Enhancing Productivity in Greenfield Mining Projects through Earned Value Management and Timely Contractor Payments [1, 2]

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ABSTRACT

Greenfield mining construction projects present unique challenges and opportunities, requiring strong project management to ensure success. This paper explores Earned Value Management (EVM) in these projects, showing how it effectively combines schedule, cost, and scope management. By evaluating different progress measurement methods, the study identifies the best approach and highlights the importance of prompt payments to maintain a neutral cash flow and avoid delays. Using NDIA schedules and cost matrices further improves project tracking and forecasting. Additionally, motion study techniques are used to streamline workflow and increase efficiency. Real-world examples from "Gold Rush" episodes provide practical insights and illustrate common challenges. Through detailed analysis and case studies, the research demonstrates how adopting EVM can significantly boost productivity in greenfield mining projects. The findings offer valuable advice for project managers to allocate resources better, manage risks, and achieve project goals on time and within budget.

Keywords: Mine Construction, Greenfield Project, Progress Measurement, Motion Study, EVM, Prompt Payment, Cashflow Neutrality

INTRODUCTION

A. Mining Sector in Indonesia

The mining sector has been one of the backbones of Indonesia's economy. In the second quarter of 2024, the mining sector contributed 8.78% of the country's Gross Domestic Product (GDP), making it the fifth-largest industry in Indonesia.[3]

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[2] This paper was originally prepared during a 6-month long Graduate-Level Competency Development/Capacity Building Program developed by PT Mitrata Citragraha and led by Dr. Paul D. Giammalvo to prepare candidates for AACE CCP or other Certifications. https://build-project-management-competency.com/our-faqs/

[3] Central Bureau of Statistics Indonesia (BPS). (2024, August 5). *Official Statistics News, No. 60/08/Th. XXVII: Indonesia Economic Growth Quarter II-2024.*

Figure 1 Top Five Indonesia GDP Share By Sector in Q2-2024 (y-o-y)[4]

Since 2020, Indonesia's "downstream" policy has prohibited the export of raw material ores from promoting domestic value-added production, making the mining industry a top investment contributor. As the world's largest nickel producer and a primary copper, cobalt, tin, and gold source, Indonesia attracts significant foreign direct investment (FDI).[5] In Q2 2024, the mining sector received IDR 45.6T (~USD27,533 m).[6] In investments, highlighting its strategic importance. The policy aims to enhance the value chain, create jobs, stimulate technological advancements, and foster sustainable economic growth.[7]. Indonesia's mineral downstream policy offers competitive advantages, boosting economic impact and refining facility development.[8]

[4] Central Bureau of Statistics Indonesia (BPS). (2024, August 5). *Official Statistics News, No. 60/08/Th. XXVII: Indonesia Economic Growth Quarter II-2024.*
[5] Lang, T. (2024, July 30). *Investment Potential in Indonesia's Mining Sector.* Retrieved from https://www.viettonkinconsulting.com/global-business/investment-potential-in-indonesias-mining-sector/#:~:text=Indonesia%E2%80%99s%20mining%20sector%20offers%20a%20wealth%20of%20opportunities,is%20increasingly%20well-positioned%20to%20attract%20significant%20global%20investment.
[6] The Ministry of Investment (BKPM). (2024, July 29). *Press Release Realisasi Investasi Triwulan II 2024.*
[7] International Institute for Sustainable Development. (2017). *Indonesia: Downstream linkages*. Retrieved from https://www.iisd.org/sites/default/files/publications/case-study-indonesia-downstream-linkages.pdf.
[8] Firmanto, A. B., Wibisono, D., Siallagan, M. P. S., & Mubarok, M. Z. (2020*). Evaluation of Indonesia's mineral downstream policy with key factors of competitive advantage, comparative advantage, and economic impact perspective.* In Proceedings of the 7th Asia Pacific Conference on Contemporary Research (APCCR) (p. 4). Asia Pacific Institute of Advanced Research (APIAR). ISBN: 978-0-6482404-6-4. Retrieved from http://www.apiar.org.au.

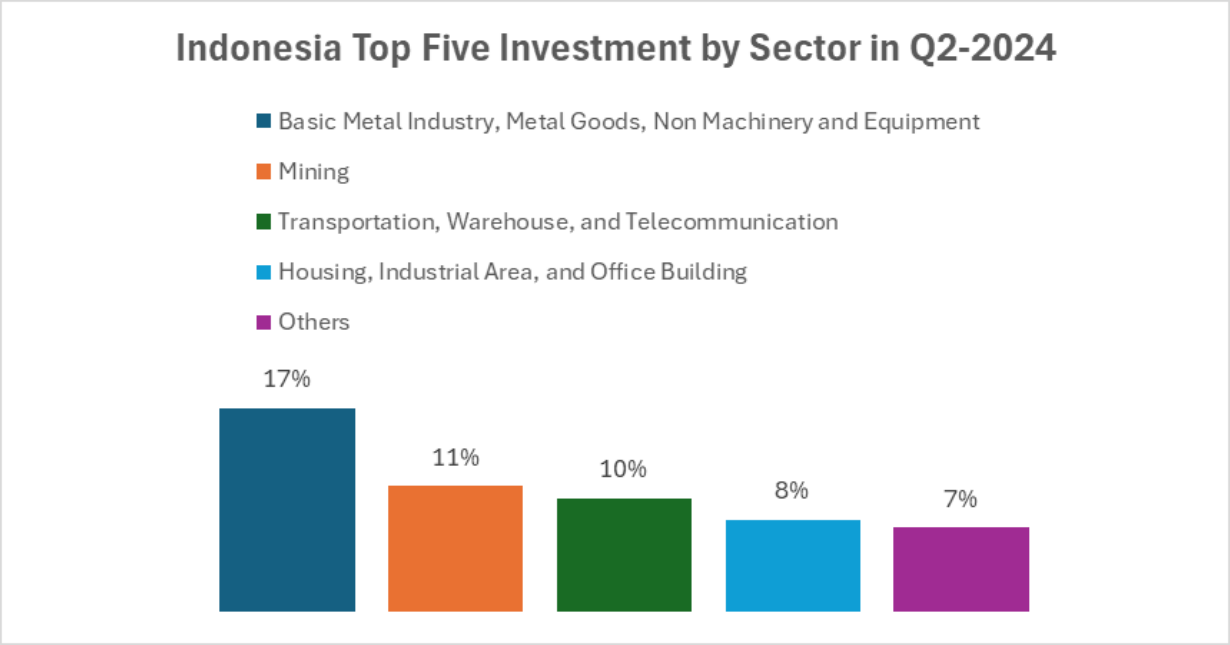

Figure 2 Top Five Indonesia Investments by Sector in Q2-2024[9]

B. Mining Lifecycle

Every mining project, regardless of its size or the mineral being extracted, goes through a series of phases, forming the mine's life cycle. It involves several stages, as illustrated in Figure 3. Each stage requires careful planning, regulatory compliance, stakeholder engagement, and good execution to ensure the success of the project and minimize the impact on the environment and local communities.

[9] The Ministry of Investment (BKPM). (2024, July 29). *Press Release Realisasi Investasi Triwulan II 2024*.

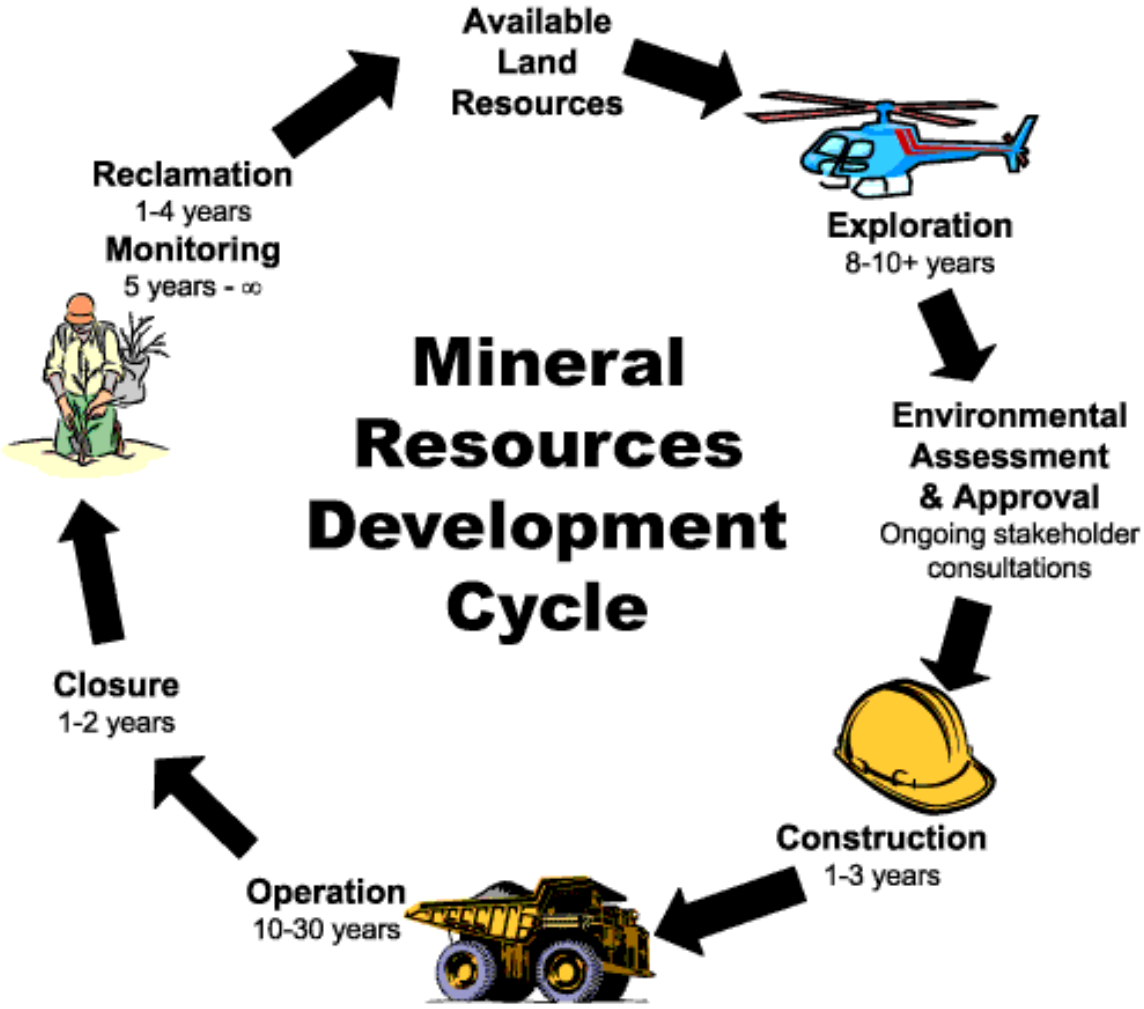

Figure 3 Typical Mining Life Cycle[10]

