Early	Finish Early	Total Cost[a]
1	Relocation of 10kV Line/Connections	0110.LCPD.C0301.C036	07.0110.B.0050	09/10/17	10/01/18	416,556
2	Relocation of Wooden Poles	0110.ACPD.C0301.C037	07.0110.B.0050	09/10/17	10/01/18	91,183
3	Administrative Offices - 1	0130.EMPD.C0101.C001	07.0130.B.0050	24/08/17	20/12/17	48,586
4	Administrative Offices - 2	0130.EMPD.C0101.C001	07.0130.B.0050	24/08/17	20/12/17	65,034
5	Relocation of Workshops - 1	0140.ACPD.C0102.C001	07.0140.B.0050	24/08/17	20/12/17	221,793
6	Relocation of Workshops - 2	0140.ACPD.C0102.C001	07.0140.B.0050	24/08/17	20/12/17	349,183
7	Relocation of Warehouses - 1	0150.ACPD.C0103.C001	07.0150.B.0050	24/08/17	20/12/17	7,254
8	Relocation of Warehouses - 2	0150.ACPD.C0103.C001	07.0150.B.0050	24/08/17	20/12/17	16,925
9	Demolition of Existing Channels - 1	0180.BCPD.C0104.C001	07.0410.D.0400	25/10/18	27/10/18	8,546
10	Demolition of Existing Channels - 2	0180.BCPD.C0104.C001	07.0410.D.0400	25/10/18	27/10/18	10,819
11	Demolition of Gutters - 1	0180.BCPD.C0104.C001	07.0410.D.0400	25/10/18	27/10/18	137
12	Demolition of Gutters - 2	0180.BCPD.C0104.C001	07.0410.D.0400	25/10/18	27/10/18	205
13	Demolition of Drains - 1	0180.BCPD.C0104.C001	07.0410.D.0400	25/10/18	27/10/18	142
14	Demolition of Drains - 2	0180.BCPD.C0104.C001	07.0410.D.0400	25/10/18	27/10/18	213
15	Removal of Metal Mesh	0180.BCPD.C0104.C001	07.7710.G.0200	19/05/19	25/05/19	741
16	Removal of Demolition Materials	0180.BCPD.C0104.C001	07.7710.G.0200	19/05/19	25/05/19	11,942
17	Removal of Dismantled Materials	0180.BCPD.C0104.C001	07.7710.G.0200	19/05/19	25/05/19	6,780
18	Removal of Wooden Poles	0180.BCPD.C0104.C001	07.7710.G.0200	19/05/19	25/05/19	234
19	Removal of Steel Poles	0180.BCPD.C0104.C001	07.7710.G.0200	19/05/19	25/05/19	684
20	Removal of Concrete Poles	0180.BCPD.C0104.C001	07.7710.G.0200	19/05/19	25/05/19	152
21	Removal of New Jersey Barriers	0180.BCPD.C0104.C001	07.7710.G.0200	19/05/19	25/05/19	924
22	Retiro de Postes Concreto - 2	0180.BCPD.C0104.C001	07.7710.G.0200	19/05/19	25/05/19	1,531
⋮	⋮	⋮	⋮	⋮	⋮	⋮
5783	Supply of Cyclopean Concrete	0210.CBPD.P0606.P527	HS2235	29/07/18	25/10/18	1,175,260
5784	Mobilization and Demobilization	0180.ACPD.C1503.C074	07.0010.B.0100	30/04/18	04/06/18	728,343
5785	Temporary Facilities	0180.ACPD.C1503.C074	07.0010.B.0200	29/05/18	12/07/18	520,000
5786	Maintenance of Roads and Access	0180.ACPD.C1503.C074	07.0020.B.0300	02/07/18	04/09/18	220,000
5787	Transport of Materials to Project	0180.ACPD.C1503.C074	07.0010.B.0100	30/04/18	04/06/18	220,000
Work Package (WP) Cost Estimates (Subtotal Direct Cost + Indirect Cost)						**158,686,610**
Contingency Reserve						11,787,964
Total CapEx						**170,474,574**
Escalation[b]						8,312,000
Budget at Completion (BAC)						**178,786,574**

[a]: Costs shown in USD.
[b]: Provision allocated to cover future increases in the primary cost elements of the project.