C. Mining Construction and Its Ineffective Project Management

Indonesia is projected to contribute nearly half of global primary nickel output in the coming years,[11] positioning the industry as a key driver for the country's construction sector in the near to medium term.[12] Numerous mining construction projects are currently underway, including those by PT Vale Indonesia Tbk. (PT Vale). Since its establishment in 1968, PT Vale has been involved in the exploration, mining, processing, and marketing of nickel and related products in the Sorowako Block, South Sulawesi. The company's

[10] MineralsEd. (2024). *Mine Development Cycle*. Retrieved from https://mineralsed.ca/learning-resources/mining101/earth-science/.
[11] Tang, J. (2023, April 25). *Infographic: Indonesian projects to boost nickel supply*. Retrieved from https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/042423-infographic-indonesian-projects-to-boost-nickel-supply.
[12] Business Indonesia. (2024, March 13). *Indonesia's construction sector remains sturdy*. Retrieved from https://business-indonesia.org/news/indonesia-s-construction-sector-remains-sturdy.

current project portfolio includes the Morowali Greenfield Saprolite Project, the Pomalaa Greenfield Saprolite and Limonite Project, and the Sorowako Limonite Project.[13]

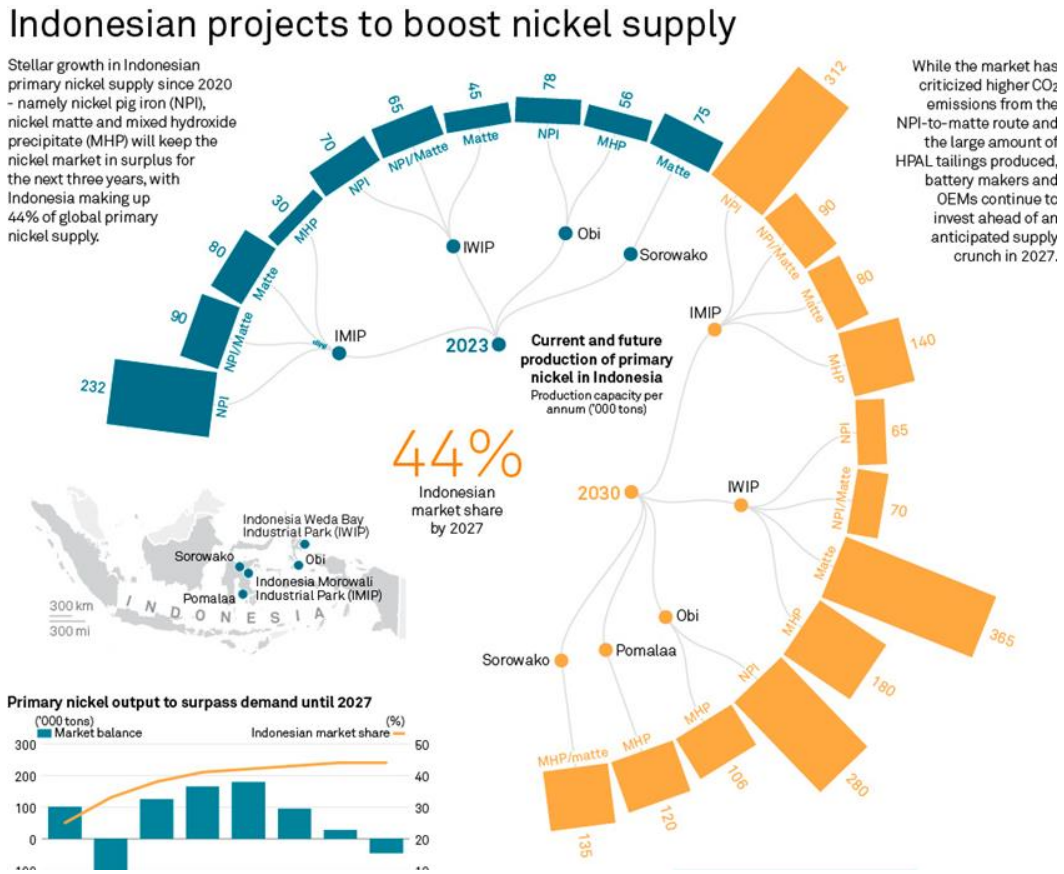

Figure 4 Infographic "Indonesian Projects To Boost Nickel Supply"[14]

Greenfield mining construction projects are complex, dynamic, and unpredictable, involving the development of new facilities on previously undeveloped land.[15] In greenfield nickel mining, this entails establishing operations in areas with no prior mining activities.[16] Figure 5 illustrates the typical components of such projects.

[13] Vale Indonesia. (n.d.). *Indonesia Growth Project*. Retrieved from https://vale.com/in/indonesia-growth-projects.
[14] Tang, J. (2023, April 25). *Infographic: Indonesian projects to boost nickel supply.* Retrieved from https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/042423-infographic-indonesian-projects-to-boost-nickel-supply
[15] Wylie, H. (2024, March 13). *Greenfield vs. Brownfield Projects: Navigating Complexities with Engineering Solutions.* Retrieved from https://crowengineering.com/engineering-design-services/greenfield-vs-brownfield-projects-navigating-complexities-with-engineering-solutions/
[16] K-Mine. (2023, May 27). *Pioneering Greenfield Mining. Part 1: Understanding the Mining Industry and Greenfield Projects.* Retrieved from https://k-mine.com/articles/pioneering-greenfield-mining-part-1-understanding-the-mining-industry-and-greenfield-projects/

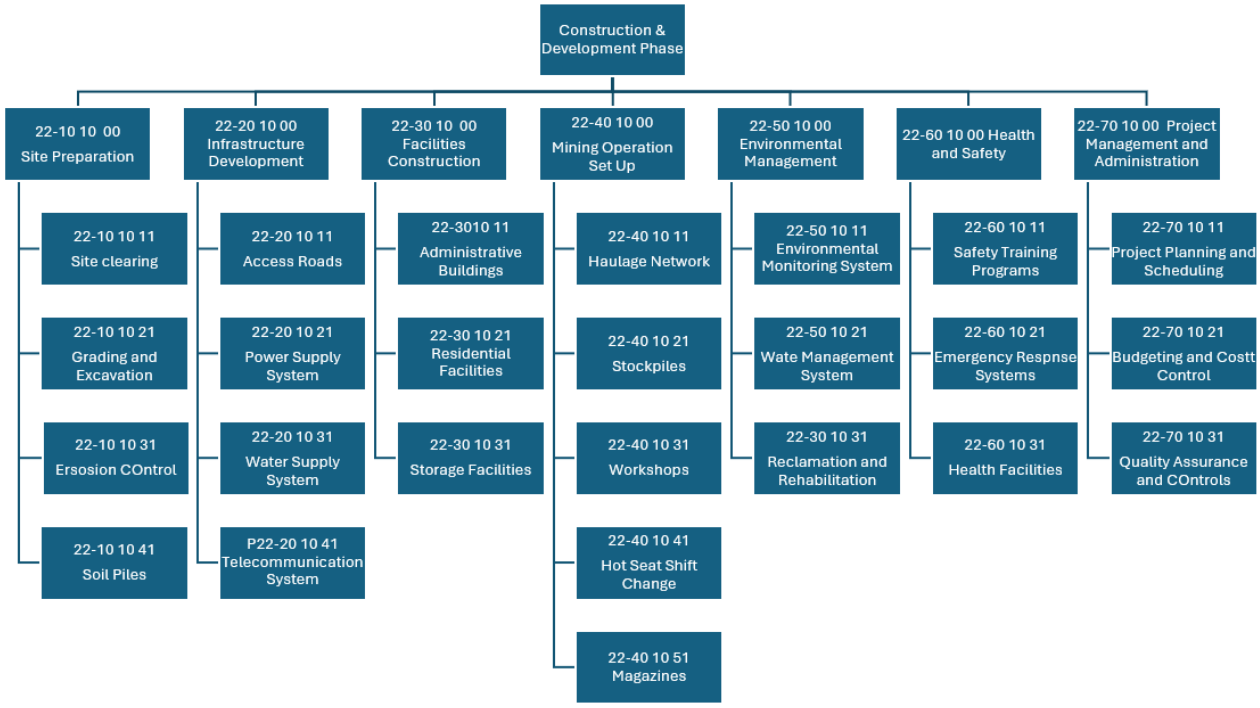

Figure 5 A typical WBS for A Greenfield Mining Project[17]

Among the available contract options depicted in Figure 6, the most common delivery models in the mining industry are Engineering, Procurement, and Construction (EPC) and Engineering, Procurement, and Construction Management (EPCM).[18] [19] Hybrid options have also emerged to better balance risk.[20] EPC contracts involve a single contractor handling all design, procurement, and construction components, while EPCM contracts feature one contractor responsible for design and management, with subcontractors performing the actual construction.[21]

[17] Author
[18] AFRY. (2019, November 13). *Project Implementation Methods in Successful Mining and Metals Investment.* Retrieved from https://afry.com/en/insight/project-implementation-methods-in-succesful-mining-and-metals-investment
[19] Reyneke, N., & Goddard, A. (2023, August 1). *Which is better - EPC or EPCM contracts for construction and mining projects? African Mining.* Retrieved from https://www.africanmining.co.za/2023/08/01/which-is-better-epc-or-epcm-contracts-for-construction-and-mining-projects/
[20] Coombs, P. (2021, October 13). *How can mine owners improve delivery in the drive to net zero*? Retrieved from https://www.turnerandtownsend.com/insights/how-mine-owners-can-improve-delivery-in-the-drive-to-net-zero/
[21] Ibid.

Figure 6 Project Delivery METHODS And Contract Types Compared[22]

According to the 2023 Global Construction Survey conducted by KPMG, only half of the owners said their projects finished on time, and 87 percent stated that projects are performing under great scrutiny.[23] The mining company is not exempt from poor execution of project management. In an era of high costs and low, volatile commodity prices, the need for good project management is acute, but many big mining projects still suffer from poor execution. An article published by McKinsey revealed that more than four out of five mining projects come in late and over budget by an average of 43 percent.[24] A recent news report that three mining companies in Indonesia were facing penalties due to delays in completing their smelter facilities.[25]

[22] Giammalvo, P. D. (2021). *Course Material: Project Controls/PMO handbook of "Best Tested and PROVEN Practices".*
[23] Armstrong, G., Gilge, C., Max, K., & Vora, S. (2023). *Familiar Challenges - New Approaches "2023 Global Construction Survey".* Retrieved from https://kpmg.com/us/en/media/news/kpmg-global-construction-survey-2023.html
[24] Kuvshinikov, M., et al. (2017, February 8). *Getting big mining projects right: Lessons from (and for) the industry.* Retrieved from https://www.mckinsey.com/industries/metals-and-mining/our-insights/getting-big-mining-projects-right-lessons-from-and-for-the-industry
[25] Journalist IBP. (2024, August 27). *Three companies fined for delays in smelter construction*. Retrieved from https://indonesiabusinessspot.com/insider/three-companies-fined-for-delays-in-smelter-construction/

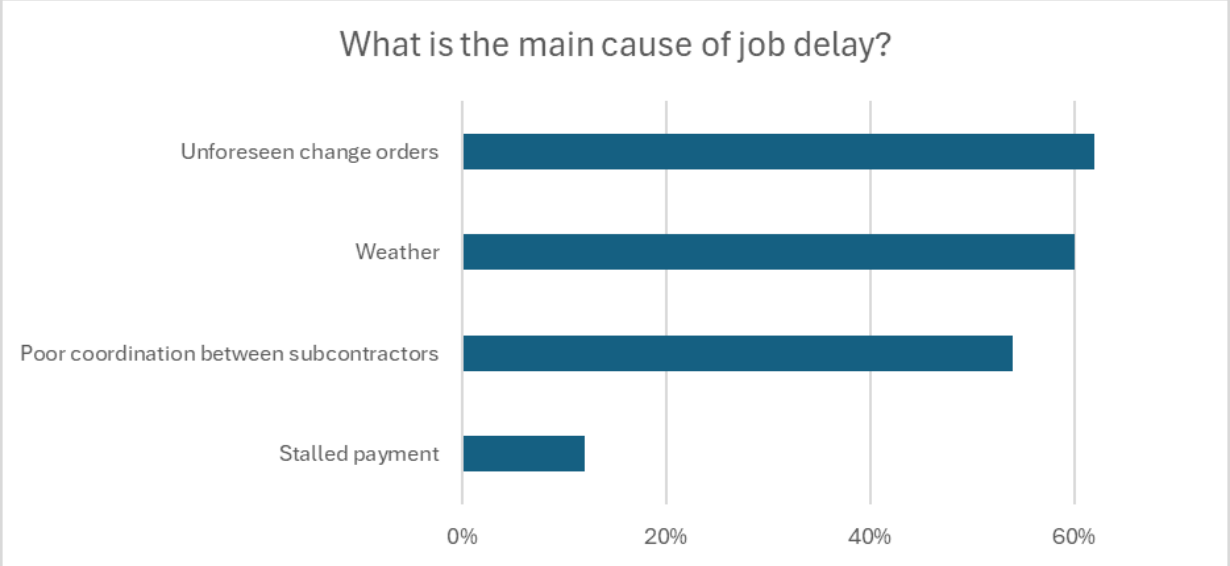

Figure 7 The Main Causes of Delay And Late Payment[26]

Delays can happen for numerous causes. According to the 2020 National Construction Payment Report conducted by Levelset, construction businesses blamed delays on unexpected change orders (62%), weather (60%), poor subcontractor coordination (54%), and stalled payments (12%).[27] Slow payments cause cash flow problems that reduce a construction business' ability to finish work quickly, effectively stunting the growth of their business.[28] A few construction businesses are trapped in a vicious cycle of late payments and limited productivity.[29]

A. Earn Value Management

In capital-intensive projects such as mining construction projects, especially in greenfield areas, the cost of delays in mining construction projects can be substantial and multifaceted. Therefore, implementing prompt payment to contractors has become crucial to ensure the projects are well-managed.

This paper adopts the Earned Value Management (EVM) technique, as pioneered by Frederick Taylor, Henry Gantt, Henri Fayol, and the Gilbreths, to link performance with prompt payment, aiming to mitigate the causes of delays in projects. EVM has evolved from the relationship between Owners and Contractors to address the issues related to the prompt payment of traded products that conform to the agreed terms and

[26] Levelset. (2020). 2020 *National Construction Payment Report*.
[27] Ibid
[28] Wolfe Jr., S. (Last updated 2022, May 05). *2020 Report: Construction suffers from wasted time & slow payment.* Retrieved from https://www.levelset.com/blog/2020-report-construction-wasted-time-slow-payment/
[29] Ibid

conditions.[30] According to fundamental EVM concepts, owners are not obliged to purchase substandard goods or services that contain latent or patent defects. They have the right to test the quality of the products or services being purchased. The contractor must provide verifiable evidence that the products, goods, or services conform to the specifications stipulated by the owner in the contractual agreement. Upon successful verification, the physical quantities are quantified, and the owner promptly disburses payment to the contractor for the delivered goods or services.[31]

Figure 8 The Underlying Concept of Earned Value Management[32]

[30] Giammalvo, P. D. (2021). *Course Material: Project Controls/PMO handbook of "Best Tested and PROVEN Practices".*
[31] Ibid.
[32] Giammalvo, P. D. (2019). *Activity-based costing (ABC) - The other side of the earned value coin?* PM World Journal, 8(2). Retrieved from https://pmworldlibrary.net/wp-content/uploads/2019/02/pmwj79-Feb2019-Giammalvo-Activity-Based-Costing.pdf

This technique is particularly pertinent to Indonesia, which has the largest Muslim population in the world,[33] As the Earned Value Management (EVM) technique aligns with Islamic/Shariah Law [34].

In conclusion, this paper addresses the following research questions:

1. What is the optimal progress measurement method for greenfield mining construction projects to ensure prompt payment to contractors for work performed in substantial compliance with contract documents while also ensuring safety, compliance, sustainability, and project resilience?
2. How can traditional Earned Value Management (EVM) approaches, float analysis, and incentive plans be integrated to enhance project performance and contractor motivation in greenfield mining projects?
3. Can a "neutral cash flow" payment system be developed to provide contractors with sufficient working capital while protecting owners from advance payments and preventing contractor bankruptcy during the project?

METHODOLOGY

The author will adopt the seven-step engineering economic procedures detailed in the following figure.