4.2 Project Monitoring and Control

For project monitoring and control, the results included the monthly Cost and Comparison reports, which provided a detailed overview of the project's status at the end of each month, focusing primarily on cost control. These reports were prepared using standardized and normalized databases, facilitating their integration into the PRISM G2 software and enabling the efficient and accurate consolidation of key information. Additionally, they incorporated essential aspects such as change management and risk management, thanks to their integration with the CAPs.

(Table 2) presents the report corresponding to September 2019, reflecting budget control (Baseline), approved changes (PDN Approved), and potential changes (PDN Potential), categorized by the corresponding project phase. For this period, the EV exceeds the PV, indicating progress ahead of schedule in terms of project execution. Similarly, the AC is below the EV, demonstrating that costs are being effectively managed in line with the progress achieved. Finally, the EAC is reported to exceed the current budget (3) due to the identification of trends or potential changes that could impact the project in the future.

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Table 2. Cost & Comparison September 2019.

WP	Description	Baseline (1)	PDN (2)	CB (3)	Trend (4)	PV (5)	EV (6)	AC (7)	ETC (8)	EAC (9)
E	**ENGINEERING**	**10.37**	**3.02**	**13.39**	**0.36**	**10.84**	**13.39**	**13.16**	**0.59**	**13.75**
E0000	Concentrator Plant	6.12	1.47	7.59	0.36	6.40	7.59	7.57	0.38	7.95
E1000	Component Engineering	3.54	0.00	3.54	0.00	3.70	3.54	3.53	0.01	3.54
E2000	SS.EE. Expansion 138/10kV	0.14	0.00	0.14	0.00	0.15	0.14	0.15	0.00	0.14
E3000	Dewatering System	0.33	-0.03	0.30	0.00	0.35	0.30	0.30	0.00	0.30
E4000	Mining + Liquefaction Station	0.23	1.58	1.81	0.00	0.24	1.81	1.60	0.21	1.81
P	**PROCUREMENT**	**48.31**	**-1.85**	**46.46**	**0.00**	**50.50**	**46.45**	**46.11**	**0.35**	**46.46**
P0000	Equipment Procurement	47.10	-1.70	45.40	0.00	49.23	45.39	45.05	0.35	45.40
P1000	Procurement and Contracts Management	1.21	-0.15	1.06	0.00	1.27	1.06	1.06	0.00	1.06
C	**CONSTRUCTION**	**62.91**	**5.83**	**68.74**	**4.35**	**60.38**	**64.20**	**63.02**	**10.07**	**73.09**
C0000	Early Works	6.29	-0.02	6.27	0.00	6.57	6.16	6.11	0.16	6.27
C1000	Complementary Works	9.25	0.18	9.44	0.66	9.24	9.16	9.01	1.08	10.10
C2000	SS.EE. + Transmission Line	2.81	-0.02	2.79	0.00	2.94	2.79	2.60	0.19	2.79
C3000	Concentrator Plant	23.72	3.35	27.07	1.13	24.79	27.07	27.05	1.15	28.20
C4000	Component	9.64	0.69	10.34	0.90	6.06	6.77	6.69	4.54	11.23
C5000	Mine (Deposit)	3.74	0.67	4.40	0.48	3.90	4.40	4.40	0.48	4.88
C6000	Pisco Plant	1.10	0.47	1.57	0.00	0.98	1.44	1.25	0.32	1.57
C7000	Fire Protection System	1.52	0.21	1.73	0.00	1.59	1.73	1.72	0.01	1.73
C8000	Control System	0.08	0.00	0.08	0.00	0.09	0.08	0.09	-0.01	0.08
C9000	Commissioning	4.75	0.30	5.05	1.19	4.21	4.59	4.09	2.15	6.24
M	**MANAGEMENT**	**37.10**	**3.66**	**40.76**	**0.12**	**32.02**	**31.90**	**32.97**	**7.91**	**40.88**
M0000	Construction Management	10.46	3.29	13.75	0.10	10.45	11.93	13.75	0.10	13.85
M1000	Owner's Costs	20.51	0.24	20.75	0.00	15.16	14.37	13.62	7.13	20.75
M2000	Freight and Spare Parts	6.13	0.12	6.25	0.02	6.41	5.60	5.60	0.67	6.27
G	**CONTINGENCY**	**11.79**	**-10.97**	**0.82**	**-0.82**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
G0000	Contingency	11.79	-10.97	0.82	-0.82					
S	**SAVING**	**0.00**	**0.31**	**0.31**	**-0.31**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
S0000	Savings	0.00	0.31	0.31	-0.31					
TOTAL		**170.47**	**0.00**	**170.47**	**3.70**	**153.73**	**155.93**	**155.25**	**18.92**	**174.17**