[33] World Population Review. (2024). *Muslim Population by Country*. Retrieved from https://worldpopulationreview.com/country-rankings/muslim-population-by-country
[34] Taybi, Y. (2019). *Is Earned Value Management (EVM) consistent with Sharia Law? Will it help in fighting corruption?* PM World Journal, Vol. VIII, Issue VIII, September. Retrieved from https://pmworldlibrary.net/wp-content/uploads/2019/09/pmwj85-Sep2019-Taybi-is-evm-consistent-with-sharia-law.pdf

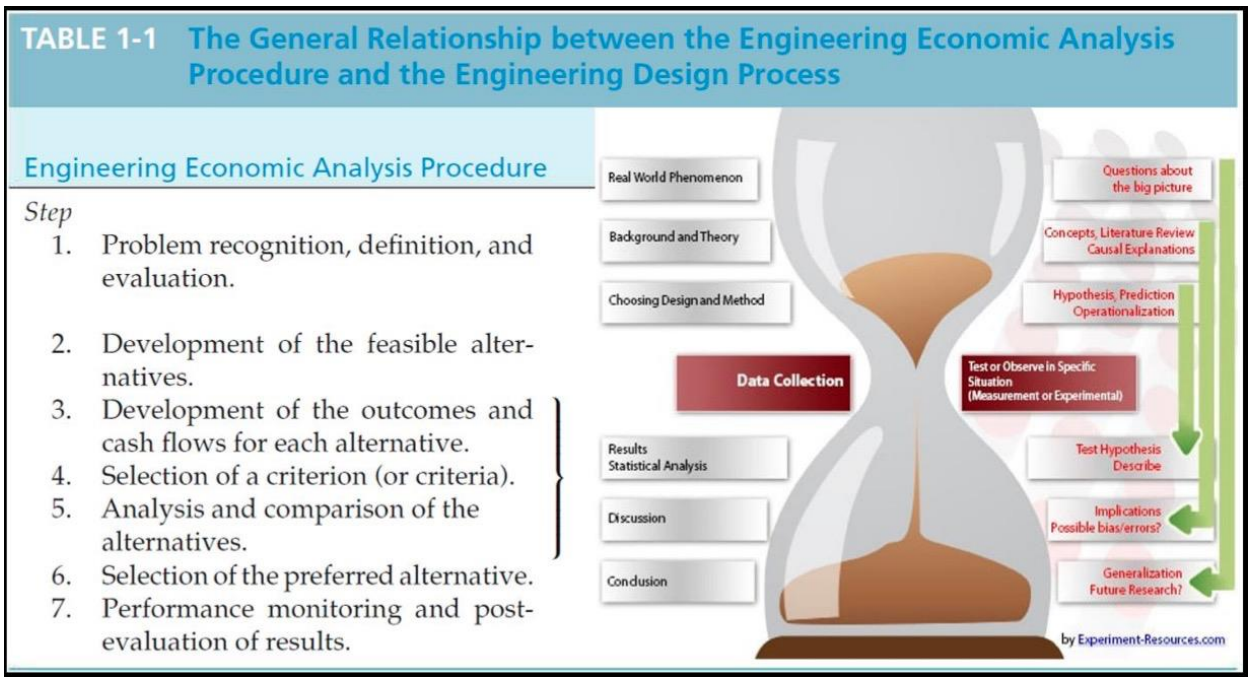

Figure 9 Engineering Economic Analysis Procedure[35] And Steps of The Scientific Process[36]

The description of each step is listed below.

Step 1 – Problem recognition, definition, and evaluation.

Problem recognition is the first and crucial step. It involves identifying and clearly defining the issue that needs to be addressed.

Step 2 – Development of the feasible alternatives.

This phase involves generating and evaluating different solutions to address the identified problem.

Step 3 – Development of the outcomes.

This stage involves several vital steps to ensure that the chosen alternative is both viable and optimal.

Step 4 - Selection criteria.

The phase involves evaluating each option against specific criteria to determine which one offers the most benefits.

[35] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2020). *Engineering Economy* (17th ed.). Pearson Education Limited.
[36] Shuttleworth, M. (2008, February 2). *What is research?* Retrieved from https://explorable.com/what-is-research

Step 5 - Analysis and comparison of the alternatives

This step thoroughly analyzes and compares different alternatives to make an informed, balanced decision.

Step 6 - Selection of the preferred alternatives.

Determination of the best solution by thorough systematic evaluation of all feasible options.

Step 7 - Performance monitoring and post-evaluation of results

To ensure the selected alternative is implemented effectively and meets the desired outcomes.

Step 1 – Problem recognition, definition, and evaluation

Project delays plague the mining construction industry, with over 80% of projects facing delays and cost overruns.[37] These delays cause disputes, productivity loss, increased costs, and strained relationships.[38] Late payments to contractors, reported by 37% of them, are a key factor. Addressing late payments is crucial to reducing delays.[39]

Step 2 – Development of the feasible alternatives

To minimize delays in greenfield mining projects, prompt and fair payment to contractors is crucial.[40] This can be achieved by choosing the right payment method.

First, the author will narrow down the generally accepted options listed below.

1. **Units Completed or Units in Place Method**: This method tracks the number of units of work completed. It's useful for repetitive tasks where each unit takes a similar amount of time and resources.

[37]Kuvshinikov, M., et al. (2017, February 8*). Getting big mining projects right: Lessons from (and for) the industry.* Retrieved from https://www.mckinsey.com/industries/metals-and-mining/our-insights/getting-big-mining-projects-right-lessons-from-and-for-the-industry
[38] Kumar, P., & Raj, P. (2015). *Delay Analysis of Projects and Effects of Delays in the Mining/Manufacturing Industries.* IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 12(6), 61-71. Retrieved from https://www.iosrjournals.org/iosr-jmce/papers/vol12-issue6/Version-4/I012646171.pdf.
[39] Thibault, M. (2022, November 10). *Late payments cost construction industry $208B in 2022: report*. Retrieved from https://www.constructiondive.com/news/late-payments-cost-construction-industry-208b-in-2022-report/636224/
[40] Author

2. **Incremental Milestone Method:** Progress is measured by achieving predefined milestones. Each milestone represents a significant step towards project completion.
3. **0/100 Method:** This method only recognizes progress when a task is fully completed. No partial credit is given for work in progress.
4. **50/50 Method:** This method assigns 50% progress when a task starts and the remaining 50% when it is completed. It provides a balanced view of progress.
5. **10/90 Method:** Similar to the 50/50 method but assigns 10% progress at the start and 90% upon completion. This method emphasizes the importance of task completion.
6. **Weighted or Equivalent Units Method:** Tasks are weighted based on their importance or complexity. Progress is measured by the completion of these weighted tasks.
7. **Professional Judgement / Expert Opinion:** Progress is estimated based on the experience and judgment of experts. This method is subjective but can be useful for complex projects.
8. **Cost Ratio Method:** Progress is measured by comparing the actual cost incurred to the budgeted cost. It provides a financial perspective on project progress.
9. **Hours Ratio Method:** Like the cost ratio method, it uses hours worked instead of costs. It compares actual hours worked to the budgeted hours.
10. **Quantity Adjusted Budgets:** This method adjusts the budget based on the quantities of work completed. It provides a dynamic view of progress based on actual work done.
11. **Person-Hour Adjusted Budget:** This method adjusts the budget based on the person-hours spent on the project. It helps in tracking labor-intensive projects.

Into 4 best-recommended progress measurement methods in greenfield mining construction projects. The process will utilize the Dominance Multi-Attribute Decision Makin (MADM) technique. It is a straightforward technique used to compare alternatives based on multiple criteria. An alternative is said to dominate another if it is at least as good in all criteria and better in at least one criterion. The decision criteria to be considered are listed below.

1. **Safety, Compliance, and Sustainability:** These essential factors can delay payments due to safety incidents or compliance issues halting progress.

Sustainability ensures financial practices align with environmental and social responsibilities. Assessing integration ease into the payment system is crucial.

2. **Cash Flow Neutrality:** Ensures funds are available for timely contractor payments, reducing financial strain and building trust. Effective payment systems balance incoming and outgoing cash flows to avoid deficits or surpluses.
3. **Protection of the Owner:** Ensures the project meets quality standards, protecting the owner from future issues and financial losses due to defects, crucial for long-term viability.
4. **Reliability of Contractor:** Essential for managing the complexities and challenges of large-scale mining projects.
5. **Contractual Reliability:** Clear obligations and expectations reduce disputes and provide legal protection. Effective dispute-resolution mechanisms are crucial to prevent delays in complex projects.
6. **Risk Allocation:** Proper risk allocation in payment methods helps manage unforeseen challenges without causing significant delays in progress and payments.
7. **Administrative Complexity:** Ensures the payment method aligns with the project's administrative capabilities, supporting efficient execution and financial management

Step 3 – Development of the outcomes

The outcome of the process detailed in the former step is tabulated below.

Options	Safety, Compliance, and Sustainability	Cash Flow Neutrality	Protection of The Owner	Risk Allocation	Contractor Reliability	Contractual Reliability	Administrative Simplicity
Units Completed or Units in Place Method	High	High	High	High	High	High	Low
Incremental Milestone	High	Moderate	High	High	High	High	Moderate
0/100	Low	Low	High	Low	Low	High	High
50/50	Low	Moderate	Moderate	Moderate	Moderate	High	High
10/90	Low	Low	High	Low	Low	High	High
Weighted or equivalent Unit Methods	High	High	High	High	High	High	Moderate
Expert Opinion	High	Moderate	High	High	Moderate	Moderate	High
Cost Ratio	Moderate	High	Moderate	Moderate	High	High	Moderate
Hours Ratio	Moderate	High	Moderate	Moderate	Moderate	High	Moderate
Quantity Adjusted Budgets	High	High	High	High	High	High	Moderate
Person-Hour Adjusted Budget	Moderate	High	Moderate	Moderate	Moderate	High	Moderate

Table 1 Results of Dominance MADM Technique

Method	High	Moderate	Low
Units Completed or Units in Place Method	6	0	1
Incremental Milestone	5	2	0
0/100	3	0	4
50/50	2	4	1
10/90	3	0	4
Weighted or equivalent Unit Methods	6	1	0
Expert Opinion	4	3	0
Cost Ratio	3	4	0
Hours Ratio	2	5	0
Quantity Adjusted Budgets	6	1	0
Person-Hour Adjusted Budget	2	5	0

Table 2 Summary of Dominance MADM Analysis Result

Based on the evaluation, the top 4 progress payment methods recommended for large-scale mining construction projects in greenfield areas are:

1. Units Completed or Units in Place Method
2. Incremental Milestone Method

3. Weighted or Equivalent Units Method
4. Quantity Adjusted Budgets.

Step 4 – Selection Criteria

The author will select the best-suited progress measurement methods for greenfield mining construction projects from the top 4 options resulting in the previous step. Two different compensatory Multi-Attribute Decision Making (MADM) will be deployed for the evaluation,

1. **Simple Additive Weighting (SAW):** assigning weights to each criterion, normalizing the scores of each alternative, and then summing the weighted scores to rank the alternative.
2. **Analytical Hierarchy Process (AHP):** pairwise comparisons to determine the relative importance of criteria and the relative performance of alternatives.

The decision criteria utilized in Step 2 will be grouped into 3 main categories.

1. Safety, Compliance, and Sustainability (C1)
2. Financial & Risk Management (C2), covering:
    a. Cash Flow Neutrality
    b. Risk Allocation
3. Integrated Project Reliability (C3), covering:
    a. Protection to the owner from both latent and patent defects
    b. Contractor reliability
    c. Contractual reliability
    d. Administrative simplicity

Step 5 – Analysis and comparison of the alternatives

1. **Simple Additive Method (SAW)**

- Weighting:

  Considering that the mining company commits to uphold C1 as important as C2, the weighting for each criterion is CI= 0.4, C2 = 0.4, and C3 = 0.2.

- Ratings :

  Each option will be rated on a scale of 1 to 10 for each criterion based on their effectiveness.

Options	Safety, Compliance, and Sustainability (C1)	Financial & Risk Management (C2)	Integrated Project Reliability (C3)
Units Completed	8	7	9
Incremental Milestone	7	8	8
Weighted Units	6	9	7
Quantity Adjusted Budgets	5	6	6

Table 3 Rating on A Scale of 1-10 for Each Option

Options	Safety, Compliance, and Sustainability (C1)	Financial & Risk Management (C2)	Integrated Project Reliability (C3)
Units Completed	0.308	0.233	0.300
Incremental Milestone	0.269	0.267	0.267
Weighted Units	0.231	0.300	0.233
Quantity Adjusted Budgets	0.192	0.200	0.200

Table 4 Normalized Ratings

Options	Weighted Sum
Units Completed	0.276
Incremental Milestone	0.268
Weighted Units	0.259
Quantity Adjusted Budgets	0.197

Table 5 The Weighted Sum of Each Option

Based on the SWP calculations, the Units Completed method is considered the best-suited progress measurement method for greenfield mining construction projects, considering the criteria and weights provided.

2. Analytical Hierarchy Process (AHP)

Criteria	Safety, Compliance, and Sustainability	Financial & Risk Management	Integrated Project Reliability
Safety, Compliance, and Sustainability	1	1	3
Financial & Risk Management	1	1	3
Integrated Project Reliability	1/3	1/3	1

Table 6 Pairwise Comparison Matrices

Criteria	Safety, Compliance, and Sustainability	Financial & Risk Management	Integrated Project Reliability	Weights
Safety, Compliance, and Sustainability	0.429	0.429	0.429	0.429
Financial & Risk Management	0.429	0.429	0.429	0.429
Integrated Project Reliability	0.143	0.143	0.143	0.143

Table 7 Normalized Comparison Matrices & Weights Calculation

C1: Safety, Compliance, and Sustainability

Options	Units Completed	Incremental Milestone	Weighted Units	Quantity Adjusted Budgets
Units Completed	1	3	5	7
Incremental Milestone	1/3	1	3	5
Weighted Units	1/5	1/3	1	3
Quantity Adjusted Budgets	1/7	1/5	1/3	1

Table 8 Pairwise of Comparison of Options for C1

C2: Financial & Risk Management

Options	Units Completed	Incremental Milestone	Weighted Units	Quantity Adjusted Budgets
Units Completed	1	3	5	7
Incremental Milestone	1/3	1	3	5
Weighted Units	1/5	1/3	1	3
Quantity Adjusted Budgets	1/7	1/5	1/3	1

Table 9 Pairwise of Comparison of Options for C2

C2: Financial & Risk Management

Options	Units Completed	Incremental Milestone	Weighted Units	Quantity Adjusted Budgets	Weights
Units Completed	0.597	0.662	0.536	0.438	0.558
Incremental Milestone	0.199	0.221	0.321	0.313	0.263
Weighted Units	0.119	0.074	0.107	0.188	0.122
Quantity Adjusted Budgets	0.085	0.044	0.036	0.063	0.057

Table 10 Normalized Matrices & Weight for C2

C3: Integrated Project Reliability

Options	Units Completed	Incremental Milestone	Weighted Units	Quantity Adjusted Budgets	Weights
Units Completed	0.597	0.662	0.536	0.438	0.558
Incremental Milestone	0.199	0.221	0.321	0.313	0.263
Weighted Units	0.119	0.074	0.107	0.188	0.122
Quantity Adjusted Budgets	0.085	0.044	0.036	0.063	0.057

Table 11 Normalized Matrices & Weight for C3

Options	Final Score
Units Completed	0.558
Incremental Milestone	0.263
Weighted Units	0.122
Quantity Adjusted Budgets	0.057

Table 12 Aggregation

The Units Completed method scores the highest (0.558), confirming its suitability as the best progress measurement method for greenfield mining construction projects.

Step 6 – Selection of the preferred alternative

In greenfield mining projects, where the environment is unpredictable and complex, having a reliable progress measurement method is essential. The unit-completed method, evaluated through both SAW and AHP techniques, is the best choice. It offers clear, quantifiable tracking and excels in safety, compliance, sustainability, financial management, and project reliability. The AHP method, with its detailed and structured approach, reinforces the SAW results, confirming the unit-completed method as optimal for successful project development. Both the SAW and AHP analyses consistently identified the unit-completed method as the best-suited progress measurement method for greenfield mining construction projects. This method's strengths include:

- **Safety, Compliance, and Sustainability:** Ensures that each unit of work meets the required standards, facilitating precise monitoring of resource usage and environmental impact.
- **Financial & Risk Management:** Links payments to completed units, reducing financial risk and ensuring better cash flow neutrality.
- **Integrated Project Reliability:** Provides clear accountability for each completed unit, protecting the owner from defects and simplifying administrative processes.

Regardless of their authenticity, the cases of the Hoffmans, the Beets family, and Parker Schnabel from "Gold Rush" highlight the importance of strategic planning, adaptability, and resilience in overcoming obstacles and achieving ambitious targets. While the show may not perfectly represent real-world mining operations, it provides valuable insights into the complexities of managing such projects.

In Season 2, Episode 4: "Crab Shells Help Hoffmans Find Big Gold Haul",[41] By the end of Week 3, they have produced 445.6 ounces of gold against a planned 758.25 ounces as they have only achieved 59% of their planned production by the end of Week 3. This means they need to increase their production rate to get back on track and meet their overall target.

Figure 10 Excerpt from Season 2, Episode 4: "Crab Shells Help Hoffmans Find Big Gold Haul"[42]

Meanwhile, Parker Schnabel hires a productivity expert to streamline operations, resulting in increased gold production, reduced costs, and enhanced team efficiency.[43] This illustrates motion study theories by Frank and Lillian Gilbreth, optimizing work motions and boosting productivity. Similarly, the Beets family brings in an expert to build new roads, solve logistical challenges, and enhance operational efficiency. This move,

[41] Discovery UK. (2024, September 4*). Crab Shells Help Hoffmans Find Big Gold Haul | Hoffman Family Gold [Video]. YouTube*. https://youtube.com/watch?v=aiU-xvAaO9M
[42] Ibid
[43] Discovery UK. (2019, December 11). *Parker Hires An Analyst To Get His Plant Running More Efficiently | Season 10 | Gold Rush [Video]*. YouTube. https://www.youtube.com/watch?v=87sLm_JdAmw

rooted in motion study principles, reduces transportation time and effort, aligning with Frederick Winslow Taylor's scientific management. Tony Beets' decision to invest in infrastructure reflects Henri Fayol's principles of planning and control, leading to a $80,000 increase in earnings.[44]

While the Hoffmans focus on meeting their schedule, Parker and the Beets family emphasize cost efficiency and productivity improvements. This highlights the different aspects of project management each team prioritizes to achieve success.

Applying NDIA Schedule and Cost Matrices[45]

1. Schedule Metrics

1.1 Schedule Performance Index (SPI)

$$SPI = \frac{BCWP}{BCWS}$$

Practical Explanation: SPI measures how efficiently we are adhering to the project schedule. An SPI of 0.59 means we are only completing 59% of the planned work on time. This indicates significant delays and requires us to reassess our scheduling and resource allocation.

SPI efficiency shows how well resources like trucks and excavation equipment are used. A low SPI indicates inefficiencies, leading to delays and higher costs. Addressing these can improve project performance.

When the Schedule Performance Index (SPI) is less than 1, indicating the project is behind schedule, it's essential to take corrective actions. Start by identifying the root causes of delays through progress reports and site visits, checking for issues like insufficient manpower or equipment breakdowns. Maintain open communication with the contractor to understand their challenges and collaborate on a plan to get back on track, which might involve adjusting schedules or reallocating resources.

Next, implement corrective actions such as allocating additional resources and streamlining workflows to eliminate bottlenecks. Increase the frequency of progress updates and meetings to monitor the implementation of these actions closely. Utilize project management tools to track real-time progress and make data-driven decisions,

[44] Discovery UK. (2024, March 1). *Tony Beets Makes $80,000 More By Building A New Road | Gold Rush [Video]*. YouTube. https://www.youtube.com/watch?v=2oSHsXxC3HE&t=528s
[45] National Defense Industrial Association. (2021). *Predictive measures guide (Rev. 3)*. Retrieved from https://www.humphreys-assoc.com/evms/evms-documents/ndia/NDIA_IPMD_PredictiveMeasuresGuide_Rev_3_March262021.pdf

ensuring the project moves back on schedule efficiently. Additionally, consider offering performance bonuses for meeting or exceeding revised milestones and enforce contractual penalties for continued delays to motivate timely completion.