Note: Cost shown in USD x1,000,000.
(2): PDN, Project Deviation Notice, refers to changes formally approved during the project lifecycle.
(3): Current Budget, refers to the sum of (1) + (2).
(9): Estimation at Complete, refers to the sum of (3) + (4), as well as the sum of (7) + (8).

(Figure 6) illustrates the monthly distribution of the project's key performance indicators, such as Planned Value (PV), Earned Value (EV), and Actual Cost (AC). From this figure, it can be observed that, for most of the project's duration, the AC remained below the EV, indicating effective cost control due to the implementation of the proposed methodology. However, between months 15 and 27, the project experienced negative schedule variances, as the PV exceeded the EV during this period, reflecting delays in the planned project progress.

Additionally, the Estimate at Completion (EAC) calculated as of the Data Date shows a projected total cost at project completion below the Budget at Completion (BAC), representing an estimated savings of approximately USD 4.63 million. Moreover, an optimization in the project timeline was evident, as the completion date was projected for December 15, 2019, 1.5 months ahead of the deterministic baseline date (January 29, 2020).

4.3 Project Performance Evaluation

The results obtained focus on the evaluation of performance indicators SPI (Schedule Performance Index) and CPI (Cost Performance Index), calculated based on the information gathered during the monthly monitoring and control of the project. This analysis facilitated the creation of a historical record for both indicators.

(Figure 7) presents the distribution of SPI values recorded throughout the project's development. From the seventh month onwards, these values stabilized, showing a trend close to 1.00, with a minimum of 0.88 and a maximum of 1.04 until project completion. This indicates that the project progressed as planned for most of its duration (Project Management Institute, 2017). However, significant fluctuations were observed during the

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initial months, attributed to the project startup process and the gradual implementation of the methodology in collaboration with the involved teams (contractors and the owner). This behavior reflects the initial adaptation process and the positive impact of the methodology on stabilizing schedule performance.