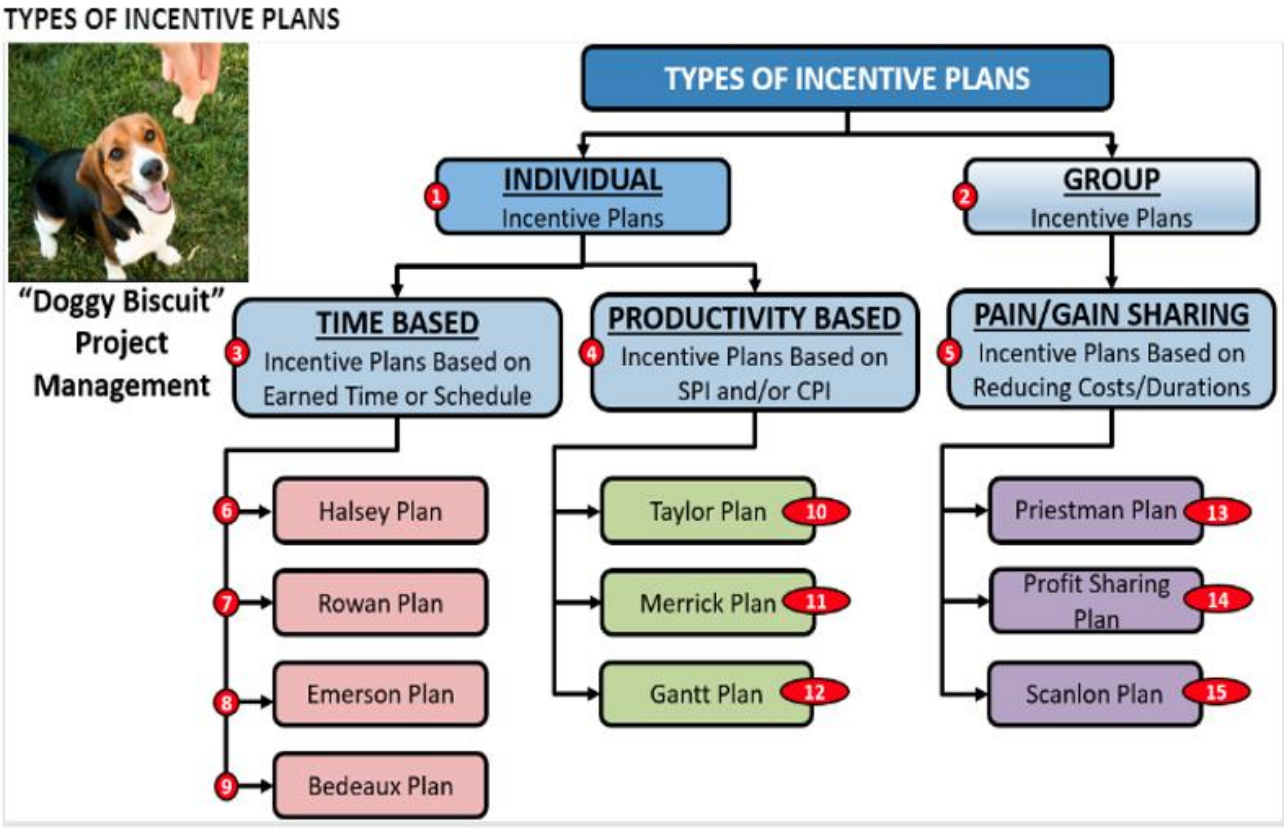

Figure 11 Types of Incentive Plans[46]

In Season 3 of "Hoffman Family Gold," the Hoffmans began with an ambitious target of 3,000 ounces of gold, as revealed in Episode 1, "Richer by the Ounce." However, the season quickly proved challenging, with harsh weather and equipment failures forcing them to reassess their goals. By Episode 12, "The Gold and the Glory," Todd Hoffman and his crew decided to lower their target to 1,023 ounces.

[46] Giammalvo, P. D. (2021*). Course Material: Project Controls/PMO handbook of "Best Tested and Proven Practices".*

Figure 12 Excerpt from Season 2, Episode 12: "The Gold and the Glory"[47]

Despite these setbacks, the Hoffmans' determination and unity shone through. They worked tirelessly, overcoming each obstacle with innovative solutions and relentless effort. Their hard work paid off as they reached their revised target, showcasing their resilience and teamwork. To celebrate their success, Todd announced bonuses for each crew member, acknowledging their dedication and reinforcing the sense of camaraderie among the team.

This approach of adjusting targets based on real-time challenges can be a good practice to prevent delays in any project. Setting realistic goals, being flexible, managing risks, and keeping the team motivated are key strategies that can help ensure steady progress and timely completion.

1.2 Baseline Execution Index (BEI)

BEI measures how well we execute tasks compared to the baseline plan. If Hoffman is getting only 59% of his necessary gold, his BEI is 0.59, meaning his team completes 59% of planned tasks. This could be due to equipment delays, labor shortages, or site conditions. Improving BEI involves better planning and addressing bottlenecks.

[47] Discovery UK. (2024, October 30*). Hoffmans End The Season With $2 Million Of Gold Before Winter Shuts Them Down | Hoffman Family Gold [Video]. YouTube*. https://www.youtube.com/watch?v=odJu1nqkpDo

$$BEI = \frac{\#\ Tasks\ Actually\ Completed}{\#\ Tasks\ Planned\ to\ Be\ Completed}$$

If Todd Hoffman mines 59 ounces for every 100 planned, he needs to increase gold recovery or reduce costs to stay profitable. Measuring how much pay dirt is processed versus gold recovered helps test equipment efficiency. Low recovery might mean fine gold is lost or equipment isn't effective. Corrective actions include checking equipment and adjusting techniques.

When BEI is less than 1.00, indicating tasks aren't completed as planned, corrective actions include improving project planning, addressing delays, and enhancing team communication to ensure timely task completion

1.3 Critical Path Length Index (CPLI)

CPLI measures the efficiency of the critical path, which determines the project's duration. A CPLI of less than 1 indicates that the critical path is longer than planned, leading to potential delays. To address this, it's crucial to focus on critical tasks, ensuring they are prioritized to prevent further delays. Additionally, reevaluating the sequence of tasks can help find more efficient ways to complete them, optimizing the overall workflow.

$$CPLI = \frac{Critical\ Path\ Length\ +\ Critical\ Path\ Total\ Float}{Critical\ Path\ Length}$$

Allocating additional resources to critical tasks can also expedite their completion, helping to bring the project back on track. By concentrating efforts on these key areas, we can improve the efficiency of the critical path and ensure timely project completion.

1.4 Current Execution Index (CEI)

CEI measures the project's execution efficiency. A low CEI indicates that tasks are not being executed as efficiently as planned, often due to various operational issues. To address this, it's essential to conduct a thorough analysis to identify inefficiencies in current operations. This analysis will help pinpoint specific areas that need improvement.

Implementing industry best practices can significantly enhance execution efficiency. Adopting these practices ensures that the project aligns with proven methods and standards. Additionally, providing training and development opportunities for workers can boost their skills and productivity, further improving overall project performance. Focusing on these corrective actions can enhance the project's execution efficiency and achieve better outcomes.

1.5 Total Float Consumption Index (TFCI)

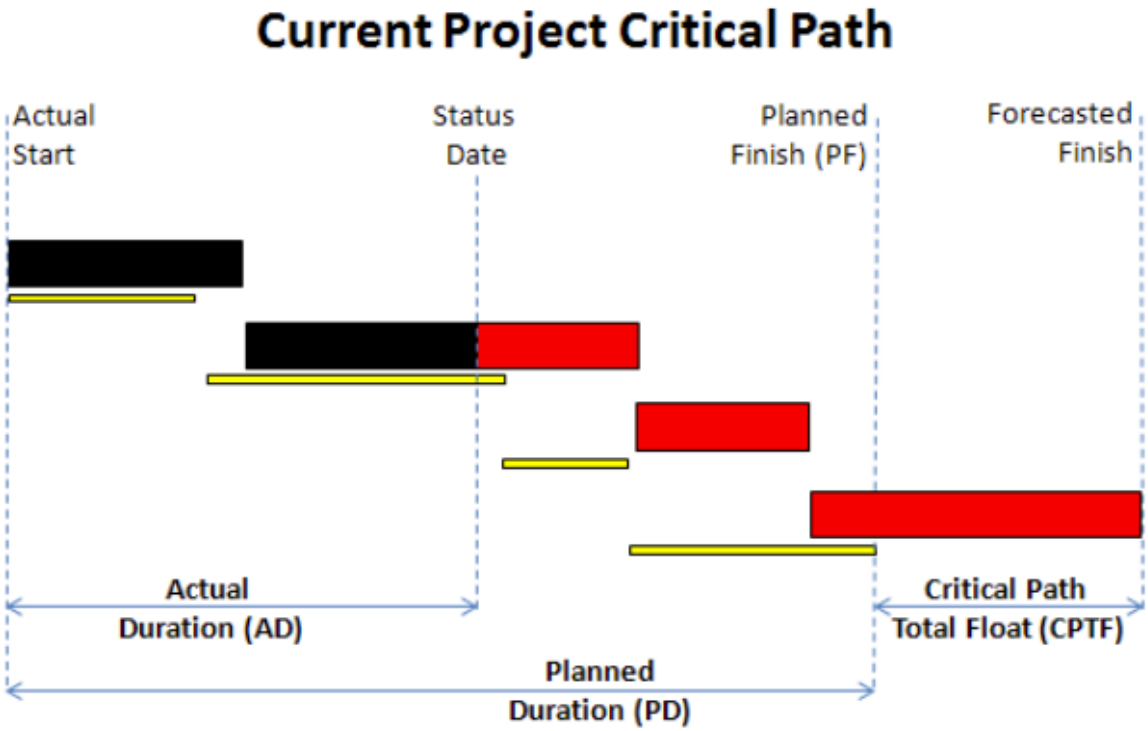

Figure 13 Component of TFCI[48]

Planned Finish (PF) vs. Forecast Finish (FC)

Planned Finish (PF): This is the date when a task or project is originally scheduled to be completed.

Forecast Finish (FC): This is the date when the task or project is now expected to be completed based on current progress and any delays.

Negative Float

Negative Float occurs when the Forecast Finish (FC) is later than the Planned Finish (PF), indicating the project is behind schedule. For example, if Parker Schnabel's team is scheduled to finish mining by October 1st (PF) but now expects to finish by October 15th (FC), the 15-day difference is the Negative Float.

[48] National Defense Industrial Association. (2021). *Predictive measures guide (Rev. 3)*. Retrieved from https://www.humphreys-assoc.com/evms/evms-documents/ndia/NDIA_IPMD_PredictiveMeasuresGuide_Rev_3_March262021.pdf

Planned Duration (PD) is the original time allocated for a task, while Forecast Duration (FD) is the updated expected time. If Parker's team planned to complete mining in 30 days (PD) but now expects 45 days (FD), the 15-day difference is also a Negative Float.

Negative Float highlights delays and areas needing immediate attention, potentially increasing costs and requiring resource adjustments. TFCI measures buffer time usage; a high TFCI indicates quick buffer consumption, posing schedule risks. For example, consistent delays in the "Gold Rush" due to equipment breakdowns or bad weather would result in a high TFCI, pushing the forecast completion date further out.

To address high TFCI, closely monitor float usage, adjust schedules, and proactively manage risks to keep the project on track.

1.6 Earned Schedule (ES)

ES measures schedule performance by showing how much of the planned schedule has been achieved. If ES is less than planned, it indicates delays. To address this, accelerate work through overtime or additional shifts, reallocate resources from non-critical to critical tasks, and conduct regular progress reviews to track and adjust as needed.

1.6.1 Time-Based Schedule Performance Index (SPIt)

$$SPI(t) = \frac{Earned\ Schedule\ (ES)}{Actual\ Duration\ (AD)}$$

SPIt is similar to SPI but focuses on time, measuring how efficiently we are using our time compared to the planned schedule. A low SPI indicates that we are behind schedule. To address this, it's important to improve time management practices to ensure tasks are completed on time, identify and eliminate time-wasting activities to increase overall efficiency, and reevaluate and adjust deadlines to reflect realistic timelines.

1.6.2 SPIt vs. TSPIed

SPIt measures our time efficiency compared to the planned schedule. If SPIt is much lower than TSPIed, we need corrective actions to get back on track. TSPIed measures the efficiency required to complete the remaining work on time.

In Hoffman's case, the target is 3033 ounces of gold, with 445.5 ounces produced by the end of week 3, leaving 9 weeks to produce 2587.5 ounces. This requires increasing weekly production from 252.75 to 287.5 ounces.

For field workers, this means increased production pressure, possibly longer hours, and more resources like additional equipment or labor. Delays can affect cash flow and profit margins due to higher production costs.

Corrective actions include adding shifts or hiring more labor, optimizing processes to eliminate bottlenecks, conducting regular progress reviews, and reallocating resources from non-critical to critical tasks. By addressing these metrics, we can better manage production schedules, ensure timely completion, and protect profit margins

2 Cost Metrics

2.1 Cost Performance Index (CPI)

When the Cost Performance Index (CPI) is less than 1.00, it indicates the project is over budget. To address this, implement strict cost control measures to reduce unnecessary expenses, optimize resource allocation to avoid wastage, and negotiate better rates with suppliers and contractors.

$$CPI = \frac{BCWP}{ACWP}$$

In Hoffman's case, if the operation produces 59% of the new target (758.25 ounces), it will produce 447.37 ounces. The earned value (EV) in monetary terms would be $863,414.28, while the actual cost (AC) to mine this amount at $795 per ounce would be $355,059.86. This results in a CPI of approximately 2.43, indicating that for every dollar spent, the operation is earning $2.43 worth of value.

While this suggests excellent cost efficiency, the low production rate still poses a challenge for meeting revenue goals. Maintaining cost efficiency is crucial, especially in remote locations with high operational costs. Additionally, consistently missing production targets can affect team morale and productivity.

2.2 Cost Performance Index vs. To Complete Cost Performance Index Estimate at Completion (CPI vs. TCPIeac).

When the Current Cost Performance Index (CPI) is below the Target Cost Performance Index (TCPIeac), it indicates that cost performance is below target. To address this, improve cost efficiency by identifying areas for improvement and implementing corrective actions. Regularly monitor costs to ensure they align with the budget and reevaluate and adjust the budget to reflect realistic cost estimates.

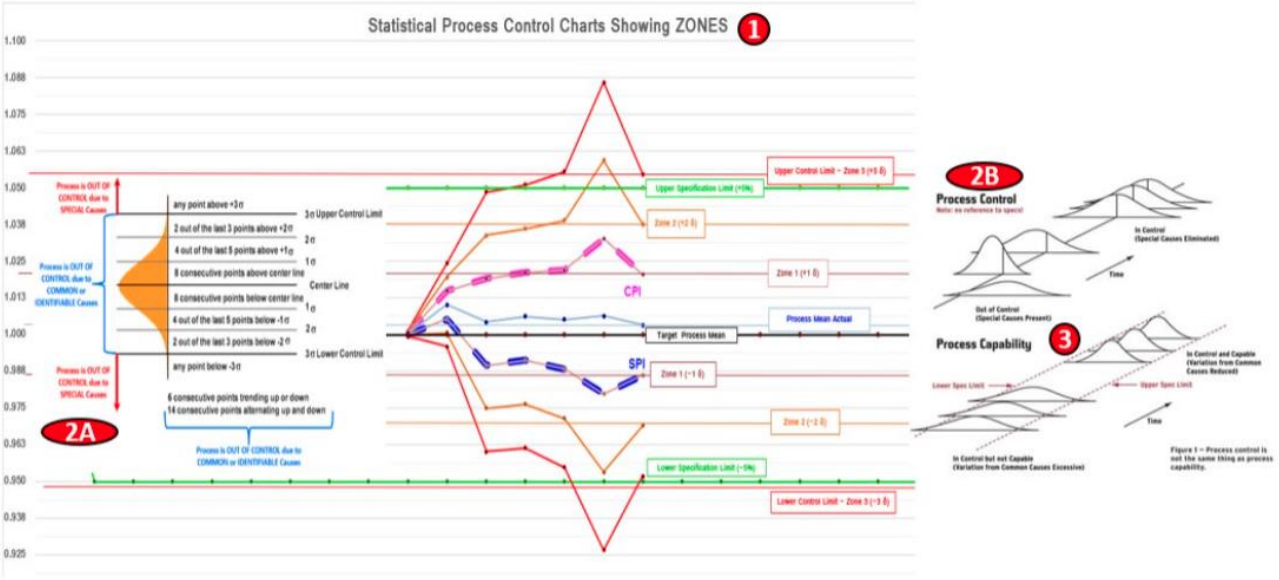

Figure 14 Sample of integrated Process Linking SPI And CPI to Statistical Process Control Charts Applied to Process Control and Process Capability[49]

Statistical Process Control (SPC) Charts are used to track the Schedule Performance Index (SPI) and Cost Performance Index (CPI), monitoring workflow stability and capability over time. By using SPC charts, we can visualize trends and variations in project performance, which aids in making informed decisions to keep the project on track. Regular monitoring of these indices helps us identify areas for continuous improvement, ensuring that the project remains efficient and cost-effective. SPC charts are important because they help determine if our processes can consistently meet performance standards and show if our processes are stable and free from unexpected variations.

In the TV show “Gold Rush,” both Tony Beets and Parker Schnabel have seen varying degrees of success with the help of efficiency engineers. Tony Beets optimized his dredge operations to reduce downtime and improve productivity, leading to higher gold yields and better resource management. Parker Schnabel identified bottlenecks in his workflow and implemented process improvements, which allowed him to streamline operations, reduce costs, and increase gold output. Overall, hiring efficiency engineers has helped both Beets and Schnabel achieve their goals of improving efficiency, reducing costs, and boosting productivity, despite ongoing challenges

[49] Giammalvo, P. D. (2021). *Course Material: Project Controls/PMO handbook of “Best Tested and Proven Practices”.*

2.3 Range of IEACs (Independent Estimates at Completion)

When IEACs indicate potential cost overruns, implement effective cost management practices, conduct regular reviews of cost estimates to identify potential overruns early, and take prompt corrective actions to bring the project back on budget.