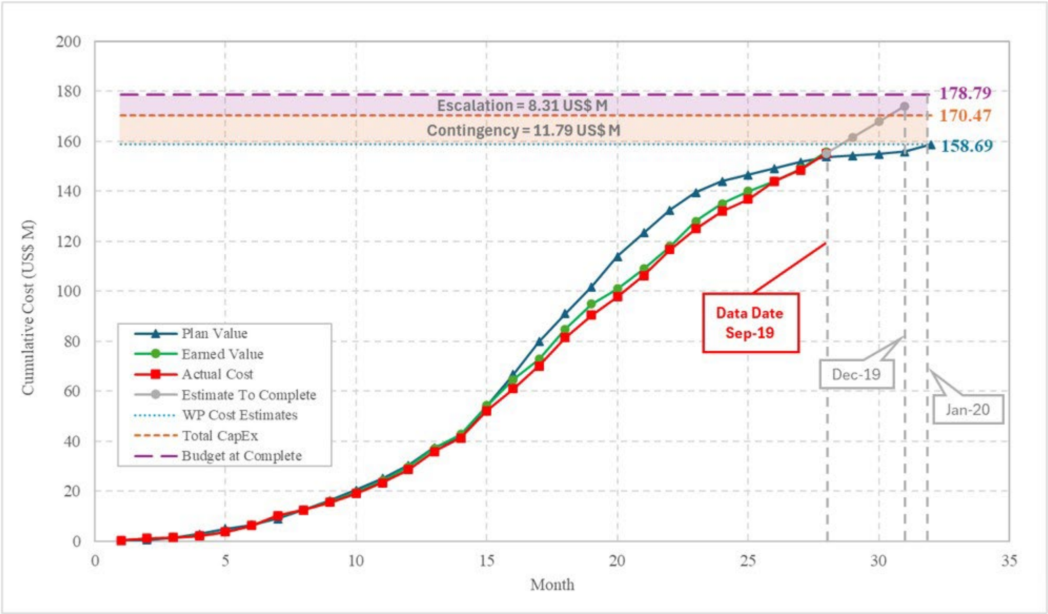

Figure 6. Earned Value Management Analysis of the Project.

(Figure 7) also illustrates the distribution of CPI values over the project. This figure shows a general trend approaching a value of 1.00, indicating adequate cost control throughout the project. The minimum value recorded was 0.99, suggesting that costs remained under control and aligned with project progress. This trend reflects the effectiveness of the applied methodology, as most monthly values exceed the threshold of 1.00, reaching a maximum of 1.06. This highlights not only proper cost monitoring but also a slight positive trend, implying efficient and optimized management of financial resources.

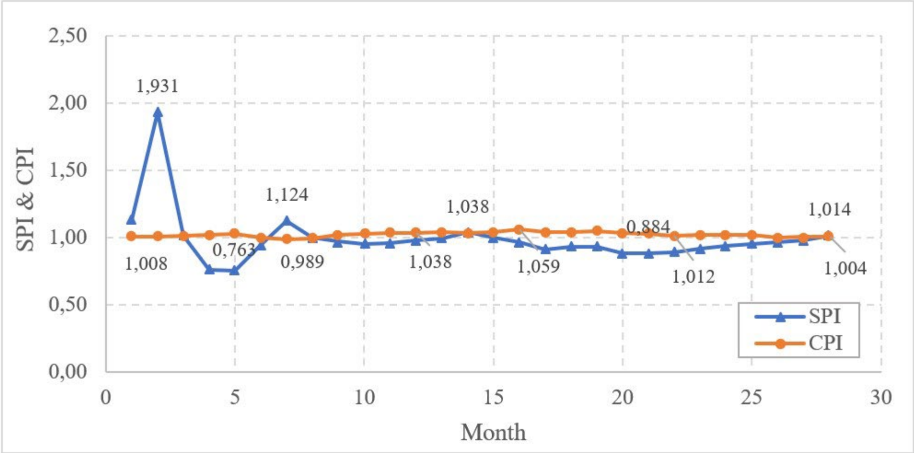

Figure 7. SPI and CPI Values of the Project.

4.4 Comparison of Project Performance

Most of the selected projects were executed within an approximate duration of 12 months, with Projects 5, 4, and 1 standing out as the most impactful due to their investment levels. Additionally, for this analysis, PERT values for the SPI and CPI indicators were calculated based on the data collected from all analyzed projects. It is important to note that the KPIs of these projects were measured during 75% of their execution.

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Therefore, to establish a comparable scenario, the SPI and CPI values for the case study were used, corresponding to the period between months 7 and 15.