STEP-7 MONITORING AND PEOT_EVALUATION RESULT

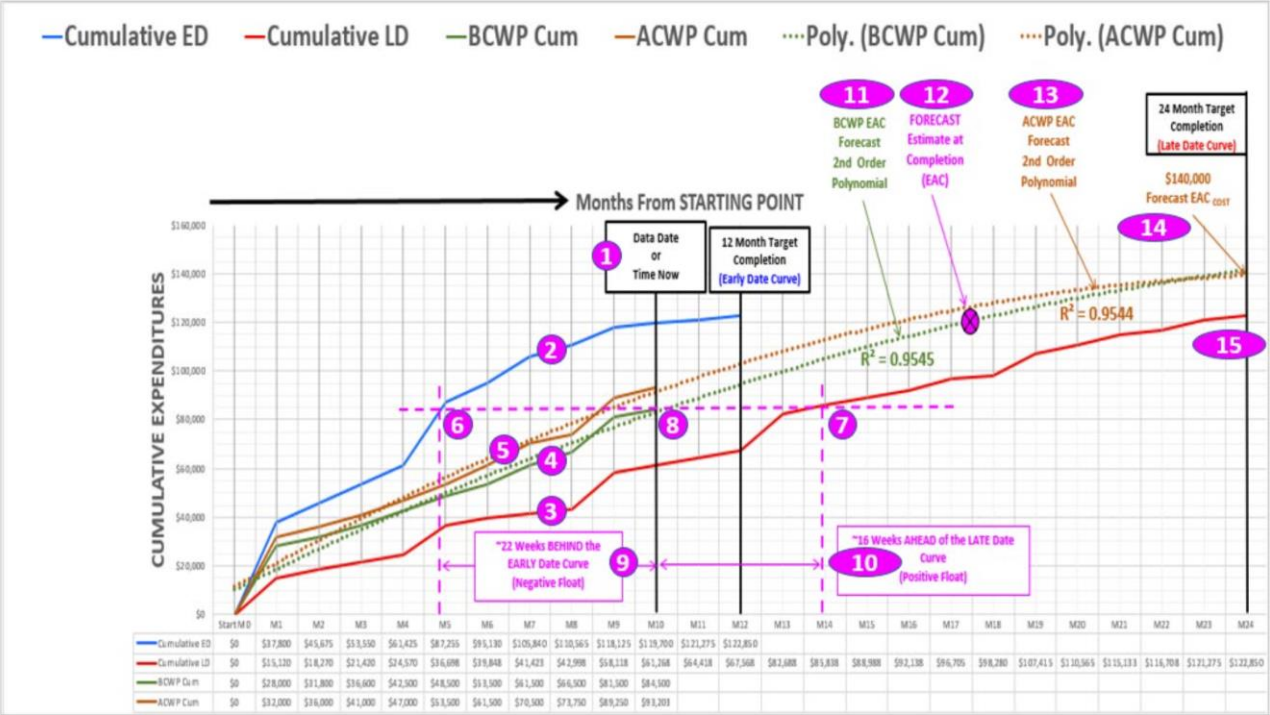

Figure 15 Example of EVM Monitoring Curve[50]

We always start the analysis by establishing the "Time Now" or "Data Date Line" (Line 1: Month 10, Week 2). Next, we plot the BCWS Early Date (Line 2) and BCWS Late Date (Line 3), followed by plotting BCWP (Line 4) and ACWP (Line 5). We also plot BCWP at the time (Point 8).

For schedule comparison, we stretch a horizontal line from 6 to 7. This line intersects the Early Date (ED) at Point 9, indicating we are 22 weeks behind schedule, and intersects the Late Date (LD) at Point 10, showing we are 16 weeks ahead of schedule. We then forecast BCWP (Line 11) using the trendline function, forecast EAC (Line 12), and forecast ACWP (Line 13) also using the trendline function.

[50] Giammalvo, P. D. (2021*). Course Material: Project Controls/PMO handbook of "Best Tested and Proven Practices".*

Line 14 indicates that we are over budget (ACWP > BCWP), and Line 15 shows the project finishes in the worst-case scenario, which is Month 24.

The gap between the ED and LD curves indicates the current amount of float. If the BCWP intersection begins to approach the LD curve, it serves as an early warning that the project may encounter issues, allowing sufficient time to take corrective or remedial actions.

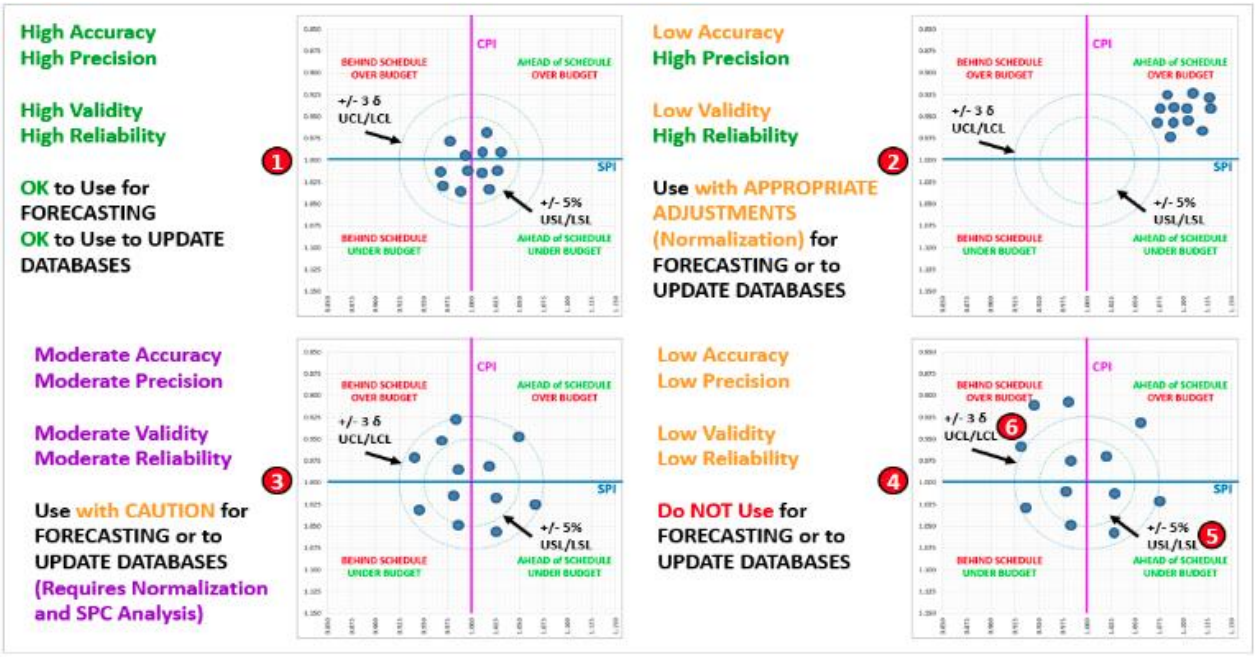

Figure 16 Illustration of Data Quality Matrices Validity, Precision, Reliability And Accuracy[51]

To ensure the quality of our SPI and CPI data, we should focus on validity, precision, reliability, and accuracy. Validity ensures data accurately represents real-world conditions through validation rules and consistency checks. Precision involves maintaining detailed data by standardizing units and documenting methods. Reliability is about achieving consistent data over time through repeatability tests and systematic reviews. Accuracy ensures data correctly reflects real-world values by analyzing error rates and cross-verifying with benchmarks.

In practice, use automated tools for data quality checks, train personnel on standards, conduct regular audits, and foster continuous improvement. This ensures robust SPI and CPI data, leading to better project performance assessments and decision-making.

[51] Giammalvo, P. D. (2021). Course Material: *Project Controls/PMO handbook of "Best Tested and Proven Practices".*

CONCLUSION

Integrating Earned Value Management (EVM) with NDIA schedule and cost matrices in mining projects, like those seen in “Gold Rush,” enhances performance tracking and decision-making. Key reports such as Project Performance, Schedule Variance, and Cost Variance provide critical insights into project health, schedule deviations, and cost control. Utilizing the Units Completed method for progress payments ensures accurate assessment of work done. This comprehensive approach leads to more successful and cost-effective project outcomes.

Combining EVM with unit measures significantly enhances project performance tracking and decision-making for mining companies managing construction projects in greenfield areas. EVM provides a clear picture of schedule and cost performance, while units completed offer a tangible metric for progress assessment. This integration ensures timely payments, boosts productivity, and reduces project delays by linking payments to actual work done and providing clear performance metrics.

This approach breaks the vicious cycle that often hampers project success by addressing common issues such as late payments, low productivity, and project delays. Timely payments maintain cash flow and contractor morale, while EVM's forecasting capabilities and detailed resource tracking enable proactive management and efficient resource allocation. Ultimately, this integrated approach leads to more successful and cost-effective project outcomes, ensuring that mining companies can achieve their project goals effectively.

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Sita Ariana Pangestu is a dedicated Project Engineer at a multinational mining company. She is currently overseeing the construction of a greenfield mining area in Southeast Sulawesi, Indonesia. She holds a Bachelor's degree in Civil Engineering from Institut Teknologi Bandung (ITB) and a Master's degree in Professional Engineering from the University of Western Australia (UWA).

Sita began her career as a Geotechnical Engineer and has steadily advanced to her current role in project engineering. She brings extensive industry experience, including offshore surveys, renewable energy, mineral resources, and insurance. Her past role as a loss adjuster has also made her proficient in project risk management. Sita excels in handling complex projects, ensuring timely delivery while upholding high standards of quality and safety. Her expertise in project engineering facilitates seamless collaboration within multidisciplinary teams and efficient project execution.

Currently, Sita is attending a distance learning course led by Dr. Paul D. Giammalvo, CDT, CCE, MScPM, MRICS, GPM-m, Senior Technical Advisor at PT Mitrata Citragraha, to obtain the Earned Value Professional (EVP) certification from AACE International.