(Figure 8) presents a comparison of SPI between the best-performing project (Project-5), the worst-performing project (Project-1), the project based on PERT analysis (Project-PERT), and the study project (Project-0). The most consistent SPI was achieved by Project-0, which remained close to the ideal value during the analysis period, with a dispersion of 3% from 1.00. In contrast, the other evaluated projects exhibited an average dispersion of 9% for Project-PERT. These results highlight the effectiveness of the proposed methodology compared to traditional approaches, demonstrating greater efficiency in schedule control and monitoring.

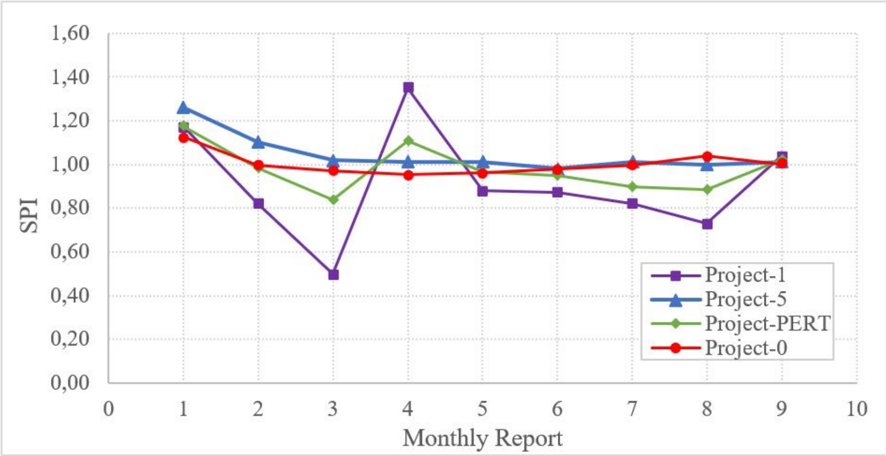

Figure 8. SPI Comparison: Case Study vs. Traditional Methodologies.

(Figure 9) shows a comparison of CPI between Project-5, Project-1, Project-PERT, and Project-0. The most consistent CPI was achieved by Project-0, which remained above 1.00 during the analysis period, with a dispersion of 3%. The other projects showed both positive and negative variations in this indicator, with a percentage variation of 11% from 1.00 for Project-PERT. These results underscore the advantage of applying an integrated methodology, evidencing more efficient cost management, which translates into significant savings for the project.

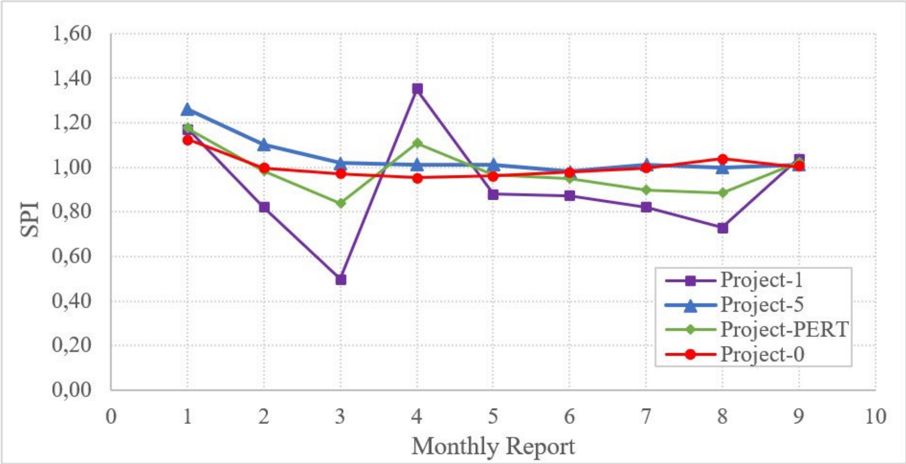

Figure 9. CPI Comparison: Case Study vs. Traditional Methodologies.

(Figure 10) illustrates a comparison of cost and schedule performance (CSI) between Project-5, Project-1, Project-PERT, and Project-0. Project-0 stands out as the only project that remained consistently within the recommended margins for this indicator, with values ranging from 1.11 to 0.99 throughout the analysis period. On the other hand, Project-5, while demonstrating better performance in terms of schedule, showed significant variations in costs, resulting in CSI values that reached the review zone (0.8 to 0.9 and 1.2 to 1.3), according to established criteria (Amendola et al., 2005). These discrepancies can be attributed to the lack of integration between cost control and scheduling, which are often

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managed independently in many projects (Kasprowicz and Starczyk-Kołbyk, 2024). Furthermore, the absence of standardized processes in change and risk management likely contributed to these deviations.

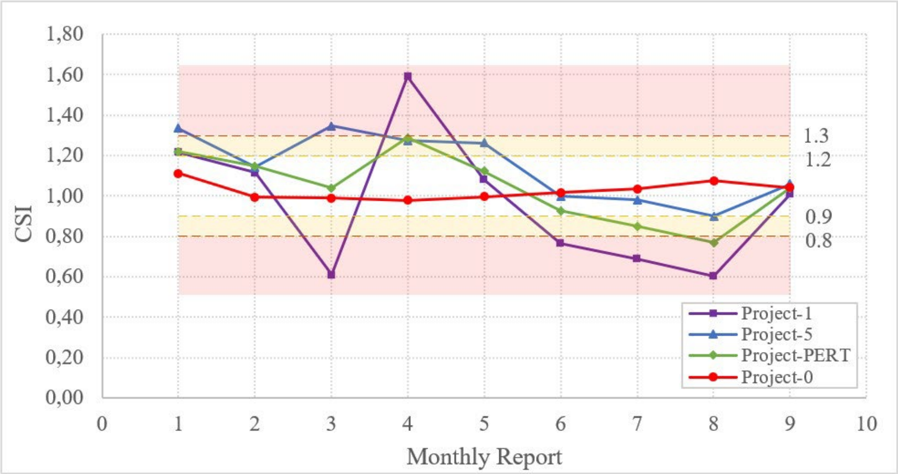

Figure 10. CSI Comparison: Case Study vs. Traditional Methodologies.

5. Conclusion and Recommendations

The proposed methodology proved to be an effective tool for optimizing project management processes by efficiently integrating the key components of cost, schedule, and scope. Its implementation allowed the project to be executed without significant deviations, reflecting superior performance compared to traditional methods. Additionally, this methodology incorporated essential aspects such as change and risk management, elements that are generally underutilized by companies (Zaneldin and Ahmed, 2024). This integration not only ensured control over the allocated resources but also generated significant savings, securing the project's viability.

Moreover, the implementation of the Master Plan emerged as a critical component for effective project control. Its configuration during the planning phase provided a solid foundation for the integrated management of scope, schedule, and cost, enabling more precise monitoring during execution and enhancing resource management efficiency. Similarly, the use of CAP as a key unit for project control proved to be a fundamental strategy, as it linked schedule activities to costs defined in the CapEx, effectively incorporating identified changes and risks.

The proposed method demonstrated high effectiveness when applied to the case study. In terms of cost, the project achieved an EAC below the BAC, resulting in savings of USD 4.36 million. Regarding the schedule, the project was completed 1.5 months ahead of the planned date. The SPI and CPI curves displayed a trend close to 1.0, indicating efficient project management. Compared to other mining projects in Peru, the studied project exhibited the best-integrated performance in cost and schedule, with a CSI consistently maintained between 0.9 and 1.2 throughout the analysis period.

Finally, the effective integration of scope, cost, and schedule remains a critical challenge in traditional project management methodologies, particularly due to the lack of integration with change and risk management (Mahamid, 2024). In this context, focusing efforts on developing standardized databases to ensure information traceability and consistency is essential, thereby promoting better integration and more efficient data management (Wolf and Specker, 2024). Despite the positive results obtained, this study revealed limitations in data collection, as the various areas involved did not adopt a uniform standard, hindering integration and analysis. Consequently, further research is recommended to develop new methodologies that promote the integration and standardization of data collection procedures..

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